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Positive emotion regulation

Forecasting the future, savoring the present and reminiscing about the past

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Positive emotion regulation: Forecasting the future, savoring the present and reminiscing about the past

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"Our message is to remind our field that psychology is not just the study of pathology, weakness, and damage; it is also the study of strengths and virtues. Treatment is not just fixing what is broken; it is nurturing what is best. Psychology is not just a branch of medicine concerned with illness or health; it is much larger. It is about work, education, insight, love, growth, and play."

Seligman et al. (2000)

INDEX

LIST OF TABLES

LIST OF FIGURES

PRESENTATION

This doctoral dissertation is presented as a compendium of six publications. Five of them have already been published in indexed journals, whereas one article has been submitted to a scientifically relevant journal. The co-authors of all the articles have expressed their agreement to present the aforementioned manuscripts as part of this doctoral dissertation.

The articles included in this dissertation will be presented in six separate chapters. Besides, two additional sections have been included: A general introduction, to provide an overview of the research field of interest and define the main aims of the current investigation; and a final discussion, to summarize and discuss in more detail the overall findings of this research work.

According to the Royal Decree 99/2011 which regulates doctoral studies to obtain the recognition as an international doctorate, the publications that make up this dissertation and the additional chapters were written in English, which is the most commonly used language to communicate scientific knowledge in psychology.

CHAPTER 1

General introduction

CHAPTER 1: GENERAL INTRODUCTION

This chapter encompasses a general preface to the thesis in order to highlight the previous evidence and existing gaps in the current literature, which justify the importance of this research.

First, the theoretical background underlying the present work will be presented. This dissertation is framed within the field of positive psychology: That is, the study of positive experiences, individual traits and factors that boost people's happiness and well-being. In the present chapter, the concepts of positive emotions and positive emotion regulation will be deepened, outlining the growing evidence suggesting their significance for well-being and mental health. More specifically, the process of regulating positive emotions will be discussed in relation to three different time frames: The regulation of emotions *before* (i.e., affective forecasting), *during* (i.e. savoring) and *after* (i.e., reminiscing) the experience of an emotion.

Second, a brief methodological background will be provided. Unlike most of the previous literature which relied on laboratory experiments and retrospective questionnaires, the research works presented in this dissertation attempted to adopt an ecological approach to the study of positive emotion regulation. Accordingly, the advantages of using Ecological Momentary Assessment to better grasp affective dynamics in daily life will be presented. A specific focus will be given to the use of technology to further enhance this methodology.

Finally, two further sections defining the general aim and the specific research questions of the present dissertation will be provided. Also, an outline of the thesis will be presented in order to explain in more detail the included articles, each of them constituting a separate chapter of this dissertation.

THEORETICAL BACKGROUND

Positive emotions

For a long time, most of the research in the psychological field has been devoted to the study of vulnerability factors and psychopathology. Accordingly, clinical psychology has mainly focused on how to alleviate symptoms, and, whereas the regulation of negative emotions has been widely explored, the regulation of positive states has been often understudied.

The elaboration of a new integrative research domain called "positive psychology" represented an important change against the perspective that had been dominant for many decades, stating that "[…] *psychology is not just the study of pathology, weakness or damage; it is also the study of strengths and virtues*" (Seligman & Csikszentmihalyi, 2000). Positive psychology is, indeed, the scientific field that aims at studying human positive experiences and functioning at the subjective, individual and group levels, with a main focus on the identification of factors that increase people's resilience and happiness.

In the last decades, the study of positive emotions caught the attention of many researchers, and there is now increasing evidence showing the importance of cultivating positive emotions for mental health (Diener & Seligman, 2002; Lyubomirsky, King, & Diener, 2005; Quoidbach, Mikolajczak, & Gross, 2015).

Positive emotions are a core component of well-being (Taylor & Brown, 1988; Taylor, Kemeny, Reed, Bower, & Gruenewald, 2000), producing short and long term benefits in terms of physical and psychological health (Gruber, Kogan, Quoidbach, & Mauss, 2013; Kok et al., 2013; Tugade & Fredrickson, 2007; Tugade, Fredrickson, & Barrett, 2004). While the experience of negative emotions entails avoidance and withdrawal behaviours, positive emotions have been shown to encourage approach behaviours and to foster the exploration of novel situations (Cacioppo & Berntson, 1999). Accordingly, the Broaden and Build Theory (Fredrickson, 2001, 1998, 2004) states that positive emotions extend the scope of attention, cognition and action, thus promoting resilience and well-being (Fredrickson & Joiner, 2002). In this sense, positive emotions do not only reflect the experience of pleasant states, but they rather represent an important source to build coping skills and face challenging situations (Pavani, Le Vigouroux, Kop, Congard, & Dauvier, 2016).

Not surprisingly, abnormal levels of positive emotions have been associated with deficits in emotional functioning. Reduced levels of positive affect, for instance, are a core component of anhedonia, which in turn is a hallmark of depression (Watson & Naragon-Gainey, 2010), whereas excess in positive affect has been shown to represent a risk factor for bipolar disorder (Gruber, Johnson, Oveis, & Keltner, 2008). Furthermore, the habitual use of strategies that aims at decreasing rather than increasing the experience of positive states (i.e., dampening strategies) has been linked to reduced emotional well-being, such as enhanced and prolonged levels of negative affect (Li, Starr, & Hershenberg, 2017; Wood, Heimpel, & Michela, 2003), and a dysfunctional regulation of positive affect has been recognised as an important key feature of many emotional disorders (Carl, Soskin, Kerns, & Barlow, 2013; Carl, Fairholme, Gallagher, Thompson-Hollands, & Barlow, 2014).

Together, there is evidence to suggest that positive emotions and the regulation of positive emotional states are a core component of mental health. Exploring the mechanisms underlying the experience of positive affective states is therefore crucially important to understand human's positive functioning and open new avenues for the promotion of well-being.

Positive emotion regulation

The pursuit of happiness is one of the most important life goals of individuals (Diener, 2000), who spend most of their time trying to downregulate negative emotions and upregulate positive ones (Gross, Richards, & John, 2006). Considering their crucial role for mental health, it is of paramount importance to understand how people create and maintain positive experiences and, more specifically, to investigate the regulatory mechanisms underlying positive emotions.

Emotion regulation is the process that explicitly or implicitly aims at influencing an individual's emotional state (Gross, 1998). More specifically, positive emotion regulation refers to the attempt to create, maintain and enhance positive emotions by means of savoring (Quoidbach, Mikolajczak, & Gross, 2015; Bryant, 2003) as opposed to dampening strategies (Wood et al., 2003), which are usually associated with emotional disorders (Li et al., 2017; Liu & Thompson, 2017).

Traditionally, emotion regulation has been conceptualized considering the process that leads to the generation of an emotion (Gross, 2015). Thus, the regulation of positive emotions may occur at different stages of this process (Quoidbach et al., 2015): 1) situation selection, i.e. by selecting situations or activities that are supposed to produce positive emotions; 2) situation modification, i.e. by modifying a situation in order to increase its impact on positive emotions; 3) attentional deployment, i.e. by focusing the attention on the positive features of a situation; 4) cognitive change, i.e. by changing the interpretation of an eliciting stimulus to enhance its emotional impact; and 5) response modulation, i.e. by influencing the physiological, experiential or behavioural response to the elicited positive emotions.

Regardless of the type of strategy adopted, the regulation of positive emotions has been shown to entail beneficial effects on mental health, including greater happiness, higher positive affect and enhanced well-being (Jose, Lim, & Bryant, 2012; Quoidbach, Berry, Hansenne, & Mikolajczak, 2010). Accordingly, the upregulation of positive emotions serves two main functions. On the one hand, people regulate positive emotions for its own sake: That is, to experience pleasurable affective states and enhance their happiness (Livingstone & Srivastava, 2012). On the other hand, the upregulation of positive emotions constitutes an efficient mood-repair mechanism, thus helping to reduce the experience of negative affect and recover from stressful situations (Folkman & Moskowitz, 2000; Tugade & Fredrickson, 2004).

Despite a long tradition of research has conceptualized emotion regulation at a micro-temporal scale (i.e., considering the brief temporal window needed to generate and experience an emotion) (Gross, 2015), Quoidbach et al. (2015) recently proposed a new temporal framework for the understanding of positive regulation, inspired by Bryant's savoring beliefs theory (1989, 2003). Accordingly, positive emotion regulation does not only involve the regulation of emotions *during* the occurrence of a positive event or the experience of a positive emotion. Rather, positive emotion regulation also occurs *before* (i.e., anticipating) and *after* (i.e., reminiscing) the emotion-generative process. In the following sections, we will discuss each of the three temporal frames in more detail.

Forecasting the future

Most of the experience of positive emotions comes from anticipation (Quoidbach et al., 2015). People are used to mentally time travel (Tulving, 1985): That is, to imagine future situations and anticipate the associated affective states (Gilbert, Driver-Linn, & Wilson, 2002; Gilbert & Wilson, 2009; Kahneman & Snell, 1990). While waiting for an important event, for instance, an individual may want to plan all the details in advance in order to take the most out of the situation, as well as to focus his/her attention on the future emotional experience. This latter ability has been called affective forecasting (Gilbert et al., 2002), and there is evidence to suggest that this mechanism can affect both behavioural, cognitive and emotional processes.

First, the anticipation of future emotional states represents an essential source of information to drive behaviours and decisions in the present (Crawford, McConnell, Lewis, & Sherman, 2002; Mellers, Schwartz, Ho, & Ritov, 1997). People are, in fact, likely to engage in situations that are expected to be pleasant and avoid situations that could generate negative emotions (Dunn & Laham, 2006). Second, affective forecasting is considered a future-oriented regulatory process (Goodhart, 1985), that leads people to act in order to match the actual emotional experience with the forecasted one (Persson & Sjöberg, 1985). People who expect to experience high mood have been found to actually experience greater levels of positive emotions (Totterdell, Parkinson, Briner, & Reynolds, 1997), which suggests that affective predictions may exert a certain rate of cognitive control on one's emotional state. Finally, the anticipation of positive emotional states has been recognized as an emotion regulation strategy, that allows to increase current levels of positive emotions (Bryant, 2003) and emotional well-being (Westermann, Spies, Stahl, & Hesse, 1996) by mentally imagining future positive experiences (Quoidbach et al., 2015). Accordingly, individuals who are better at generating vivid mental simulations report greater levels of happiness (Blackwell et al., 2013; Odou & Vella-Brodrick, 2013).

Notably, affective predictions have been shown to be often inaccurate (Wilson & Gilbert, 2003); for instance, individuals are likely to overestimate the likelihood of future positive events and to underestimate negative ones (Sharot, 2011). Considering its important role on behavioural, cognitive and emotional processes, it seems possible that the way people anticipate future emotional experiences may impact on different dimensions of mental-health and, more specifically, that differences in the ability to forecast positive experiences may lead to dissimilar outcomes on well-being.

According to the Positive Illusion Theory, holding favorable self-evaluations, exaggerated perception of control, and unrealistic optimism boost well-being and happiness (Brookings & Serratelli, 2007; Taylor & Brown, 1988; Taylor & Brown, 1994) by enhancing the perception of owning successful coping skills (Brown, 1993). Moreover, holding a positive future-oriented disposition is a protective factor for mental health (Mikus et al., 2017; Weinstein, 1980; Botella et al., 2018), and the manipulation of optimism towards the future has been shown to increase one's current level of positive emotions (Meevissen, Peters, & Alberts, 2011).

Nevertheless, no previous study has explored the association among affective forecasting abilities, well-being and mental health. Moreover, whereas most of the previous literature has focused on the anticipation of the emotional experience associated with a specific event, little is still known about how people make predictions of future general mood.

Savoring the present

So far, most of the previous literature has investigated emotion regulation in relation to ongoing emotions (Bryant, 1989), thus exploring the mechanisms underlying the enjoyment of positive emotions as they occur. Despite the existence of a growing body of research conducted in laboratory settings and/or adopting trait questionnaires, we will here focus on those studies that adopted an ecological approach to explore the daily dynamics of positive emotion regulation.

As briefly mentioned in the previous paragraphs, the regulation of positive emotions entails adaptive affective consequences. Heiy and colleagues (2014), for instance, showed that the use of positive strategies such as savoring or future focus predicts an enhancement in subsequent positive affect levels. In another research, the use of reflection and sharing in response to positive emotional states was associated with a significant increase in subsequent positive emotion level (Brans, Koval, Verduyn, Lim, & Kuppens, 2013). Furthermore, a more intense use of reappraisal in response to positive experiences has been found to predict higher levels of daily self-esteem, psychological adjustment and positive affect (Nezlek & Kuppens, 2008; Brans et al., 2013).

Importantly, there is now evidence to suggest that not only can positive emotion regulation influence subsequent affect, but also momentary affect can determine subsequent regulation processes (Brans et al., 2013; Pavani et al., 2016). Nevertheless, the previous literature was inconsistent regarding the direction of this association.

According to the Broaden and Build Theory (Fredrickson, 2001, 1998, 2004), positive emotions broaden the thought-action repertoire of an individual and trigger broadening mechanisms, such as increased cognitive flexibility or creativity (Davis, 2009; Lin, Tsai, Lin, & Chen, 2014). This mechanism has been hypothesized to also affect emotion regulation processes: Thus, the experience of positive emotions could encourage the adoption of adaptive, broadminded strategies that further enhance positive affect (Burns et al., 2008; Fredrickson & Joiner, 2002). This hypothesis is supported by the findings of previous ecological studies, showing that the experience of high levels of positive emotions predicts a subsequent greater adoption of positive strategies, such as problem solving (Pavani et al., 2016) and mindfulness (Brockman, Ciarrochi, Parker, & Kashdan, 2017).

Beyond the Broaden and Build Theory, a different association between positive emotions and positive emotion regulation has been conceptualized by pro-hedonic theories (Simon, 1967), such as the hedonic flexibility principle (Taquet, Quoidbach, de Montjoye, Desseilles, & Gross, 2016). According to this perspective, the experience of low positive emotions motivates actions and behaviors that aim at enhancing mood and, more specifically, at minimizing negative affect and maximizing positive affect. In other words, individuals are likely to increase the use of strategies to upregulate positive emotions when experiencing a low rather than high level of positive emotions. In this direction, there is evidence showing that people seek mood enhancing activities when experiencing a bad mood (e.g., doing sport, chatting with a friend), and useful but mood-decreasing activities when feeling good (e.g., housework, solitude) (Quoidbach, Taquet, Desseilles, de Montjoye, & Gross, 2019; Taquet et al., 2016).

To resume, while the previous literature was consistent regarding the beneficial affective outcomes of positive emotion regulation, the association between positive emotions and subsequent emotion regulation processes is still controversial.

Recalling the past

Beyond anticipating and savoring positive emotions, people are also used to recall positive experiences from the past and to re-experience the associated emotional states (Tulving, 1985). Past positive memories are indeed an important source to generate positive emotions in the present (Quoidbach et al., 2015).

The set of memories an individual has of his/her own life represents the core structure of one's identity, that enables to create a coherent Self and guide present and future decisions (Pascuzzi & Smorti, 2017). Moreover, the retrieval of past events not only produces memories: Rather, it also entails the re-experience of the associated believes, emotions, thoughts and desires (Klein, 2015). Accordingly, positive reminisce is widely recognized as an effective emotion regulation strategy to recreate positive feelings and increase current levels of positive emotions (Mitchell et al., 1997; Wilson and Ross, 2003; Bryant et al., 2005; Quoidbach et al., 2010).

Similar to affective forecasting abilities, however, people are not accurate at recalling past emotional experiences. This phenomenon, called affect recall bias, has received increasing attention in the last decades. According to the Rosy View theory (Mitchell et al., 1997), while people tend to exaggerate the negativity of an episode while experiencing it, they tend to develop a more optimistic appraisal of the event within a short period of time after its occurrence. This mechanism is considered an adaptive strategy that allows to reframe adverse life episodes.

Interestingly, this recall bias has been observed not only in relation to the retrieve of specific events. Rather, there is evidence to suggest that people are also inaccurate in recalling past general affect (e.g., the emotions experienced during the last days or weeks). In this regard, the findings of the previous literature are quite consistent: People tend to overestimate experienced levels of both positive and negative emotions when asked to retrospectively recall them (Hedges et al., 1985; Thomas and Diener, 1990; Kardum and Tićac Daskijević, 2001; Wirtz et al., 2003; Ben-Zeev et al., 2009a; Colombo et al., 2019b). While the overestimation of past negative experiences has been hypothesized to be an evolutionary mechanism of survival (Miron-Shatz, Stone, & Kahneman, 2009) or the consequence of a negative bias associated with the presence of depressive and anxiety symptoms (Wenze, Gunthert, & German, 2012), still little is known about the mechanisms underlying the tendency to overestimate past positive affect.

As aforementioned, holding positive illusions has been associated with enhanced happiness, satisfaction in life, and well-being (Brookings & Serratelli, 2007; Taylor & Brown, 1988; Taylor & Brown, 1994). Therefore, individual differences in the tendency to recall past positive memories may entail important consequences for mental health. More specifically, if it is true that focusing on past positive experiences increases positive emotions in the present (Quoidbach et al., 2015), holding an optimistic, yet biased, past-oriented disposition (i.e., overestimating past affective experiences) may represent an adaptive strategy that helps to maintain and up-regulate positive emotions over time. Nevertheless, no previous study has explored the mechanisms underlying this positive bias.

METHODOLOGICAL BACKGROUND

Despite the growing body of studies showing its dynamics and context-dependent nature, emotion regulation has been mostly investigated in laboratory settings and/or by means of retrospective questionnaires. Nevertheless, there is now increasing evidence showing the limitations of these traditional methodologies. First, emotional experiences are not static: Rather, people's affect is characterized by continuous fluctuations and rapid shifts over time depending on the occurrence of internal and/or external events (Kuppens, Oravecz, & Tuerlinckx, 2010). As a matter of fact, these dynamics can't be captured through laboratory experiments or by means of retrospective questionnaires. Second, the previous literature has shown that people are generally not able to accurately recall past emotional experiences without altering their content (Hedges et al., 1985), thus making traditional, retrospective assessments sensitive to potential biases. Finally, there is evidence to suggest that emotion regulation is not a stable, cross-situational trait of a person: Rather, contextual and momentary factors play a key role in shaping this process (Brockman et al., 2017). Traditional assessment tools fail to grasp the context-dependent nature of emotion regulation.

Ecological Momentary Assessment (EMA), also called Experience Sampling Method (ESM), emerged in the late 80s as an alternative methodology to capture people's affective dynamics in daily life (Stone & Shiffman, 1994; Trull & Ebner-Priemer, 2009). On the one hand, the term "*ecological*" refers to the environment in which data are collected: Individuals are asked to report behaviors, thoughts and feelings in the real-world context and during the flow of daily experiences. On the other hand, the term "*momentary*" refers to the focus of the assessment on the current state of the individual, opposed to the retrospective nature of traditional questionnaires. Altogether, EMA enabled researchers to obtain repeated affective measures over time, thus increasing the reliability, generalizability and ecological validity of data, and overcoming the limitations of traditional approaches.

For many years, EMA application has been difficult. The use of paper diaries, indeed, imposed several barriers, such as low control over time response and errors in manual data entry.

The past decades, though, have seen a surge of studies using EMA as a result of the increased availability of Information and Communication Technologies (ICTs), which have been successfully used both for subjective (Suso-Ribera et al., 2018) and objective data collection (Mohr, Zhang, & Schueller, 2017). The adoption of technological solutions such as smartphones allowed to integrate all the needed processes into one device (i.e., notification, assessment, automatic data storage), thus decreasing the discomfort observed with paper diaries. Furthermore, mobile devices allowed to further expand the information collectable: While embedded sensors (e.g., accelerometer, GPS) made it possible to indirectly collect data about people's behaviours and habits, such as social media use, physical activity, or social interactions (Mohr et al., 2017; van de Ven et al., 2017), the use of unobstructed wearable biosensors allowed to continuously monitor physiological parameters throughout the day with high precision (Marzano et al., 2015). Recent studies confirmed the feasibility, adherence and interest of people in using these technologies, thus highlighting the great potential of these tools for the psychological field (Donker et al., 2013).

So far, EMA has turned out to be a promising tool for the study of emotional dynamics and its correlates, and a more complex representation of how people regulate emotions in daily life is emerging. As shown by a growing body of research, emotion regulation is intrinsically connected to the context in which emotions are regulated, and the essential role played by momentary affect and situational factors on this process is increasingly emerging (Aldao, 2013; Doré, Silvers, & Ochsner, 2016). The implementation of EMA methodologies has allowed to address important gaps in the previous literature that would have been difficult to tackle with non-ecological research, such as the temporal dynamics between affect and emotion regulation, or the moderating role of contextual and situational factors on regulation processes.

GENERAL AIM

In recent years, there has been an increase in the attention to positive emotions and, more specifically, to the mechanisms underlying the regulation of positive experiences. So far, there is strong evidence suggesting the importance of cultivating positive emotions in relation to well-being and mental health. Importantly, positive emotion regulation does not only entail the deployment of regulatory mechanisms *during* the experience of a positive emotional state. Rather, positive emotions may be regulated also *before* and *after* the generation of a positive state. Though, despite the increasing body of studies exploring the mechanisms underlying positive emotions discussed in the previous sections, several questions remain unanswered.

The general aim of the present thesis is to expand our knowledge about the regulation of positive emotions in daily life, taking into account the gaps existing in the previous literature and considering the different time frames in which emotion regulation may occur. Notably, we decided to use an ecological approach to the study of positive emotion regulation, and the EMA methodology was adopted across all studies.

This doctoral dissertation is a compendium of six publications. First, three theoretical chapters are presented, which support the use of the EMA approach to the study of daily emotional dynamics. Subsequently, three experimental studies are provided, which aim at exploring how people anticipate, savor and recall positive emotional experiences, as well as the association between these processes and mental health.

RESEARCH QUESTIONS

The research questions of the present dissertation are formulated taking into consideration the three temporal frames in which positive emotions might be regulated, namely: The forecasting of positive emotional states, the savoring of momentary positive emotions, and the recall of positive affective experiences.

1. *Forecasting of positive emotional states:* Positive emotions are often elicited by the anticipation of positive experiences (Quoidbach et al., 2015), which have been shown to influence both behavioural, cognitive and emotional processes in the present. More specifically, imagining future positive events has been recognized

as an effective emotion regulation strategy to increase current levels of positive affect (Bryant, 2003), and manipulating one's optimism towards the future has been shown to enhance current positive emotions (Westermann, Spies, Stahl, & Hesse, 1996; Meevissen, Peters, & Alberts, 2011). Therefore, the way people anticipate future experiences may have important effects on mental health, and, more specifically, the presence of distorted expectations about the future might entail significant consequences for well-being.

2. *Savoring of positive emotional states:* A long tradition of research has evidenced that savoring as opposed to dampening strategies have beneficial effects on emotional well-being (Jose et al., 2012; Quoidbach et al., 2010). More specifically, the adoption of EMA approaches allowed to disentangle the reciprocal influence between positive emotions and positive emotion regulation in daily life (Brans et al., 2013; Pavani et al., 2016). However, whereas the evidence about the beneficial effects of positive emotion regulation on well-being is consistent, the influence of positive emotions on subsequent regulatory mechanisms is still controversial.

3. *Recall of positive emotional states:* Focusing one's attention on past positive experiences is an effective strategy to increase positive emotions in the present (Quoidbach et al., 2015). Nevertheless, a growing body of research indicates that affect recall is often biased, and that people tend to retrospectively overestimate both positive and negative emotions (Hedges et al., 1985; Thomas and Diener, 1990; Kardum and Tićac Daskijević, 2001; Wirtz et al., 2003; Ben-Zeev et al., 2009a; Colombo et al., 2019b). Whereas the overestimation of past negative emotions has been deeply explored (Miron-Shatz et al., 2009; Wenze et al., 2012), the mechanisms underlying an optimistic, yet biased, estimation of past positive experiences has not been explored yet.

Accordingly, the research questions addressed by the present dissertation are the following:

1. *Anticipation of positive emotional states*: Does affective forecasting play a role for well-being? Does one's future-oriented disposition influence resilience, thus enhancing and/or decreasing one's resources to deal with stressors?

2. *Savoring of positive emotional states:* Which is the association between positive emotions and subsequent positive emotion regulation in daily life? Is positive emotion regulation fostered by the experience of high levels of positive emotions (i.e., consistent with the Broaden and Build theory) or by the presence of low levels of positive emotions (i.e., consistent with the hedonic flexibility principle)?

3. *Recall of positive emotional states:* Which are the mechanisms underlying the bias in recalling past positive experiences? Does holding a biased, yet optimistic, past-oriented disposition boost well-being and resilience?

OUTLINE OF THE THESIS

The present doctoral dissertation consists of a compendium of six articles, each of them published or submitted as publication in a scientific journal (see **Table 1.1**).

The first three chapters are meant to provide a more detailed overview of the methodological background adopted in the present dissertation. **Chapter 2** describes the advantages of a vast array of technologies, such as virtual reality and smartphones, to expand our knowledge about emotion regulation and encourage the development of innovative interventions. **Chapter 3** is a systematic review about technology based EMA and Ecological Momentary Intervention (EMI) in the field of major depressive disorder, a clinical population characterized by profound difficulties in the regulation of emotions. In this chapter, the advantages of using EMA to explore affective dynamics are pointed out. **Chapter 4** compares the EMA approach to traditional methodologies (i.e., laboratory experiments and retrospective questionnaires) within the field of emotion regulation, pointing out the similarities and differences observed in the previous literature. A technology-based theoretical framework is also proposed to better investigate emotion regulation antecedents and consequences in daily life.

The subsequent three chapters are experimental studies that aim at answering the research questions of the present dissertation. **Chapter 5** explores the ability to forecast future emotional states to investigate the potential effects of biased affective forecasting on resilience and well-being. **Chapter 6** explores the mechanisms underlying the savoring of ongoing positive emotions in daily life, in order to disentangle the reciprocal interconnection between momentary affect and positive regulation. **Chapter 7** explores people's ability to retrospectively recall past emotional experiences in order to explore whether positive, yet biased, estimations of past positive experiences may affect psychological well-being.

A final chapter with a general discussion will also be provided (**Chapter 8**), which includes a critical examination of the findings of the present dissertation as well as the potential directions for future research.

Table 1.1: Doctoral dissertation as a compendium of publications

Chapter	*Article*
2	**Colombo, D.**, Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8(*4), 465.
3	**Colombo, D.,** Fernández-Álvarez, J., Garcia Palacios, A., Cipresso, P., Botella, C., & Riva, G. (2019). New technologies for the understanding, assessment, and intervention of emotion regulation. *Frontiers in psychology, 10,* 1261.
4	**Colombo, D.,** Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.
5	**Colombo, D.,** Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., García-Palacios, A., Riva, G., & Botella, C. (2020). Biased affective forecasting: A potential mechanism that enhances resilience and well-being. *Frontiers in Psychology, 11*.
6	**Colombo, D.,** Pavani, J.B., Fernández-Álvarez, J., García-Palacios, A., & Botella, C. (2020). Savoring the present: The reciprocal influence between positive emotions and positive emotion regulation in everyday life. *(submitted to PLOSONE)*.
7	**Colombo, D.,** Suso-Ribera, C., Fernández-Álvarez, J., Cipresso, P., Garcia-Palacios, A., Riva, G., & Botella, C. (2020). Affect Recall Bias: Being Resilient by Distorting Reality. *Cognitive Therapy and Research,* 1-13.

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CHAPTER 2

New technologies for the understanding, assessment and intervention of emotion regulation

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New technologies for the understanding, assessment and intervention of emotion regulation

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ABSTRACT

In the last decades, emotion regulation (ER) received increasing attention and became one of the most studied topics within the psychological field. Nevertheless, this construct has not been fully updated with the latest technological advancements. In this perspective, we will show how diverse technologies, such as virtual reality (VR), wearable biosensors, smartphones or biofeedback techniques, can be applied to the understanding, assessment and intervention of ER. After providing a brief overview of the currently available technological developments, we will discuss the benefits of incorporating new technologies in ER field, including ecological validity, intervention personalization and the integration of understudied facets of ER, such as the implicit and interpersonal dimension.

Key words: Emotion Regulation, Virtual Reality, Biofeedback, Internet interventions, Smartphones, Serious Games.

INTRODUCTION

Mental health, understood as "*a state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community*" (World Health Organization, 2004), is witnessing a revolution due to the incorporation of new digital technologies. Although its real impact is difficult to foresee, it is a matter of fact that profound changes are already taking place at multiple levels. In this direction, different technologies have already been applied to the mental health realm. Illustrative examples are internet-based interventions (Andersson, 2016), mobile health (Firth et al., 2017; Grist, Porter, & Stallard, 2017) or the emerging field of mixed realities (MR) (Baus & Bouchard, 2014), serious games (Fleming et al., 2017) and biofeedback techniques (Schoenberg & David, 2014). ER is not the exception to the rule, and new technologies are called to transform our understanding of the field and thus to positively impact on its assessment and intervention.

In the last years, ER emerged as one of the most studied constructs in the psychological field (Fernández-Álvarez, Cipresso, Colombo, Botella, & Riva, 2018). ER is a dynamic process that every person implements with the aim of down-regulating or up-regulating positive and negative emotions in order to reach desirable states (Gross, 1998, 2015a). ER is always addressed to accomplish a certain goal (Tamir, 2016), either hedonic (i.e. maximize pleasure and/or minimize pain in the short term) or instrumental (i.e. maximize pleasure and/or minimize pain in the long term), by means of strategies (Gross & Jazaieri, 2014) that can be implemented before or after emotions occurrence (Gross, 1998). ER can be deployed both intrapersonally or interpersonally (Zaki & Craig Williams, 2013): People may try to regulate emotions in solitude, for instance by reappraising a situation, but they can also modulate emotions interpersonally, for example by seeking support from an intimate partner. Furthermore, ER can be explicit or implicit, as well as controlled or automatic (Braunstein, Gross, & Ochsner, 2017). On the one hand, ER is explicit when significant goals are deliberately pursued, and it is implicit when regulatory mechanisms are automatically activated by unconscious goals. On the other hand, automatic ER is a non-conscious attempt to regulate emotions, whether controlled ER involves top-down control mechanisms.

ER entails cognitive, behavioral and physiological processes. From a *cognitive* point of view, among the most studied ER strategies there are rumination, cognitive reappraisal, suppression, acceptance, savoring, and dampening (Naragon-Gainey, McMahon, & Chacko, 2017). The generation of emotions is also intimately related to *behaviors*, which are indeed driven by our emotional states: People tend to engage in mood-increasing activities when feeling upset and join useful rather than pleasant activities when in a good mood (Taquet, Quoidbach, de Montjoye, Desseilles, & Gross, 2016). Finally, a long tradition of research focused on the *psychophysiological* dimension of ER processes, both at a peripheral and neural level. The bed nucleus, the habenula, the striatum and the amygdala are the central cortical areas, while the prefrontal cortex (PFC), in particular dorsolateral PFC, ventrolateral PFC and ventromedial regions (vmPFC), and the anterior cingulate cortex constitute key subcortical regions (Lopez, Denny, & Fagundes, 2018; Ochsner, Silvers, & Buhle, 2012). Meanwhile, the autonomous system has also been extensively studied. A central process within this research line is the ECG activity, through which heart rate variability (HRV) can be calculated. In particular, the high frequency domain, related to the respiratory sinus arrhythmia, is considered to be an index of the vagal activity which in turn is key for stress patterns and emotion regulation processes (Balzarotti, Biassoni, Colombo, & Ciceri, 2017).

Traditionally, ER has been measured by means of self-report questionnaires, that consider ER as a stable trait of a person. Clear examples are the Emotion Regulation Questionnaire (ERQ), a 10-items self-report to assess the use of cognitive reappraisal and expressive suppression to regulate emotions (Gross & John, 2003), or the Difficulties in Emotion Regulation Questionnaire (DERS), that explores six different ER dimensions of emotion dysregulation (Gratz & Roemer, 2004). More recently, state questionnaires have been developed, that can be applied to explore the adoption of single (Ganor, Mor, & Huppert, 2018; Marchetti, Mor, Chiorri, & Koster, 2018) or multiple strategies (Katz, Lustig, Assis, & Yovel, 2017; Lavender, Tull, DiLillo, Messman-Moore, & Gratz, 2017) in specific situations.

In the last years emotion dysregulation has been shown to be a transdiagnostic factor (Aldao, Gee, De Los Reyes, & Seager, 2016; Fernández-Álvarez, Molinari, et al., 2018; Fernandez, Jazaieri, & Gross, 2016; Kring, A. M., & Sloan, 2009). Ample evidence has suggested that poor regulatory skills constitutes a vulnerability and maintenance feature among a wide range of mental disorders (Mennin & Farach, 2007; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Rottenberg, Gross, & Gotlib, 2005). The constant deployment of non-adaptive strategies to regulate emotions would elicit negative psychological health outcomes (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Sheppes, Suri, & Gross, 2015; Urzua, 2016). This lack of adaptiveness should not be understood as the utilization of specific strategies, but rather as an inflexible pattern in which the deployed strategies are incorrectly selected, inaccurately deployed or unsuccessfully monitored (Gross, 2015b). Accordingly, the action control perspective states that emotion dysregulation is the result of failures in identifying when to regulate, how to do it and how to deploy the selected strategy (Webb, Miles, & Sheeran, 2012). Beyond psychopathology, the ability to adopt a wide repertoire of strategies with high variability across different situations (i.e. ER flexibility) (Aldao, Sheppes, & Gross, 2015) has been shown to play a key role for mental well-being (Aldao & Nolen-Hoeksema, 2012; Bonanno & Burton, 2013).in naturalistic settings and deliver psychological support in daily life.

ASSESSING AND CAPTURING EMOTION REGULATION THROUGH NEW DIGITAL TECHNOLOGIES

The value of using new technologies for the understanding and assessment of ER relies undoubtedly on the possibility of increasing ecological validity and exploring this process in real-life, thus overcoming the barriers of traditional laboratory/clinical settings and leading to the exploration of new facets of this process. In the next paragraphs, we will briefly discuss the current state of the art of smartphones, smartphone-embedded sensors and wearable biosensors application within the field, showing the potentialities of these tools to assess ER and to understand its temporal dynamics in daily life as well as the role of contextual and momentary factors. Furthermore, we will suggest virtual reality (VR) as an innovative approach to understand and assess ER, that gives researchers the opportunity to develop realistic scenarios in which to elicit emotions and explore the way ER is deployed.

Ecological Momentary Assessment

In the last decade, an increasing number of Ecological Momentary Assessment (EMA) (Csikszentmihalyi & Larson, 1987; Shiffman, Stone, & Hufford, 2008) has been developed for the investigation and understanding of ER. By means of portable devices like Personal Digital Assistants (PDAs) and smartphones, EMA gave researchers the opportunity to observe and repeatedly assess people in daily life by providing prompted self-reports directly on electronic devices.

Altogether, the use of EMA through mobile devices significantly increased the knowledge about ER, shedding new light on the complexity of this process and on aspects that were still understudied. ER is indeed a dynamic process affected by situational, contextual and momentary factors (Aldao, 2013; Doré, Silvers, & Ochsner, 2016), and strategy implementation in daily life only moderately correlates with ER trait measures (Brockman, Ciarrochi, Parker, & Kashdan, 2017). This suggests that ER cannot be completely grasped and understood in traditional laboratory experiments. In that sense, EMA has been proposed as an innovative approach to explore ER (Bylsma & Rottenberg, 2011) in order to capture the temporal deployment of strategies and their impact on subsequent mood (Catterson, Eldesouky, & John, 2016; Heiy & Cheavens, 2014; Richardson, 2017), as well as the role of momentary affect (Brockman et al., 2017; Y. I. Li, Starr, & Hershenberg, 2017) and environmental factors (English, Lee, John, & Gross, 2017; Heiy & Cheavens, 2014) in implementing certain strategies.

EMA could constitute a powerful tool not only for the understanding but also for the assessment of ER. So far, many questionnaires have been developed which measure strategies deployment, considering ER as a stable trait of a person and thus underestimating the role of contextual and momentary factors. EMA could instead substitute or integrate classical paper-and-pencil, retrospective questionnaires by assessing ER directly in daily life. In turn, this would help clinicians identifying strategies to be targeted in the therapeutic process, as well as recognizing triggers and/or consequences of maladaptive strategies implementation on patients' life (see for example Anestis et al., 2010; Czyz, King, & Nahum-Shani, 2018). Nevertheless, the available literature on EMA and ER is limited to the research field, and we are not aware of studies applying EMA to assess ER in real clinical practice.

There are still many challenges ahead for EMAs. First of all, most of the studies assessing ER with EMA only rely on self-reports, assuming people to be perfectly able to recognize how they regulate emotions. Furthermore, standardized and ad-hoc items to be implemented in mobile devices for the assessment of ER are currently not available, making it difficult to compare results across studies or to apply this approach in clinical practice, as well as specific guidelines for EMA designs to increase users' adherence and reduce dropout rates (Colombo et al., 2018). Even if still not validated, a set of 20 self-regulation items specific for EMA are currently being developed (Eisenberg et al., 2017). Starting from 594 self-regulation survey items, Eisenberg and colleagues used the item response theory to choose a smaller set of items to specifically assess momentary self-regulation processes through EMA. To the best of our knowledge, this is the first attempt in this direction, leading the way to the possibility of developing standardized, specific items for the assessment of ER by means of EMA.

Sensors and Wearable Biosensors

Ideally, an accurate understanding and assessment of ER should not be based only on self-report questionnaires but also on the associated behavioral and physiological mechanisms, that could be provided by sensors (Harari et al., 2016) and biosensors (Marzano et al., 2015) (**Figure 2.1**).

Different studies used mobile phone embedded-sensors data to infer and predict users' mood (see for example Ma, Xu, Bai, Sun, & Zhu, 2013). Nevertheless, no attempt to integrate self-reports with sensors information has been done in the field of EMA for ER. As a matter of fact, little is known yet about the behavioral consequences or antecedents of adopting certain strategies in daily life and the available limited literature is only based on EMA assessing behaviors through self-reports. Undoubtedly, the behavioral aspect of ER could be further deepened through the use of sensors such as accelerometer, Global Positioning System (GPS) or microphone, that can give us important behavioral information and that in turn could be very informative of the behavioral antecedents or consequences of the ER strategies (Wampold, 2001). Beyond behaviors, ER-associated cognitive processes could also be grasped by means of the eye-tracker, a tool that allows to measure eyes and gaze movements and, therefore, conscious and/or unconscious attentional deployment. Notably, eye-trackers are nowadays available in portable solutions such as wearable glasses (MacInnes, Iqbal, Pearson, & Johnson, 2018) or smartphone application (Krafka et al., 2016).

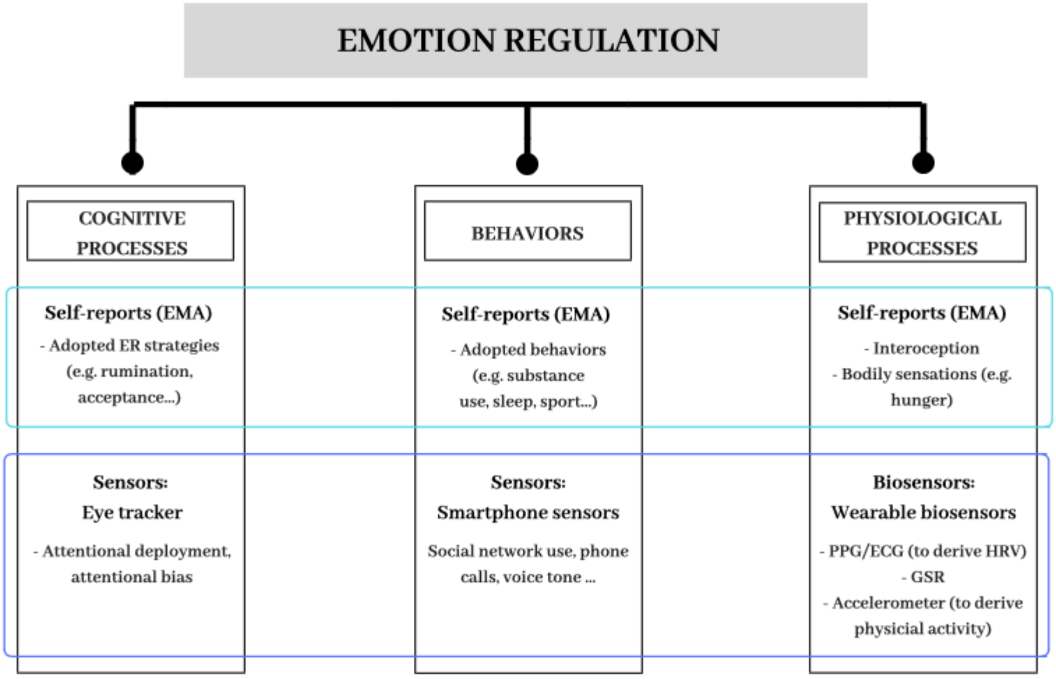

Figure 2.1: ER is composed of different facets: Cognitive mechanisms, behavioral aspects and physiological processes. The integration of different technologies could grasp all these facets, leading to a more comprehensive understanding of ER. On the one hand, the use of self-reports by means of EMA could assess the three dimensions, i.e., by asking people to report them on a mobile device. On the other hand, the use of embedded-sensors and biosensors could further increase the quantity and objectivity of this information. Cognitive processes, such as attentional deployment or attentional bias, could be investigated using an eye-tracker or other implicit measures like Go/No Go Tasks. Behaviours could be assessed using data gathered from embedded sensors, like number of calls/messages or use of social networks. Finally, the underlying physiological processes could be grasped thanks to wearable biosensors, such as wristwatches that monitor HRV or GSR parameters. *ER, emotion regulation; EMA, ecological momentary assessment; PPG, photoplethysmography; ECG, electrocardiogram; HRV, heart rate variability; GSR, galvanic skin response*.

Beyond sensors, new breakthrough tools like wristband-like devices or wearable chest-straps were created, enabling a non-invasive continuous physiological monitoring outside laboratory settings (Palix, Akselrod, Cungi, Giuliani, & Favrod, 2017; Paradiso, Faetti, & Werner, 2011). This integration could foster the early detection of dysfunctional patterns. As for the behavioral component, the physiological correlates in daily life are still an understudied aspect of ER. A huge body of studies focused on the physiological markers of ER (Balzarotti et al., 2017) but mainly in laboratory settings, while just few studies investigated these mechanisms in daily life by means of wearable biosensors. In that sense, the combined use of EMA self-reports with daily physiological monitoring already showed its potential in the field of rumination and perseverative negative thinking (Ottaviani et al., 2016), highlighting the association between this strategy and heightened activation of the hypothalamic–pituitary–adrenal axis (HPAA) and decreased heart rate variability (HRV) during waking, which is considered a robust predictor of maladaptive ER. Although existing technical difficulties to have accurate enough wearables to asses physiology in the wild, there are already available options to hurdle this obstacle (for a review of existing wearables see Peake, Kerr, & Sullivan, 2018).

Virtual reality

The incorporation of developed VR- and augmented reality (AR)- based tools both for research and practice in different branches of psychology has emerged 20 years ago but steadily increased its preponderance in the last years (Cipresso, Giglioli, Raya, & Riva, 2018).

With regard to ER, the assessment by means of VR and AR has an undoubted potentiality although scant research has been conducted yet. VR allows to generate real-life simulated scenarios that may provide a contextualized situation to measure a certain construct through significant environments, though in a controlled way (Riva, 1997; Riva, Wiederhold, & Mantovani, 2018). This may be the case for ER, given that it would help substantially if a complementary process to the traditional self-report assessment could be carried out by means of the deployment of certain behaviors for which the person involved could spontaneously and therefore ecologically implement ER strategies that usually utilizes. This may be also of paramount importance to gauge the complexity and diversity that defines the process of ER. Although there are available studies using VR to enhance psychological assessment (Alcañiz, Parra, & Giglioli, 2018; Chicchi Giglioli, Pallavicini, Pedroli, Serino, & Riva, 2015; Cipresso & Riva, 2016), to the best of our knowledge just one VR system was specifically developed for ER assessment: The Gameteen System (GT-System). The GT-System is a VR-based serious game to induce negative emotion and train ER strategies in adolescents (Rodriguez et al., 2015). More specifically, negative emotion induction is performed through a "whack a mole" VR-game, which is expressively developed in order to be scarcely accurate and induce frustration. Preliminary results showed that participants' performance levels were highly correlated with DERS scores, suggesting this game as a possible VR tool to assess ER.

INTERVENING IN EMOTION REGULATION THROUGH NEW DIGITAL TECHNOLOGIES

Interventions targeting ER can be greatly benefited by means of the incorporation of new digital technologies. Among those advantages, a greater dissemination of treatments (Fairburn & Patel, 2017) and the customization of self-help treatments by means of novel statistical procedures are some of the most important (Perna, Grassi, Caldirola, & Nemeroff, 2018). As for the previous paragraph, we will here provide an overview of current technological applications in the ER field, including mobile applications, internet-based interventions, virtual reality and biofeedback techniques, showing the advantages of each technology for the research and clinical fields.

Ecological Momentary Interventions and mHealth Applications

Ecological Momentary Interventions (EMIs) (Heron & Smyth, 2010) and mental health (mHealth) applications (Naslund, Marsch, McHugo, & Bartels, 2015) are innovative approaches to provide psychological support through mobile devices in everyday life, without necessary involving the presence of a real therapist or a face-to-face clinical setting. Among all, the real innovative aspect relies on the possibility of providing personalized and just-in-moment interventions, based on the current needs and affective state of the user.

Many mHealth applications for ER training were developed, mainly focused on cognitive change (Beck, 2017), mindfulness (Plaza, Demarzo, Herrera-Mercadal, & García-Campayo, 2013) or, more generally, on cognitive behavioral therapy (CBT) principles (Rathbone, Clarry, & Prescott, 2017). Nevertheless, most of them does not have a scientific validation or evidence supporting its efficacy (Plaza et al., 2013). Furthermore, the available applications mainly rely on self-reports and do not try to integrate the different dimensions of ER. An innovative recent attempt is represented by Calm Mom, a mobile application that specifically aims at enhancing ER through the integration of data from self-reports and electrodermal activity (Leonard et al., 2018). Thanks to the continuous EDA monitoring, the application triggers alerts when a high level of stress is detected, providing users with a consistent customized ER support (i.e. motivational messages or behavioural strategies).

Ecological Momentary Interventions and mHealth Applications

Under the umbrella of Internet-based Interventions (IBT), a vast array of recent developments are comprised, including computerized and bibliotherapy interventions (Andersson, 2016; Botella, Hofmann, & Moscovitch, 2004). The advantages are many, such as the possibility to reach a great number of people in need that otherwise would not have any kind of access to psychological treatment. Apart from dissemination, internet-based interventions are supposed to increase the cost-effectiveness in comparison with other active treatment (Beecham et al., 2019), although existent literature shows inconclusive results in this regard (Kolovos et al., 2018).

Internet interventions are generally an adaption of classical face-to-face protocols in which emotion regulation plays a relevant role. In this line, different initiatives were carried out taking an already validated protocol and translating the content for an Internet delivery format, many of which entail one or more components to train emotion regulation. The Unified Protocol, one of the first transdiagnostic treatments developed for emotional disorders which has ER as one of the principal therapeutic targets, constitutes an illustrative example of this (Barlow, Allen, & Choate, 2004) and different IBTs have been developed following this model. The first IBT in this line was called Smiling is Fun. A randomized control trial (RCT) with 124 participants showed its effectiveness in reducing depressive symptomatology through the enhancement of ER strategies (Mira et al., 2017). Furthermore, two other RCTs are being conducted. One aims to analyze the effectiveness of a transdiagnostic IBT compared to treatment as usual (González-Robles et al., 2015). The other one studies the differential efficacy of the same transdiagnostic IBT but compared to a transdiagnostic IBT with additional components of positive affect enhancement (Díaz-García et al., 2017).

Virtual Reality and Serious Games

Despite the potentiality described for the assessment, MR have initially emerged in the psychological realm as a powerful intervention tool for facilitating exposure therapy for specific phobias (Botella et al., 1998; Riva, Bacchetta, Baruffi, Rinaldi, & Molinari, 1999; Rothbaum et al., 1995). From the 90's on, a significant amount of research has yielded evidence on the efficacy of MR, particularly VR, for several clinical conditions (Opriş et al., 2012; Turner & Casey, 2014). With the emergence of low-cost devices as well as massive commercial products, VR has become a more feasible tool to be implemented in clinical contexts (Lindner et al., 2017).

Overall, VR can be of paramount importance for the intervention of ER. Illustratively, VR can be an effective tool for emotions' induction and, therefore, an innovative and more experiential way to train ER strategies in controlled environments. An illustrative example in this direction was developed by Bosse et al. (2012, 2013), who created a virtual scenario that could provide real-time feedbacks of users' coping skills based on a ER computational model and on the monitoring of behaviors and physiological parameters. Another interesting study targeted ER skills through VR with the aim of preventing adolescents risk behaviors, and although VR did not turn to be more effective that the non-VR condition, adolescents did attend more sessions and incremented their self-efficacy (Hadley et al., 2018). As previously mentioned, the GT-System is another example of a VR-based serious game to assess but also train ER strategies in adolescents through respiration and attention strategy games, which have been shown to significantly reduce frustration levels (Rodriguez et al., 2015).

Furthermore, novel 360 degrees cameras can easily create immersive 360 degrees videos that can be explored from all angles of recording. These videos can be integrated and manipulated by means of software like InstaVR or Google toolkit creator in order to elaborate ad hoc scenarios in which to simulate eliciting situations and improve, for example, ER strategies. However, there are also 360 degrees videos in different web platforms that can be downloaded for free. Notably, Li et al. validated a public set of 360 degrees videos for valence and arousal dimensions, that can be easily used to experimentally induce emotions (Li, Bailenson, Pines, Greenleaf, & Williams, 2017).

Finally, the incorporation of gamified features in the context of treatments can be of tremendous help, not only for the increase of engagement (Looyestyn et al., 2017) but also for the use both at an experimental and intervention level. A recent systematic review has synthesized the evidence of studies exploring the connection between videogames and ER, showing that there are 23 studies that have explored this in the context of commercial and bespoke games (Villani et al., 2018). Although the review grasps a broad concept of ER, including emotional and mood regulation and even stress responses, it is a first approximation to better understand how such an ecological stimulus for young, adolescents and event adults may be incorporated in the current perspective of ER assessment and intervention.

Biofeedback

Biofeedback constitutes an effective and non-invasive procedure, whose basic operating principle is the conscious registration of normally unconscious body procedures (e.g. brain activity, electrocardiogram, electromyography or skin conductance) (Gaume, Vialatte, Mora-Sánchez, Ramdani, & Vialatte, 2016) that are represented by a visual, haptic or audio signal. As aforementioned, there is a large body of evidence showing the strongly relation of ER with physiological processes such as HRV (Appelhans & Luecken, 2006; Balzarotti et al., 2017). Precisely, HRV biofeedback has shown to be effective for stress and anxiety (Goessl, Curtiss, & Hofmann, 2017), conditions that have shown to be greatly explained by emotion regulation (Barlow et al., 2004). Besides, the neural activity, in particular the activity of the amygdala which constitutes a key area for emotion activity and regulation, has shown to be successfully regulated through neurofeedback procedures (Johnston, Boehm, Healy, Goebel, & Linden, 2010; Zich et al., 2018; Zotev, Phillips, Young, Drevets, & Bodurka, 2013).

Finally, the integration of biofeedback with VR constitutes a very powerful research line. It would permit to provide users with engaging interfaces of the physiological targeted stimuli, which could in turn positively impact on the therapeutic outcomes. As an example, Lorenzetti and colleagues (2018) implemented a real-time functional magnetic resonance imaging neurofeedback protocol to enhance emotional states in healthy subjects.

FUTURE PERSPECTIVES IN THE INCORPORATION OF NEW TECHNOLOGIES FOR ER

All the described developments show that new digital technologies not only constitute a potentiality but also an already current way to improve our knowledge of ER.

Specifically, the following aspects are the most relevant to take into consideration for the further developments within the field.

Ecological validity: In ER research field, many smartphone-based EMAs have been adopted in order to ecologically investigate ER in daily life, showing the potentialities of this approach to grasp emotion dynamics in real-life settings. However, few studies integrated self-reports with data gathered from embedded-sensors or wearable biosensors, which could instead bring new insights into ER daily processes in terms of determinants and consequences as well as contextual factors affecting ER. Notably, no EMA for ER assessment has been developed so far with the aim of being applied to clinical practice, where retrospective self-reports are still the most used method. We suggest that EMA could increase assessment accuracy by considering ER as a situated process, in which momentary and contextual factors play a key role. This would, in turn, help clinicians identifying the strategies to be addressed by the therapy as well as the potential triggers of maladaptive strategies. Similarly, VR could constitute a powerful tool to develop realistic scenarios in which to elicit emotions and explore/assess ER deployment as well as train ER strategies. Nevertheless, this field is still completely understudied.

Individual differences: In line with the first point, the potentiality of utilizing embedded sensors and wearable biosensors along with complex machine learning techniques is still undeveloped in the specific case of EMI for ER. Its progress could lead to the development of aware-systems able to more accurate explore and predict users' emotion and affect regulation and provide support in specific moment of the day (Kuppens, 2015). Furthermore, VR could also be a powerful tool to increase intervention personalization. The possibility of manipulating VR scenarios could indeed represent a new way of intervening in ER, where it would be possible to adapt environments to the needs and characteristics of each individual.

Overcoming a schematic study of single ER strategies: Instead, the previously cited possibility of gathering large amount of data may allow grasping the complex interplay of the different strategies. In this way, the commonly used classification of adaptive or maladaptive strategies may be left aside in order to incorporate a context-based perspective. An integration of implicit, automatic and interpersonal ER processes could also be achieved through an articulated study of cognitive, behavioral, experiential and psychophysiological dimensions by means of the incorporation of all the described technologies.

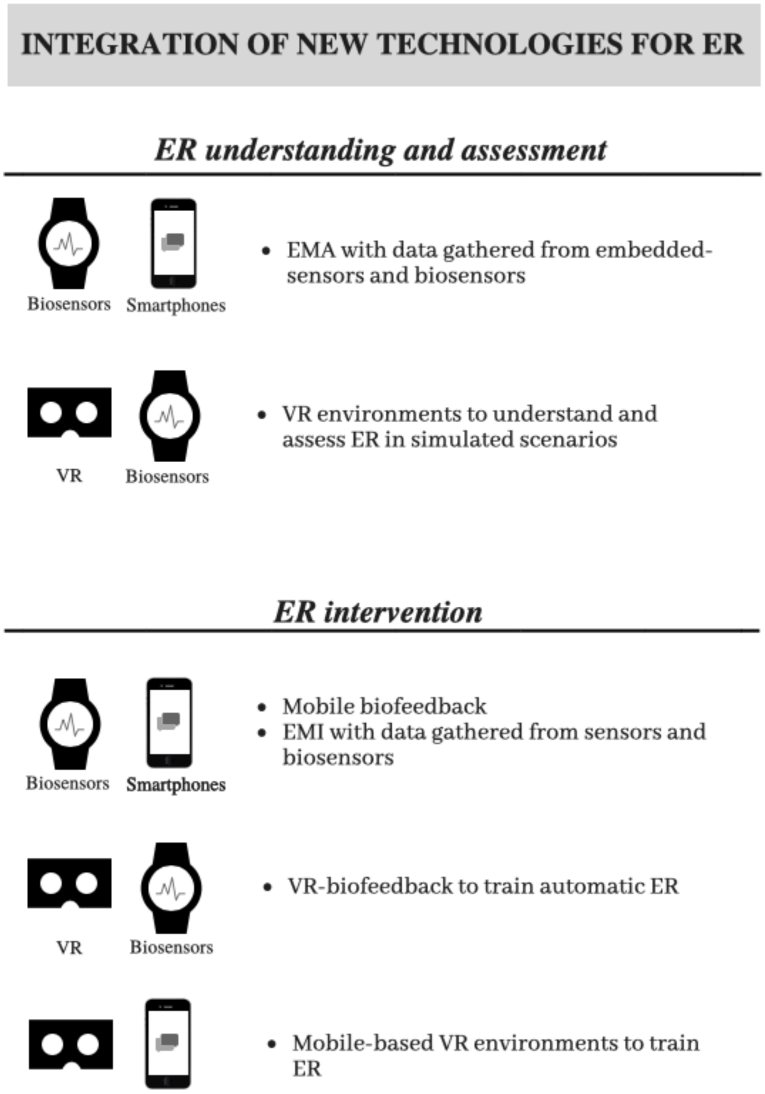

Figure 2.2: Examples of the complementary and integrative role f new technologies for the understanding assessment and intervention of ER. ER, emotion regulation; EMA, ecological momentary assessment; VR, virtual reality; EMI, ecological momentary intervention.

Integrated knowledge of ER: An integrated understanding of ER (i.e. implicit, automatic and interpersonal dimensions) could be achieved through an articulated study of cognitive, behavioral, experiential and psychophysiological dimensions by means of the incorporation of all the described technologies. For instance, a wide range of technologies such as VR-based avatars could embrace an embodied cognition perspective

(Bailey, Bailenson, & Casasanto, 2016), which is also an essential aspect within the emotion regulation field (Koole & Veenstra, 2015).

For the aforementioned reasons, the pursuit of integrated prototypes of technologies could lead to a successful understanding, assessment and training of ER (**Figure 2.2**). All these advancements should be conducted in a multidisciplinary way, i.e. in active collaboration with the latest Human Computer Interaction and Biomedical Engineering findings. Ongoing examples of integrated technologies are already occurring, like the development of an interpersonal VR-based biofeedback called "DYNECOM" (Salminen, M., Järvelä, S., Ruonala, A., Timonen, J., Mannermaa, K., Ravaja, N., & Jacucci, 2018). DYNECOM is an immersive VR system for the practice of empathy-evoking compassion meditation by dyads (Salminen, M., Järvelä, S., Ruonala, A., Timonen, J., Mannermaa, K., Ravaja, N., & Jacucci, 2018). Within the virtual environment, real-time EEG and breath rate visual feedbacks are provided, as well as a visual representation of the signals synchronization between participants. According to preliminary results, this innovative couple-biofeedback is able to increase the perceived affective interdependence between the dyad, suggesting the potentiality of this device to improve implicit ER. Other examples are VR-based intrapersonal biofeedback (Gaggioli et al., 2014), a mobile biofeedback with serious games (Dillon, Kelly, Robertson, & Robertson, 2016), gamified virtual reality (Miloff et al., 2016) or fMRI neurofeedback in virtual environments (Lorenzetti, Melo, Basilio, et al., 2018). If this integration is further developed, a powerful path for the upcoming years can be expected, resulting in the enhancement of the field of emotion regulation.

AUTHOR CONTRIBUTION

JFA and DC: developed the idea for this perspective and equally contributed to the conceptualization and writing—original and subsequent drafts until last version. CP, AGP, CB and GR: writing—review, conceptualization, editing and supervision.

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CHAPTER 3

Current state and future directions of technology-based ecological momentary assessments and interventions for major depressive disorder: A systematic review

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Current state and future directions of technology-based ecological momentary assessments and interventions for major depressive disorder: A systematic review

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ABSTRACT

Ecological momentary assessment (EMA) and ecological momentary intervention (EMI) are alternative approaches to retrospective self-reports and face-to-face treatments, and they make it possible to repeatedly assess patients in naturalistic settings and extend psychological support into real life. The increase in smartphone applications and the availability of low-cost wearable biosensors have further improved the potential of EMA and EMI, which, however, have not yet been applied in clinical practice. Here, we conducted a systematic review, using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, to explore the state of the art of technology-based EMA and EMI for Major Depressive Disorder (MDD). A total of 33 articles were included (EMA=26; EMI=7). First, we provide a detailed analysis of the included studies from technical (sampling methods, duration, prompts), clinical (fields of application, adherence rates, dropouts, intervention effectiveness), and technological (adopted devices) perspectives. Then, we identify the advantages of using Information and Communications Technologies (ICTs) to extend the potential of these approaches to the understanding, assessment and intervention in depression. Furthermore, we point out the relevant issues that still need to be addressed within this field, and we discuss how EMA and EMI could benefit from the use of sensors and biosensors, along with recent advances in machine learning for affective modelling.

Key words: Major depressive disorder; ecological momentary assessment; ecological momentary intervention.

INTRODUCTION

Major depressive disorder (MDD) is a common debilitating psychiatric disease characterized by mood disturbances, loss of interest and pleasure in daily activities, disturbed appetite and sleep, loss of energy, and psychomotor retardation or agitation. According to the World Health Organization, depression is one of the leading causes of disease and disability in the world, annually affecting 4.4 % of the general adult population (World Health Organization, 2017). In addition to producing high costs for the public health system, depression seriously impairs patients' functioning, leading to increased mortality, high suicide rates, exacerbated medical conditions, and high consumption of alcohol and illegal drugs (Katon & Ciechanowski, 2002; Simon, 2003; Sullivan, Fiellin, & O'Connor, 2005; Swendsen & Merikangas, 2000).

As a result of the increased availability of smartphones and portable and wearable devices, a growing body of research has begun to explore new digital technologies as potential tools to foster assessments and interventions in clinical practice. More specifically, technology-based ecological momentary assessment (EMA) and ecological momentary intervention (EMI) have been proposed as alternative strategies to assess patients ecologically in naturalistic settings and deliver psychological support in daily life.

Ecological Momentary Assessment

Traditional clinical assessments are based on retrospective self-reports in which patients are asked to summarize their symptoms and affective experiences over the past few weeks. Nevertheless, increasing evidence shows that these tools are not able to capture MDD dynamics, such as symptom fluctuations or mood shifts over time (McConville & Cooper, 1996; Peeters, Berkhof, Delespaul, Rottenberg, & Nicolson, 2006). Likewise, self-reports are affected by recall bias. In other words, depressed patients have been found to alter the content of past experiences when asked to retrieve them retrospectively (Ben-Zeev, Young, & Madsen, 2009; Chamberlain & Sakakian, 2006), judging symptoms as more severe (Möller & von Zerssen, 1995) or increasing the elaboration of negative information (Gotlib & Joormann, 2010).

EMA emerged as an alternative assessment strategy to better grasp affective and behavioral dynamics in daily life (Csikszentmihalyi & Larson, 1987; Shiffman et al., 2008; Stone, Shiffman, Atienza, & Nebeling, 2007). Not surprisingly, a growing body of research has applied this approach to exploring mood disorders (Aan het Rot, Hogenelst, & Schoevers, 2012; Ebner-Priemer & Trull, 2009). On the one hand, the term "ecological" refers to the environment where the data are collected. Behaviors, thoughts, and affect are repeatedly written down in real-world contexts. On the other hand, the term "momentary" refers to the focus of the assessment, i.e. close in time to the experience. The first studies to use this approach adopted paper-and-pencil daily diaries, but the discomfort, low compliance and low experimental control over backfilling made them not very efficacious (Stone et al., 2007).

The exponential progress of Information and Communication Technologies (ICTs) and the increasing availability of smartphones offered novel opportunities to ecologically assess patients. On the one hand, mobile technologies allow to overcome the shortcomings of traditional diaries by eliminating the need for manual data entry and by increasing control on backfilling, thus obtaining more accurate data. On the other hand, all the necessary processes can be integrated in one tool, for instance a smartphone, thus decreasing intrusiveness and increasing users' comfort, and providing a more engaging and dynamic experience. During the day, indeed, patients are automatically prompted by the device to fill in self-reports that are subsequently stored and safely sent to clinicians and/or researchers. More recently, the potential of EMA was extended due to the integration of self-reports with data gathered from embedded sensors and wearable biosensors, hence allowing for a multimodal approach. Unobtrusive wearable biosensors can continuously monitor physiological parameters throughout the day with high precision (Marzano et al., 2015), whereas smartphone embedded sensors make it possible to indirectly collect data about patients' behaviors and habits, such as their social media use, physical activity, or social interactions (Mohr, Zhang, & Schueller, 2017; van de Ven et al., 2017).

Overall, the integration of these tools has the potential to revolutionize traditional assessments, leading to the exploration of new facets of MDD obtained in daily life contexts that are often difficult to capture in laboratory settings.

Ecological Momentary Intervention

According to statistics, 70% of people suffering from mental disorders do not receive adequate psychological treatment or reach complete clinical remission (Henderson, Evans-Lacko, & Thornicroft, 2013). Affordances of technological developments, as Kazdin suggested, may facilitate new solutions for disseminating evidence-based psychotherapy (Kazdin & I, 2011).

The same "ecological" and "momentary" principles have been applied to the development of innovative interventions (EMI) (Heron & Smyth, 2010) that go beyond traditional clinical settings and extend the delivery of psychological support into real life (Donker et al., 2013). EMI has the advantage of providing psychological support directly on hand-held mobile technologies during the flow of daily experiences, in real-time settings, and at specific time points in the day, without the need for face-to-face meetings with a clinician (Cuijpers, Donker, Van Straten, Li, & Andersson, 2010). EMIs can be delivered both as stand-alone treatments or in combination with other treatments. Moreover, similarly to EMAs, the use of data gathered from biosensors and embedded sensors along with machine learning techniques can increase the customization of the proposed interventions (Asada, Shaltis, Reisner, Rhee, & Hutchinson, 2003; Ebner-Priemer & Trull, 2009).

Objectives

Recent studies have confirmed the feasibility of mobile health (mHealth) applications and patients' interest in and adherence to these technologies, suggesting the great potential of this approach in the clinical field (Donker et al., 2013; Torous, Friedman, & Keshvan, 2014). Nevertheless, no systematic review has explored technology-based EMA and EMI for MDD. Although two reviews focused on EMAs for mood disorders (Aan het Rot et al., 2012; Ebner-Priemer & Trull, 2009), most of the included studies were based on paper-and-pencil daily diaries, and the target population included adults and adolescents with Bipolar Disorder (BD) and Borderline Personality Disorder (BPD).

Coinciding with our field of interest, the aim of this systematic review is to provide an overview of the state of the art of technology-based EMA and EMI for MDD from both a clinical and technological point of view. Our final objective is to show how and why clinical practice could benefit from the use of these approaches. In doing so, we will describe the potential of new technologies in this field, and we will discuss how EMAs and EMIs could be performed with sensors and biosensors along with recent advances in machine learning for affective modelling.

METHODS

Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) criteria (Moher D, Liberati A, Tetzlaff J, 2009) were followed. For the systematic review protocol, see (Colombo, Palacios, et al., 2018).

Search strategy

To collect relevant publications, a computer-based search was performed (March 2019). We searched in two high-order databases, PubMed and Web of Science (Web of Knowledge), using the following string: ((EMA) OR ("ecological momentary assessment") OR (EMI) OR ("mobile health") OR (mhealth) OR (smartphone) OR ("ecological momentary intervention") OR (ESM) OR ("experience sampling method") OR ("ambulatory assessment") OR ("personal digital assistant") OR ("ambulatory monitoring") OR ("real time data capture") OR ("real time monitoring") OR ("real time interventions") OR ("electronic diary") OR ("repeated observations") OR ("diary data") OR ("time series")) AND (("affective disorder") OR ("mood disorder") OR (depress*) OR (depression) OR (MDD) OR ("major depressive disorder") OR ("major depression") OR ("unipolar depression") OR ("affective symptoms")).

Table 3.1: Detailed search strategy

	Results
PubMed / Medline	2758
Web of Science	2235
Total	4993
Not duplicated	3613
Excluded (after reading title and abstract)	3212
Retrieved	401
Excluded (after applying inclusion criteria)	361
Excluded (missing experimental data)	0
Final included articles	40

This search produced a total of 4993 articles. After eliminating duplicate papers, we made a first selection by reading titles and abstracts, and 401 articles were retrieved. We finally selected publications by applying the selection criteria described in the following paragraph, obtaining 40 papers. Three individual researchers (D.C., J.F.A. and M.S.) performed the search for publications in the English language. We provide more details in **Table 3.1** and in the flow diagram (**Figure 3.1**), in order to make this search replicable in the future.

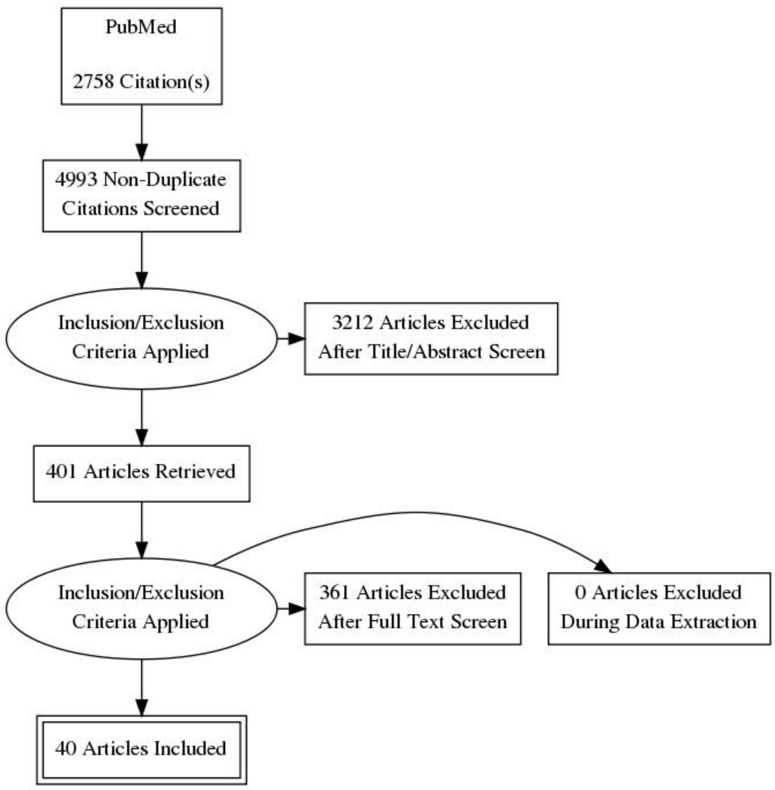

Figure 3.1: PRISMA flow diagram.

Selection criteria

We included all studies involving a sample of adults with a primary (both current or past) diagnosis of MDD, using recognized diagnostic criteria (Diagnostic and Statistical Manual of Mental Disorders – DSM; International Classification of Disease – ICD). We excluded non-English papers and studies that did not meet the inclusion criteria. We also excluded articles that did not have full-text available, and the following types of manuscripts: Conference papers, reviews and systematic reviews, metanalyses, meeting abstracts, notes, case reports, letters to the editor, editor's notes, extended abstracts, proceedings, patents, editorials, and other editorial materials. We tried to contact the corresponding authors, when necessary, to obtain missing or supplementary data.

Ecological Momentary Assessment: We included studies that adopted an Ecological Momentary Assessment by means of hand-held technologies (such as smartphones, Personal Digital Assistants, or hand-held computers) for the collection of daily self-reports, thus excluding studies that used paper-and-pencil diaries. Additionally, we included studies that integrated daily self-reports with data supplied by sensors and biosensors.

Ecological Momentary Interventions: We included EMIs that were provided to patients through hand-held technologies. We selected studies in which the proposed EMI was either a stand-alone intervention or combined with other types of treatment. We also included EMI that collected data from wearable biosensors or device-embedded sensors. Because providing continuous feedback to patients has been shown to be a valuable therapeutic procedure (Delgadillo et al., 2018), we also included studies that adopted EMA-based feedback as a therapeutic tool for clinically depressed patients.

Quality assessment and data abstraction

To control for the risk of bias, PRISMA recommendations for systematic literature analysis were followed. Studies were independently selected by three different authors (D.C., M.S. and J.F.A.), who first analyzed titles and abstracts and subsequently selected the full papers that met the inclusion criteria, resolving disagreements through consensus. For what concerns EMA included studies, the main aim was to provide a perspective of clinical, technical and technological issues related to this approach: In other words, we were interested in EMA as a clinical and experimental tool to be used in the psychological field, regardless of study design or variables of outcome (Colombo et al., 2018). No risk of bias assessment was therefore performed. Differently, risk of bias of EMI studies was assessed by two independent reviewers (D.C and J.F.A.). As both randomized and non-randomized controlled trials were included, quality assessment was assess with the Downs and Black Quality Index (Downs & Black, 1998).

The data extracted from each study were as follows: Author(s), Sample(s), Variable(s), Device(s), Sensor(s), Duration, Prompt(s) per day, Sampling Schema, Primary Outcome(s) for the selected studies on EMA (**Table 3.2**); and Author(s), Name of the intervention, Sample(s), Content of the Intervention, Duration, Device(s), Sensor(s), and Primary Outcome(s) for the studies proposing an EMI (**Table 3.3**).

RESULTS

Ecological Momentary Assessment in MDD

After applying the inclusion criteria, 32 studies were retrieved that investigated and assessed MDD through a technology-based EMA. A synthesis of the results is provided in **Table 3.2**.

Electronic devices and use of sensors

Most of the selected studies administered daily self-reports either through a personal digital assistant (PDA) or a smartphone. Only three studies adopted different technological solutions that allowed them to collect both self-reports and data gathered from sensors and biosensors. Conrad et al. (Conrad, Wilhelm, Roth, Spiegel, & Taylor, 2008) used the LifeShirt System (Vivometrics, Inc., Ventura, CA, U.S.A), a comfortable garment with integrated biosensors that can continuously monitor various cardiopulmonary parameters, including HR, respiration, and posture. With an embedded hand-held computer, patients can also complete self-reports following daily beep signals. In another study, Kim and colleagues adopted ECOLOG (Kim et al., 2015), a watch-type computer characterized by an 8-direction joystick and an integrated actimetry sensor. Via a beep signal, the wristwatch prompts patients to complete momentary assessments directly on the watch screen. Similarly, a compact wrist–worn electronic diary was used by Littlewood et al. to collect both self-reports and sleep/wake cycles with an embedded actimetry sensor (Littlewood et al., 2018).

Table 3.2: More detailed information about the selected EMA studies.

	AUTHORS	SAMPLE	VARIABLES	DEVICE	DURATION	PROMPTS PER DAY	SAMPLING SCHEMA	COMPLIANCE	SENSORS	PRIMARY OUTCOME(S)
Recall bias	(Ben-Zeev et al. 2009)	MDD (n=26), and HCG (n=25)	Affect	Palm Tungsten E2	7 days	8	Semi-randomized	89%	No	Both depressed and non-depressed participants overestimate the retrospective recall of PA and NA. Depressed patients are more inaccurate in recalling NA.
	(Torous et al. 2015)	MDD (n=13)	Randomized items from PHQ-9 questionnaire	"Mindful Moods" mobile application	29/30 days	3	Randomized	78%	No	Even if strongly correlated, the PHQ-9 scores collected through the mobile application are significantly higher than those obtained though the retrospective paper-and-pencil PHQ-9.
Symptoms	(Husky et al., 2010)	MDD (n=20), and BD (n=21)	Affect; stressors; behaviours; 76nalyzing	PDA	3 days	5	Fixed sampling scheme	85.7%	No	High rates of acceptance and compliance are observed among both samples.

			77t; social context							Participants show a practice effect, i.e. faster responses over the course of the study.
	(Schaffer et al. 2013)	MDD (n=26)	Depressive and anxiety symptoms	Palm Treo 650 Smartphone (Mental Health Telemetry mobile application)	14 days	1	Selected by the patient	/	No	Self-reported ratings of improvement at day 7 predict response to the treatment.
	(Hung et al. 2016)	MDD (n=59)	Symptoms, sleep patterns, cognitive functioning	iHOPE smartphone application	8 weeks	2 (symptoms) 1 (sleep duration and quality)	Not specified	/	No	Baseline depression scores evaluated with HAM-D are associated with scores of PHQ-9, VAS for depression and anxiety symptoms collected with the application.
Cortisol	(Stetler, Dickerson, and Miller 2004)	MDD (n=32), mD (n=18), and HCG (n=50)	Daily activities (frequency, social contacts); cortisol	Palm Pilot M100	4 days (over a maximum period of 7 days)	4 (saliva samples) 1 (self-report)	Fixed sampling scheme	/	No	In the control sample, daily activities are negatively associated with cortisol levels. This association

									is not observed in depressed patients.
	(Stetler and Miller 2005)	MDD (n=37), and HCG (n=36)	Sleep patterns; social contacts; cortisol	Palm Pilot M100	3 non-consecutive days (over a maximum period of 7 days)	3 (saliva samples) 1 (self-report)	Fixed sampling scheme	93%	No	Depressed patients show lower cortisol awakening response, lower sleep quality, and more negative social interactions.
	(Conrad et al. 2008)	MDD (n=46) and HCG (n=19)	Physiological indices (HR, respiration, accelerometer, cortisol); mood	LifeShirt System, with an integrated hand-held computer	1 day	6 (self-reports) 5 (saliva samples)	Fixed sampling scheme	91%	LifeShirt System (HR, respiration, actigraphy)	Cortisol level and HRV do not differ between the two groups. Interestingly, NA is negatively correlated with HRV only in the control sample.
	(Huffziger et al. 2013)	Remitted MDD (n=31) and HCG (n=32)	Mood; ruminative self-focus; stressful events; cortisol	Palm Tungsten E2	2 consecutive days	10	Semi-randomized	94%	No	Rumination and low mood are associated with increased activation of the HPAA. In remitted patients, HPAA is less responsive to subtle emotional events.

	(Booij et al., 2015)	MDD (n=15), and HCG (n=15)	Affect; cognition; daily activities; cortisol	PsyMate	30 days	3	Fixed sampling scheme	92.5%	ActiCal (Respironics, Bend, OR, USA)	Compared to healthy participants, depressed patients report higher cortisol levels, higher α-amylase levels and a greater ratio of α-amylase over cortisol. This latter association, however, disappears when correction for lifestyle factors is applied.
	(Booij et al., 2016)	MDD (n=15), and HCG (n=15)	Affect; cortisol	PsyMate	30 days	3	Fixed sampling scheme	92.5%	No	PA and NA are bidirectionally associated with cortisol levels. Nevertheless, the direction, sign and timing of this association show a great variability among subjects.
Sleep patterns	(Bower et al. 2010)	MDD (n=35), mD (n=25), and HCG (n=36)	Positive and negative affects	PDA	3 days	10	Semi-randomized	65%	No	Sleep quality predicts lower PA, but not NA. Low PA is associated with poor subjective sleep quality and self-reported

										daily dysfunction.
	(O'Leary et al. 2017)	MDD and mD (n=60), and HCG (n=35)	Positive and negative affects; events appraisal	Palm Pilot Zire 22	3 days	10	Semi-randomized	65%	No	In the non-clinical sample, sleep disturbances are associated with enhanced NA in response to negative events. Considering depressed patients, sleep disturbances negatively influence the emotional reactivity to both neutral and negative events.
	(Bouwmans et al. 2017)	MDD (n=27), and HCG (n=27)	PA and NA, sleep quality; tiredness; rumination	PsyMate	30 days	3	Fixed sampling scheme	96%	No	Sleep quality directly influences PA and NA experienced during the following day, but not vice versa. Tiredness is a mediator.

	(Bouwmans et al. 2018)	MDD (n=14) and HCG (n=15)	PA; NA; fatigue; sleep; activities; cognition; melatonin	PsyMate	30 days	3	Fixed sampling scheme	93%	No	Melatonin is associated with changes in affect and fatigue. However, also changes in affect and fatigue are predictors of melatonin levels. Individuals that do not show this association report higher depression severity and worse sleep quality.
	(Bouwmans et al., 2018)	MDD (n=27), and HCG (n=27)	Sleep patterns	PsyMate	30 days	3	Fixed sampling scheme	96%	ActiCal (Respironics, Bend, OR, USA)	Sleep duration affects next-day physical activity. Depression does not moderate this association.
	(Littlewood et al. 2018)	MDD (n=51)	Sleep patterns and quality; suicide ideation; entrapment perception	PRO-Diary actigraph watch (CamNtech)	7 days	6	Semi-randomized	89%	Accelerometer	Poor sleep quality, both objectively and subjectively evaluated, is associated with higher next-day suicide ideations. Suicide ideation does not influence sleep

										patterns and quality.
Physical activity	(Mata et al. 2012)	MDD (n=53), and HCG (n=53)	Physical activity; positive and negative affects	Palm Pilot Zire 22	7 days	8	Randomized	75%	No	Both samples show higher PA following physical activity. More specifically, depressed patients show a significantly higher increase in experienced PA levels after physical activity.
	(Kim et al. 2015)	MDD (n=14) and HCG (n=43)	Mood; physical symptoms; physical activity	Ruputer ECOLOG	Average: 37.43 days (range:18–67 days)	4	Semi-randomized	93%	Ambulatory Monitors Inc. – actigraph	Depressive mood is associated with increased intermittency of locomotor activity.
	(Stavrakakis et al. 2015)	MDD (n=10), and HCG (n=10)	Mood; cognition; daily activities; physical activity	PsyMate	30 days	3	Fixed sampling scheme	91%	ActiCal Respironics – actigraph	Despite the observation of large interindividual differences, results show a positive effect of physical activity on PA in all participants.

Rumination	(Putnam and McSweeney 2008)	MDD (n=6) and HCG (n=7)	Context; mood; depressive symptoms; EEG (at baseline)	Palm Pilot and EEG (at baseline)	7 days	5	Not specified	/	No	Lower activation of bilateral PFC predicts higher rates of rumination, whereas higher levels of self-esteem are associated with lower right PFC activity.
	(Ottaviani et al. 2015)	MDD (n=18) and HCG (n=18)	Thoughts; disturbing events; feelings; possible influencing factors; feelings; HR	Electronic diary implemented on a smartphone	1 day	Not reported	Semi-randomized	/	RS 800CX; Bodyguard2 (HR and HRV)	Depressed participants show higher rates of perseverative cognition, which are associated with lower HRV.
	(Ruscio et al. 2015)	MDD(n=38), GAD (n=36), MDD with GAD comorbidity (n=38), and HCG (n=33)	Events stressfulness; rumination	Palm Pilot Zire 22	7 days	8	Randomized	72%	No	MDD and GAD participants show the same level of rumination, which is even more severe in comorbid cases. Higher rates of rumination are predictive of worse affect, more maladaptive behaviors, and

										more severe symptoms.
	(Kircanski et al. 2017)	MDD (n=16), GAD (n=15), MDD with GAD comorbidity (n=20), and HCG (n=19)	Rumination; worry; PA and NA; significant events	Palm Pilot Zire 22	6 to7 days	8	Semi-randomized	65%	No	Levels of rumination among all the clinical samples are higher in response to significant events. Decreased PA and increased NA are associated with higher momentary rumination.
Emotional reaction	(Husky et al. 2009)	Remitted MDD (n=55) and HCG (n=55)	Perceived stress; mood	Handheld Psion “Revo” computer	7 days	5	Randomized	90%	No	Past episodes of depression are likely to increase the vulnerability to stressful events, especially in male participants.
	(Bylsma et al. 2011)	MDD (n=35), mD (n=26), and HCG (n=38)	Context; mood; events (nature of the event; location; people involved;	Palm Pilot Zire 22	3 non-consecutive days (over a period of 5 days)	10	Semi-randomized	65%	No	Both MDD and mD patients show lower levels of positive affect and rate events as more stressful and unpleasant than

			affective rating)							the control group. Furthermore, they show higher reduction in negative feelings after positive events.
	(Thompson et al. 2012)	MDD (n=53), and HCG (n=53)	Affect; significant events	Palm Pilot Zire 22	7/8 days	8	Randomized	78%	No	Results point out greater emotional instability with respect to NA in depressed patients. No differences are observed in terms of reactivity, inertia, and instability in PA.
	(Kohling et al. 2015)	MDD (n=21) and MDD with BPD comorbidity (n=20)	Affect and mood; events; subjective affective reactivity	Smartphone to access a web platform	7 days	5	Randomized	94%	No	Comorbidity with BPD does not imply major affective instability, but it is associated with lower subjective perception of affective reactivity.

	(Slofstra et al. 2017)	Remitted MDD (n=10) and HCG (n=11)	Mood; PA and NA; visual mental imagery	“Imagine your Mood”, smartphone application	3 days a week, for 8 weeks	10	Semi-randomized	/	No	In both samples, higher levels of visual imagery-based processing are associated with higher levels of PA and better mood, regardless of the valence of the imagery content. Elevated levels of visual imagery-based processing are not associated with daily affective reactivity.
	(Hepp et al. 2017)	MDD (n=51), and BPD (n=80)	PA, NA, fear; hostility; sadness; interperson al events	Palm Pilot Zire 31	28 days	6	Semi-randomized	86%	No	Rejection and disagreement increase NA (especially hostility and sadness) both at a momentary and daily level, regardless of the diagnosis. The association between rejection/disagree ment and hostility is

										stronger in BPD patients.
	(Quilty et al. 2017)	MDD (n=12), DD (n=3), BD (n=15)	Affect; location; social context; gambling desire/ motivation /activities;	Palm Pilot Zire 22	30 days	3	Randomize d	73%	No	High levels of sadness and arousal are predictive of gambling desire, regardless of the diagnosis. Depressed individuals are likely to gamble to increase PA or for social reasons.
	(Fisher et al., 2017)	MDD (n=15), GAD (n=25)	Symptoms, PA, NA, rumination, behavioural avoidance, reassurance seeking	Web-based survey	30 days	4	/	/	No	Using a person-by-person approach, results show that moment-to-moment symptomatology is mainly driven by positive mood, hopelessness, anger and irritability, but not depressed mood, anhedonia or worry.

MDD: major depressive disorder; mD: minor depression; HCG: healthy control group; BDP: borderline personality disorder; GAD: generalized anxiety disorders; PDA: personal digital assistant; DD: dysthymic disorder; PFC: prefrontal cortex; PA: positive affect; NA: negative affect; HRV: heart rate variability; PHQ-9: Patient Health Questionnaire-9; QUID-SR: Quick Inventory of Depressive Symptomatology – Self Report; HADS-A: Hospital Anxiety and Depression Scale; PANAS: Positive and Negative Affect Schedule; HPAA: hypothalamic-pituitary-adrenal axis.

Table 3.3: More detailed information about the selected EMI studies.

AUTHORS	NAME	SAMPLE	INTERVENTIO N	DURATIO N	PROMPT S	SAMPLIN G SCHEMA	SENSOR	PRIMARY OUTCOMES
(Burns et al. 2011)	Mobylize!	MDD (n=7), with different comorbiditie s	Mobylize! Is a context-aware system, composed of three main elements: (1) a mobile application for the collection of self-reports; (2) a website with feedback and theoretical lessons; (3) periodic contacts with trained coaches	8 weeks	5/day	Randomized	38 concurrent sensors integrated in the phone	Mobylize! Significantly reduced depressive symptoms. Predictive models did not reach high levels of accuracy, especially for mood.
(Kramer et al. 2014)	PsyMate	MDD (n=102): experimental condition (n=33), pseudo-experimental condition (n=36), control condition (n=33)	Daily assessment of self-reports and weekly EMA-derived feedback through face-to-face sessions	3 days per week, for 6 weeks	10/day	Semi-randomized	No	The use of EMA-derived feedback as a complementary intervention to pharmacological treatment significantly decreased depressive symptoms. These improvements were also

							maintained over time.
(Simons et al. 2015)	PsyMate	MDD (n=102): experimental condition (n=33), pseudo-experimental condition (n=36), control condition (n=33)	Daily assessment of self-reports and weekly EMA-derived feedback through face-to-face sessions	3 days per week, for 6 weeks	10/day	Semi-randomized	No	The use of Psymate as a technique of self-monitoring could improve patients' feelings of empowerment.
(Hartmann et al. 2015)	PsyMate	MDD (n=102): experimental condition (n=33), pseudo-experimental condition (n=36), control condition (n=33)	Daily assessment of self-reports and weekly EMA-derived feedback through face-to-face sessions	3 days per week, for 6 weeks	10/day	Semi-randomized	No	Face-to-face EMA-derived feedback sessions did not increase the rate of PA experienced during or shortly after the intervention.
(Mohr et al. 2015)	Medlink	MDD (n=8)	Medlink is a mobile application delivering psychological support to MDD patients. The	4 weeks	1/week	/	No	Medlink was positively evaluated by participants, especially regarding the

			application provides users with: (1) psychoeducation; (2) weekly symptom assessment; (3) medication adherence monitoring; (4) monthly communication with a professional based on the previous points					weekly psychoeducation lessons. Depression severity of participants significantly decreased over the course of the experiment.
(Burton et al. 2016)	Help4Mood	MDD (n=28): experimental condition (n=14) and control condition (n=14)	Web platform providing daily assessment of symptoms, self-monitoring, and tailored activities. The delivered content is created in response to the user's actions through a virtual agent	About 5 weeks	CESD-VAS-VA: 1/day PHQ-9: 1/week	/	Accelerometer and acoustic speech analysis	Only half of the participants used Help4Mood regularly. Significant changes in depressive symptoms were observed only among regular users.
(Snippe et al. 2016)	PsyMate	MDD (n=102): experimental condition (n=33),	Daily assessment of self-reports and weekly EMA-derived feedback	3 days per week, for 6 weeks	10/day	Semi-randomized	No	The use of EMA-derived feedback decreased depressive

		pseudo-experimental condition (n=36), control condition (n=33)	through face-to-face sessions				symptoms and improved maladaptive behaviors.
(Widdershoven et al., 2019)	PsyMate	MDD (n=79): experimental condition (n=25), pseudo-experimental condition (n=30), control condition (n=24)	Daily assessment of self-reports and weekly EMA-derived feedback through face-to-face sessions	3 days per week, for 6 weeks	10/day	Semi-randomized	No	The use of a self-monitoring EMA improves negative emotion differentiation.

MDD: major depressive disorder; PA: positive affect; CESD-VAS-VA: brief Visual Analogue Scale version of the Center of Epidemiological Studies Depression Scale; PHQ-9: Patient Health Questionnaire.

Although a growing number of studies analyzes data from embedded- sensors and biosensors in research on mental health disorders (Adams et al., 2017), their use in association with EMA has been low in the field of MDD. Among our selected studies, only seven of the 32 studies collected physiological measures in addition to self-reports. Conrad and colleagues collected cardiac and respiratory measures as indices of vagal activity, along with physical activity measured through an embedded actimetry sensor (Conrad et al., 2008), whereas Ottaviani and colleagues collected ambulatory HR (Ottaviani et al., 2015). The remaining five articles investigated the association of depressive symptoms with sleep/wake cycles (Booij et al., 2015; Kim et al., 2015; Littlewood et al., 2018) and physical activity (Bouwmans, Oude Oosterik, et al., 2018; Stavrakakis et al., 2015) using actimetry sensors.

Sampling methods

Currently, different EMA designs can be used to define prompt scheduling, depending on the main purpose of the study. It is possible to prompt participants using fixed time periods or randomized/semi-randomized samplings (time-based sampling). Alternatively, participants can be asked to personally fill in the assessment after the occurrence of a specific 92behavior or event (event-based sampling). Whereas time-based samplings depend on a signal emitted by the device (signal-contingent), event-based samplings are not preceded by a prompt (event-contingent). Signal-contingent schemas are useful when repeated measures are needed to obtain a representative value of a variable or when the objective is to capture dynamic variables (e.g. mood), whereas event-contingent schemas are more likely to be adopted when the main focus is on a specific 92behavior that occurs randomly or less frequently during the day (e.g. smoking a cigarette). Regarding our selected studies, none of them adopted event-based sampling. Most of the studies collected data using randomized or semi-randomized schemas, whereas nine studies prompted participants at fixed time points during the day. This latter approach was adopted especially by the studies that investigated the association between cortisol or melatonin and depression, i.e. when the assessed variable required greater temporal precision and accuracy.

The duration of the data collection showed great variability. Some studies collected self-reports for a brief time period (less than 3 days); this choice was especially observed in the field of cortisol and sleep pattern research. Other studies required longer periods of assessment, where participants were involved for one or two months. This was especially true for studies investigating physical activity and its association with depressive symptoms. The same high variability was observed in the number of prompts, which varied from 1 to 20 prompts per day.

Compliance and dropout rates

With the term "compliance", we refer to the percentage of answered prompts. A few studies did not report this information (Fisher, Reeves, Lawyer, Medaglia, & Rubel, 2017; Hung et al., 2016; Ottaviani et al., 2015; Putnam & McSweeney, 2008; Schaffer, Kreindler, Reis, & Levitt, 2013; Slofstra et al., 2017; Stetler, Dickerson, & Miller, 2004). However, the majority clearly addressed this issue. Sixteen studies reported compliance rates higher than 85%, five studies showed rates between 84% and 70%, and four studies collected 65% of the total possible answers. Patient dropout was related to diagnosis change, subjective burden, technical problems, incomplete data, retrospective completion of the electronic diary, missed prompts, worsening of symptoms, or non-attendance at follow-up sessions.

To prevent backfilling, different solutions were adopted. In most of the studies, participants could complete self-reports for a fixed time period after the prompt, ranging from a few minutes to a maximum of one hour. To increase compliance, two studies also gave participants the possibility of postponing.

Contribution of EMA to the study of MDD

As **Table 3.4** shows, so far EMA has been applied to seven different fields. In the following paragraph, we will provide an overview of EMA's contribution to the understanding and assessment of MDD.

Table 3.4. Fields of application of EMAs for MDD

Field of application	Retrieved articles	Aim	Advantages
Recall bias	Ben-Zeev et al., 2009 Torous et al., 2015	Experimental	No retrospective bias; Control over backfilling; Repeated momentary measurements;
Symptoms monitoring	Hung et al., 2016 Schaffer et al., 2013 Husky et al., 2010	Clinical	Continuous monitoring (symptoms assessment, treatment progress); Real-time feedback to clinicians (e.g. crisis plan) and users (e.g. patterns visualization);
Cortisol dysregulation	Conrad et al., 2008 Huffziger et al., 2013 Stetler et al., 2004 Stetler et al., 2005 Booij et al., 2015 Booij et al., 2016	Experimental	Role of contextual variables; Temporal relationship between physiological measures and self-reports;
Sleep patterns	Bower et al., 2010 O'Leary et al., 2017 Bouwmans et al., 2017 Littlewood et al., 2018 Bouwmans et al., 2018 Bouwmans et al., 2018	Experimental	Control over backfilling; No retrospective bias; Integration of self-reports with passive data supplied by sensors and biosensors;
Physical activity	Kim et al., 2015 Mata et al., 2012 Stavrakakis et al., 2015	Experimental	Role of contextual variables; Integration of self-reports with passive data supplied by sensors; Temporal relationship between physiological measures and self-reports;
Rumination	Ottaviani et al., 2015 Putnam et al., 2008 Ruscio et al., 2015 Kircanski et al., 2017	Experimental	Role of contextual variables; Rumination deployment across time;
Affect and emotional reactivity	Bylsma et al., 2011 Husky et al., 2009 Kohling et al., 2015 Thompson et al., 2012 Slofstra et al., 2017 Hepp et al., 2017 Quilty et al., 2017 Fisher et al., 2017	Experimental	Role of contextual variables; Temporal deployment of affect and emotional reactivity;

Recall bias: Increasing evidence shows that memories often have inaccurate and imprecise content due to recall bias. In the case of EMAs, two studies were carried out to investigate this bias, comparing EMA daily data to retrospective assessments. Ben-Zeev and colleagues compared positive (PA) and negative (NA) affect collected through an EMA to scores obtained by means of traditional paper-and-pencil retrospective questionnaires (Ben-Zeev et al., 2009). When retrospectively recalled, both PA and NA were overestimated, regardless of the diagnosis. Interestingly, the control group was more likely to exaggerate the retrieval of PA rather than NA, but this trend was not observed in depressed patients. By contrast, Torous and colleagues (2015) developed a smartphone application to administer randomized subsets of items taken from the Patient Health Questionnaire (PHQ-9), compared to the traditional paper-based PHQ-9. Symptoms were evaluated as more severe in daily EMA evaluations, compared to the retrospective PHQ-9 assessment. According to the authors, this discrepancy could be due to different factors, such as recall bias or stigma.

Symptom monitoring: Unexpectedly, we could only retrieve three studies within this research field, i.e. studies that actually applied EMA to monitor clinically depressed patients. Husky and colleagues investigated the acceptability of a three-days computerized ambulatory monitoring on MDD and BD patients, showing encouraging compliance and acceptance rates among both samples. Practice effects were observed (faster response time over the course of the study), thus suggesting the importance of considering the potential effects of EMA duration on self-reports (Husky et al., 2010). Schaffer et al. developed a system called "Mental Health Telemetry" to monitor symptoms of patients receiving pharmacological treatment (Schaffer et al., 2013). According to the results, a reduction in depressive symptoms was already observable one day after beginning the treatment, and symptoms on day 7 were predictive of treatment outcome. Similarly, iHOPE is a smartphone application for the daily monitoring of depressive symptoms and sleep patterns (Hung et al., 2016). EMA assessments of depression, sleep quality, and anxiety were highly associated with the Hamilton Depression Rating Scale (HAM-D), administered at baseline. Nevertheless, application use decreased significantly over the weeks, from 3.4 days per week to 0.4 days per week after 8 weeks, highlighting the important issue of compliance in EMA assessments.

Cortisol secretion: Stetler and colleagues investigated the associations among cortisol and sleep patterns, social interactions (Stetler & Miller, 2005), and daily activities

(Stetler et al., 2004). Not only were cortisol levels after awakening different in depressed and healthy participants, but the impact of psychosocial variables on cortisol secretion was also dissimilar. Consistently, the HPA axis of depressed patients was no longer able to respond to the timing of the sleep-wake cycle, daily routines, and external social experiences. One study explored the impact of cortisol on affect, showing a bidirectional association between PA and NA and daily cortisol levels (Booij, Bos, de Jonge, & Oldehinkel, 2016). Nevertheless, high variability was observed among participants regarding the timing, direction and sign of this association. For instance, NA was positively associated with cortisol 50% of the times, while the association between cortisol and PA was almost always negative. Booij et al. identified higher cortisol and α-amylase levels among depressed individuals (Booij et al., 2015). Similarly, when applying individual correction for lifestyle factors, the association of depression to cortisol and the ratio of α-amylase over cortisol was no longer significant, suggesting that generalization from groups does not always reflect the single individual. Nevertheless, Conrad and colleagues could not find cortisol differences between depressed and non-depressed participants. Interestingly, a negative correlation between NA and heart rate variability (HRV) was observed only in the control group, suggesting that constant NA may alter the normal interaction between affectivity and the autonomic nervous system (Conrad et al., 2008). Finally, interesting outcomes were also observed among remitted MDD patients (Huffziger et al., 2013). Despite remission, patients showed reduced cortisol levels throughout the day and a different interaction between affect and cortisol, thus suggesting a reduction in HPA axis responsiveness as a potential marker of recurrent depression.

Sleep patterns: According to our search, six studies adopted an EMA to explore sleep disturbances in depression. Through the daily administration of morning self-reports about sleep patterns, O'Leary et al. found that depression was associated with lower perceived sleep quality, which in turn affected negative emotional reactivity to both neutral and unpleasant events during the day (O'Leary, Small, Panaite, Bylsma, & Rottenberg, 2017). However, in healthy participants, sleep disturbances only affected emotional reactivity to unpleasant events. In other words, depression could be a factor affecting the relationship between sleep quality and emotional reactivity. Similarly, two studies analysed the influence of sleep quality on daily affect (Bouwmans, Bos, Hoenders, Oldehinkel, & de Jonge, 2017; Bower, Bylsma, Morris, & Rottenberg, 2010). As expected, higher sleep quality was associated with higher PA in both healthy and depressed participants. Surprisingly, there was no evidence of the moderating role of depression in the association between sleep and affect. Nevertheless, sleep quality affected daily mood, but not vice versa, because higher sleep quality was associated with increased PA and decreased NA the following day. This association did not differ between depressed and healthy participants. Similarly, sleep duration was found to affect next-day physical activity but again, no difference between depressed and non-depressed individuals was observed (Bouwmans, Oude Oosterik, et al., 2018). An EMA was finally adopted to investigate the association between sleep patterns and suicide ideation in a sample of depressed patients (Littlewood et al., 2018). Poor sleep quality, both at subjective and objective levels, was associated with increased suicide ideations the following day. However, suicidal thoughts did not predict sleep patterns the following night. Bouwmans and colleagues also collected repeated saliva samples to analyse the association of depression with melatonin, an important hormone related to sleep onset (Bouwmans, Beltz, et al., 2018). A bidirectional relationship between affect and fatigue, and melatonin was pointed out: Melatonin is associated with changes in affect and fatigue; however, affect and fatigue are also predictors of melatonin levels. Participants that did not show this association were likely to report higher rates of depression, worse sleep quality and lower energy expenditure.

Physical activity: In order to analyse the effect of self-initiated physical activity on mood, clinically depressed patients were asked to report their daily physical activity (Thompson et al., 2012). Both healthy and depressed participants showed higher levels of PA following physical activity, but no decrease in NA. Notably, the increase in PA after physical exercise was greater in depressed patients, which is consistent with the ample evidence supporting behavioural activation in general, and physical activity in particular, for the treatment of depression. Confirming these results, another study found that physical activity was associated with subsequent increased PA, regardless of the diagnosis (Stavrakakis et al., 2015). However, the analysis also revealed high subjective variability in the association between physical activity and mood in terms of strength, direction, and temporal aspects. Finally, Kim and colleagues developed a statistical model with cross validity that identified a significant association between higher intermittency of locomotor activity and worse mood ratings (Kim et al., 2015), suggesting the possibility of predicting patients' moods through the analysis of momentary locomotor patterns. According to their model, a worsening of depressive mood was associated with increased intermittency of locomotor activity.

Rumination: Ruscio and colleagues investigated the relationship between stressful events and rumination in MDD and GAD patients (Ruscio et al., 2015). Both clinical samples showed higher levels of rumination in response to stressful situations, which were further worsened by symptom severity and extensive comorbidity. In addition, rumination significantly mediated the impact of stress on symptoms and affect; that is, higher rumination after a stressful event predicted greater NA and more maladaptive behaviours. Putman and colleagues investigated rumination and self-esteem through the assessment of resting baseline PFC alpha activity, along with the momentary assessment of affect and depressive symptoms, in a sample of clinically depressed individuals (Putnam & McSweeney, 2008). Rumination was found to be associated with an increased alpha signal in the bilateral prefrontal cortex (i.e. decreased neural activation), whereas an increased alpha signal in the right prefrontal cortex was positively correlated with higher self-esteem ratings. One study investigated perseverative thoughts (i.e. depressive rumination, worry, and reactive rumination) in relation to mind wandering (Ottaviani et al., 2015). Participants were instructed to complete a smartphone diary every 30 minutes for one day, and these self-reports were integrated with continuous HR monitoring. Confirming the hypothesis that mind wandering is not a maladaptive behavior per se, only perseverative cognition was associated with health risk factors such as lower HRV, worse mood, and higher interference in daily functioning. Finally, one study examined the dynamics of worry and rumination in daily life (Kircanski, Thompson, Sorenson, Sherdell, & Gotlib, 2017). Contrary to the hypothesis, levels of worry were not significantly associated with the occurrence of significant events, whereas rumination was significantly higher in response to these circumstances. Compared to the control group, clinically depressed individuals showed decreased PA and increased NA as a consequence of high rumination levels.

Affect and emotional reactivity: Thompson and colleagues investigated emotional reactivity, emotional inertia, and emotional instability in depressed patients (Thompson et al., 2012). Compared to healthy participants, clinically depressed patients showed higher NA instability, whereas no differences in PA instability were observed. Both samples reported increased NA after a negative event; however, depressed patients showed a greater decrease in NA and increase in PA after a positive event. These results were confirmed by another study that showed a greater reduction in NA following positive events in depressed individuals (Bylsma, Taylor-Clift, & Rottenberg, 2011). When considering BPD comorbidity, depressed patients were found to be less emotionally influenced by events, and to perceive themselves as less emotionally reactive (Kohling et al., 2015). Other factors that affect emotional reactivity are gender and past depression (Husky, Mazure, MacIejewski, & Swendsen, 2009). In one study, women and remitted patients evaluated daily events as more negative than men, and they showed worse mood and higher emotional reactivity in response to daily stressors. Finally, a smartphone application was developed to assess visual mental imagery and its impact on mood and affective reactivity in healthy people and remitted MDD patients (Slofstra et al., 2017). Participants were asked to focus on their mental representations, i.e. what they had in mind, eight times per day. Imagery-based processing was associated with better mood, regardless of the valence of the mental representation. This pattern was similar in healthy and depressed participants. However, no association between mental imagery and affective reactivity was observed. Regarding daily affect, one study explored the impact of gambling desire on mood in a sample of depressed individuals (Quilty, Watson, Toneatto, & Bagby, 2017). Higher levels of sadness and arousal were associated with higher rates of gambling desire. Consistently, depressed participants were also likely to perform gambling behaviors to increase their current PA levels. However, momentary affect did not predict actual gambling behaviors. An EMA was also used to investigate the influence of social rejection and disagreement on daily affect in MDD and BPD patients (Hepp et al., 2017). As expected, momentary and daily negative interpersonal events triggered higher NA (fear, hostility, and sadness) in both groups. High levels of hostility predicted rejection and disagreements, whereas sadness was only a predictor of social rejection. The aforementioned relationships were stronger in BPD patients than in depressed participants. Finally, one study investigated the topology and temporal dynamics of depression and anxiety symptoms using contemporaneous and temporal network models (Fisher et al., 2017). Positive (positive, content, enthusiastic, energetic) and negative (down) mood were the most representative variables of patients' core symptoms. While “worried” and “down” did not show temporal influence, “positive mood”, “hopelessness”, “anger”, and “irritability” were the strongest drivers of moment-to-moment symptomatology.

Ecological Momentary Intervention in MDD

The selection process resulted in 8 studies that administered an EMI to clinically depressed patients. In all, four different interventions were identified: Psymate, Mobylize!, Hel4Mood, and Medlink.

General overview of the interventions

Psymate is a PDA-based EMA for symptom monitoring that aims to increase awareness about depression and the dynamics that characterize this disorder (Hartmann et al., 2015; Kramer et al., 2014; Simons et al., 2015; Snippe et al., 2016; Widdershoven et al., 2019). Psymate allows patients to record daily symptoms and affect. Based on these daily assessments, patients meet a clinician weekly and receive graphical feedback on the association between PA levels and daily life activities, events, or social interactions, as well as on the association between PA changes and the number of depressive complaints. In this way, patients have the chance to reflect on their affective state and the relationship between symptoms and contextual variables with a professional. According to Heron’s definition, “*the key feature of all EMIs is that the treatment is provided to people during their everyday lives (i.e., in real time) and settings (i.e., real world)”* (Heron & Smyth, 2010). Therefore, Psymate does not meet all the criteria for an EMI, as EMA-feedbacks are provided during weekly face-to-face sessions. However, we decided to include this intervention because we think it provides important insights about the potential of self-monitoring EMA as a therapeutic tool.

Likewise, Mobylize! Constitutes an ecological intervention composed of a mobile application, an interactive website, and a system for email/telephone support (Burns et al., 2011). The most innovative aspect of this application is the integration of self-reports with data from smartphone sensors. Mobylize! Is provided with a context-aware system. Thanks to a machine learning algorithm, the application can predict the state of the patient (mood, emotions, cognitive/motivational states, activities, environmental context, and social context). Specifically, the system works in three different phases: (1) Data collection, during which 38 sensors collect sensor information; (2) learners, during which prompted self-reports are matched and paired with simultaneously labelled state data to develop predictive models; and (3) action components, a continuous process that analyses sensor data in order to update previous predictive models without the direct input of the user. Mobylize! Is designed to prompt patients to assess mood, intensity of emotions, fatigue, pleasure, accomplishment, concentration, engagement, perceived control, location, and interactions five or more times a day. To accommodate new data, every new self-report is subsequently associated with the generation and modification of previous models. Thanks to this complex system, the mobile application sends tailored feedback to participants. Through the website, users can graphically visualize self-report patterns, read theoretical lessons, and use interactive tools such as tailored plans and calendars for monitoring daily activities. Lastly, a trained clinician contacts user periodically by phone or email to provide technical support, reinforce adherence, and enhance motivation.

Help4Mood is a web-platform to self-monitor daily symptoms, mood, activities, and thoughts (Burton et al., 2016). Based on a CBT approach, Help4Mood helps patients to reflect on the emotional and cognitive patterns related to depression. In addition to collecting daily self-reports, the application receives data from an actimetry sensor and acoustic analysis of speech. The innovative aspect of Help4Mood is the use of a virtual agent, completely customizable in terms of voice, clothing style, sex, and language, that communicates with users to provide tailored exercises and activities and guide them through the daily questionnaires. The application also has an emergency section called the "crisis plan": As soon as symptom worsening is detected, the application prompts users to contact a professional or a relative.

Finally, Medlink is a mobile application to support and monitor MDD patients taking antidepressant medication (Mohr et al., 2015). The main purpose of the app is to address the failure points that usually occur between professionals and newly diagnosed patients. On the one hand, the application provides users with weekly psychoeducation material and sends suggestions about medication management and how to deal with depressive symptoms. On the other hand, it monitors patients' treatment and depressive symptoms. Every four weeks, personal communication with a professional is scheduled to give patients monthly feedback about disease progression.

Effectiveness of the intervention

Psymate was tested in a sample of 102 clinically depressed patients in a three-arm randomized controlled trial (Hartmann et al., 2015; Kramer et al., 2014; Simons et al., 2015; Snippe et al., 2016) with an experimental condition (TAU and six-week Psymate treatment, with weekly face-to-face feedback sessions), a pseudo-experimental condition (TAU and Psymate without EMA face-to-face feedbacks), and a control condition (TAU). Three different categories of weekly feedback were provided: (1) positive affect, (2) positive affect in relation to events appraised with an internal versus external locus of control, and (3) positive affect in relation to social interactions. Results showed a significant reduction in depressive symptoms in the experimental group that was maintained in the follow-up assessment. Participants in the pseudo-experimental condition reported decreased depressive symptoms in the first weeks of the treatment, but this gain was not maintained across the weeks. Notably, the use of Psymate was associated with increased levels of perceived empowerment, regardless of the presence of weekly feedback, and with increased experienced PA throughout the treatment. Decreased depressive symptoms were also associated with increased positive daily behaviours. Finally, Widdershoven and colleagues observed a significant improvement in negative emotions differentiation and a close-to-significance improvement in positive emotions differentiation after 6-weeks of self-monitoring, regardless of EMA-derived feedbacks (Widdershoven et al., 2019).

Mobylize! Was tested in a small pilot study with a sample of 7 MMD patients (Burns et al., 2011). According to the results, the use of Mobylize! Significantly reduced depressive symptoms, both on a self-rated measure (PHQ-9) and a clinician-based evaluation (Quick Inventory of Depressive Symptomatology – Clinician Rating, QUIDS-C), as well as anxiety symptoms, measured with the Generalized Anxiety Disorder Scale (GAD-7). At the end of the treatment, participants were also less likely to meet MDD diagnostic criteria. Nevertheless, the accuracy of the predictive model was low, especially for mood; higher accuracy was achieved by models that predicted location, conversational state, and social interactions (accuracy between 60% and 90%).

A randomized controlled trial was conducted to evaluate Help4Mood (Burton et al., 2016). Twenty-eight depressed patients were recruited and randomized into two treatment groups: Help4Mood and TAU. Outcome measures, which included the Beck Depression Inventory (BDI) and Quick Inventory of Depressive Symptomatology – Self Report (QIDS-SR), indicated reduced symptoms in both samples. Nevertheless, patients in the TAU group achieved greater clinical improvement compared to patients who used the application. Notably, regular users were more likely to obtain greater clinical improvement compared to users with low compliance.

Finally, a preliminary study tested the efficacy of Medlink with 8 MDD patients (Mohr et al., 2015). On the one hand, medication monitoring showed promising outcomes. Patients reported taking 84% of their medication, which is significantly higher than medication adherence rates reported in the literature. On the other hand, depressive symptoms significantly decreased over the course of 4 weeks.

Compliance and dropout rates

Regarding Psymate, the number of answered prompts in both the experimental and pseudo-experimental groups was 135.5 out of 180 (75.3%); participants completed 39.7 out of 50 pre-assessments (79.4%) and 23.7 out of 30 (79%) post-assessment observations. Moreover, 27 of the 33 participants (81.9%) allocated to the experimental group completed the intervention, whereas 32 out of 36 participants (88.89%) allocated to the pseudo-experimental group completed it.

Throughout the 8-week treatment with Mobylize, the mean number of logins to the mobile application was 7.9 (approximately one per week), whereas the number of completed lessons on the website was 4.8 out of 9 (53.3%). The number of answered prompts drastically decreased throughout the treatment, from 15.3 in the first week to 4.8 in the last week, due to technical difficulties and connectivity problems. Seven out of 8 participants (87.5%) completed the intervention: The only dropout was caused by technical problems with the smartphone.

Regarding Help4Mood, authors indicated great variability in terms of time of use. Two participants used the application for one or two days, whereas three participants used it between 3 and 7 days. The remaining 6 participants used it more than 10 times, approximately twice a week. The mean use was 134 minutes. Eleven out of 13 (84.6%)

participants completed the protocol and were assessed for the follow-up. One participant withdrew due to worsening mood.

Finally, participants entered the Medlink application approximately 17.4 times during the 4 weeks of data collection and answered 96% of the prompts. Seven out of 9 users read the psychoeducation lessons from the first and second week, whereas only half of them read the third and fourth lessons. No dropouts were reported.

Participants' feedbacks and satisfaction

Using Likert scales ranging from 1 to 7, participants found Psymate was very simple to use and provided clear instructions (verbal instructions = 6.6 ± 0.7; written instructions = 6.5 ± 1.0; Psymate answers = 2.6 ± 1.5). The number of daily prompts and the time needed to complete assessments were not stressful (number of beeps per day = 3.1 ± 1.6; time to answer = 2.5 ± 1.5). Finally, satisfaction with its most important feature, i.e. receiving EMA-derived feedback, indicated that the feedback was highly appreciated (usefulness of feedback = 6.2 ± 0.7) and considered valuable (feedback to improve daily skills = 5.4 ± 1.1). However, participants would have appreciated to receive more specific and practical advices related to the EMA-based feedback (3.2±2).

Regarding Mobylize, satisfaction with the application was rated as 5.71 on a scale from 1 to 7. Criticism was related to technical problems, such as loss of connectivity and subsequent failure to receive prompts. Interestingly, 86% of the participants reported that the intervention was particularly helpful for identifying NA triggers and avoiding distressing and maladaptive behaviours. Participants also suggested lengthening the intervention and adding more activities, such as a blog to talk with other users or a message service between patients and coaches.

Participants involved in the Help4Mood study were quite satisfied with the application. Most of them would use it in everyday life and suggest it to other patients. The idea of a virtual agent to guide participants in completing the assessments was appreciated; however, some participants perceived the agent as too cold, repetitive and not sufficiently realistic. Among the limitations, patients reported sometimes being bored by excessively long sessions. They would have appreciated receiving more psychoeducational material and a more tailored experience, allowing them to access their preferred materials and activities without restrictions.

Medlink's usability was assessed using 4 items from the Usefulness, Satisfaction and Ease of Use Questionnaire (USE). On a scale from 1 to 7, participants reported encouraging scores for ease of use (mean = 5.7 ± 1.1) and learnability (mean = 6.1 ± 1.5), but low scores for perceived usefulness (mean = 4.6 ± 1.0) and satisfaction (mean = 4.8 ± 0.8). Furthermore, encouraging ratings were observed for the weekly psychoeducation lessons (liking = 6.0 ± 1.1; ease of use = 6.6 ± 0.5; learnability = 6.6 ± 0.5, and usefulness = 5.8 ± 1.7), which were also reported to be the most interesting and useful part of the application. Finally, feedback interviews showed neutral comments regarding daily self-reports, that were perceived as not very useful; contrasting opinions were collected regarding feedbacks graphs.

DISCUSSION

To date, the scientific literature has mostly been based on studies conducted in laboratory settings, thus understudying the daily dynamics of psychopathology (Nilsen & Pavel, 2013). Therefore, unobtrusively monitoring behavioural (i.e. sensors), physiological (i.e. biosensors), and cognitive/emotional (i.e. self-reports) factors in ecological settings collected through portable and wearable devices can provide new information about elusive psychological constructs that are usually defined by the complex dynamics of contexts and variability. Accordingly, the research field could benefit from the use of novel technologies to better explore MDD mechanisms and delineate new theoretical models based on ecological observations.

Compared to paper and pencil daily diaries, the use of electronic devices, and especially smartphones, could further increase the six EMA advantages identified by Ebner-premier (**Table 3.5**) (Ebner-Priemer & Trull, 2009): (a) The automation of the entire process directly on a mobile device such as a smartphone can provide greater control over backfilling and higher temporal precision in the administration, planning, and randomization of prompts; (b) The use of ICTs can offer additional possibilities for multimodal assessments, with data supplied by embedded sensors and wearable unobstructed biosensors that can automatically be coordinated with the collection of self-reports; (c) The use of mobile devices reduces the effort required of users in completing daily assessments and prevents errors by researchers and clinicians due to manual data entry; (d) Smartphones offer the possibility of providing real-time EMA-derived feedback that can be an important therapeutic tool for patients' self-monitoring, in addition to the possibility of sending real-time alerts to clinicians in case of need. In this regard, smartphones have the potential of becoming global low-cost tools that can also be adopted in the clinical field. Currently, 2.32 billion people in the world use smartphones, and it has been estimated that, by 2020, 70% of the world's population will own one (Ericsson Consumer Lab, 2015). The potential of these devices is also supported by the evidence showing that people with serious mental and physical illnesses own and regularly use smartphones (Ben-Zeev, Davis, Kaiser, Krzsos, & Drake, 2013) and are interested in using applications for their health (Torous et al., 2014).

Table 3.5: Benefits of using EMA for mood dysregulation and mood disorders as described by Ebner-Premier (Ebner-Priemer & Trull, 2009)

	ADVANTAGES	IMPLICATIONS
1	Real-time assessments	Reduction in retrospective bias and increase in accuracy;
2	Repeated measurements	Better comprehension of time-dependent processes and dynamic changes in symptoms;
3	Multimodal assessments	Contemporary analysis of behaviors, physiological signals, and subjective experiences;
4	Context-specific information	Assessment of symptoms as context-dependent;
5	Interactive assessments	Real-time customizable and interactive feedback;
6	Generalizability	Higher ecological validity and collection of more representative data.

As pointed out in this review, the widespread adoption of EMA for the investigation of depression has led to novel insights into different aspects of the disease, including emotion reactivity, cortisol patterns, or daily rumination. We discussed different sampling methods that can be used in EMA protocols, showing that the signal-contingent design with prompt randomization or semi-randomization is the most widely adopted option when dealing with variables such as affect and symptom monitoring. We also reported compliance and dropout rates, which showed encouraging results, with most of the studies reporting more than 70% adherence. Nevertheless, the gap between clinical practice and research is still quite wide, as revealed by the low number of studies that adopt this approach to assess and monitor patients for clinical purposes or implement EMA in clinical settings. Accordingly, many issues still need to be addressed. To date, no standard and validated sets of items have been developed for EMA protocols, raising the problem of context validity. Moreover, further research should be conducted to improve patients' compliance and reduce dropout. Due to the intrinsic nature of the disease, depressed patients could be less likely to consistently complete daily assessments. In a previous study, we observed that compliance was higher in EMA administered through a smartphone and when patients were prompted less than 8 times a day (Colombo, Cipresso, et al., 2018). However, a meta-analysis should be conducted to more precisely identify the factors that improve adherence (see for example (Karyotaki et al., 2015)), thus providing some sort of guideline for the design of EMA. Indeed, we strongly believe that clinical practice could benefit from the use of EMAs for several reasons. First, EMAs can be useful for diagnostic purposes. Traditional diagnostic procedures usually involve a static moment in time, including semi-structure interviews (e.g. Mini-International Neuropsychiatric Interview) complemented by self-report measures. However, ample evidence shows the dynamic nature of affective states and mood (Kuppens & Verduyn, 2017). Furthermore, these dynamics greatly vary from person to person, reason for which ideographic approaches may shed light upon the structure of individual symptom dynamics (Fisher et al., 2017). Consequently, by means of EMAs a more accurate diagnostic process could be pursued. Likewise, the continuous monitoring of patients' symptoms would allow clinicians to monitor the efficacy of a treatment over time (Boswell, Kraus, Miller, & Lambert, 2015), predict short-term mood changes (Mikus et al., 2017), detect symptoms' worsening in an early stage (Nuij et al., 2018), and create continuous communication between clinicians and patients. On the other hand, the use of daily mood and symptom self-ratings could provide more ecological assessments, overcoming recall bias and capturing dynamics of human functioning in daily life that cannot be detected with traditional tools.

Our results also highlight the existence of a small number of EMIs for depression. In the current literature, only four ecological interventions have been developed, and only two of them were tested in an RCT. Our review showed promising results in terms of patient satisfaction and clinical efficacy, further supporting the need for more efforts in this direction. However, compliance rates were sometimes not encouraging, and a major challenge is to encourage regular use of these technologies throughout the entire treatment process (Saranummi et al., 2013). Accordingly, future research should focus on the concept of users' motivation and engagement, taking into consideration the adoption of focus groups with patients during treatments, using mixed quantitative and qualitative designs to obtain as much information as possible to guide future developments, and extending the effects of gamification features on adherence and compliance (Brown et al., 2016). In other words, greater attention should be paid to the needs and characteristics of the target population. Considering feedback from users, here we were able to identify three EMI features that were highly appreciated: the possibility of receiving visual feedback about daily assessments and, therefore, self-monitoring daily patterns; the availability of psychoeducational material on depression and its mechanisms; and the opportunity to have continuous or periodic communication with a trained clinician.

In this review, we found that most of the EMAs were based only on self-reports, whereas more attempts to integrate this information with data gathered from sensors and biosensors were observed for EMIs. Recent advances in sensor technologies have had an impact on applications for remote health (Majumder, Mondal, & Deen, 2017), such as postoperative recovery (Aziz et al., 2007), treatment for chronic patients (Patel, Park, Bonato, Chan, & Rodgers, 2012) and monitoring of elderly individuals (Ohta, Nakamoto, Shinagawa, & Tanikawa, 2002). Consistently, the hierarchical sensing model proposed by Mohr highlights the great revolution that new sensors and biosensors can bring to the field of mental health (Seppälä et al., 2019), making it possible to collect raw sensor data (i.e. the lower level of the hierarchy) that can be converted into "behavioral markers" through machine learning and data mining methods (Mohr et al., 2017).

Smartphone sensors further increase the potentially collectable information, allowing the reconstruction of people's habits, sleep patterns, or social life by using embedded sensors such as accelerometers, calls, SMS, social network data, or geolocation. In other words, it is now possible to infer and collect behavioral information without necessarily asking the person to report it.

Even though they were not investigated in the studies targeted at MDD patients discussed here, several opportunities can be found in the integration of EMA and EMI platforms with behavioral and physiological signal processing, further mediated by machine learning algorithms. On the one hand, several behavioral signals are readily collectable with the use of smartphone sensors, even though they may lack the required specificity for mood recognition and prediction, as found by the Mobylize! Study (Burns et al., 2011). On the other hand, due to recent advancements in sensor technologies, physiological signals can be nowadays recorded unobtrusively by means of, e.g., smartwatches and chest bands. These could provide an EMA and/or EMI platform with additional markers that more closely correlate to a person's affective state, and that can be used as input to the analysis performed (Burns et al., 2011). Consistently, models can be automatically learned that continuously estimate the patient's affective state by extracting and analyzing salient features of physiological signals (Lisetti & Nasoz, 2004). For instance, electrodermal Activity (EDA) and Heart Rate Variability (HRV) have been extensively investigated as correlates of users' affective state, and they are considered non-invasive. They do not involve recording sensitive information (as opposed to, for example, cameras and acoustic signals), and associated sensors do not interfere with users' daily routine. Consistently, patient-specific models can be automatically learned that continuously estimate the patient's affective state by extracting and analyzing salient features of physiological signals (Lisetti & Nasoz, 2004).

Unfortunately, the relation between physiological signals and affective states is not trivial and mixed results are discussed in the literature (Choi et al., 2017). Building on recent advances of machine learning, recent studies obtained promising results by means of model personalisation for stress recognition (Kocielnik, Sidorova, Maggi, Ouwerkerk, & Westerink, 2013) and deep learning for mood prediction (Shen et al., 2015) using a combination of behavioural and physiological markers in non-clinical populations. If thoroughly tested and consolidated through experimental validations in EMA settings, a model of this type could provide a finer-grained description of the evolution of the patient's disorder throughout a long-term study, compared to surveys that are usually filled in just a few times a day. It can be considered less obstructive to the patient's life because physiological data are recorded passively and do not require extra effort from the patient. Furthermore, in EMI settings, if the recognition algorithm detects that the patient is in a critical state, it can automatically trigger an intervention module associated with the platform or open a communication channel between the patient and his/her therapist. Alternatively, predictive models that combine information from physiological and behavioral signals to estimate the patient's future mood, stress level, and self-reported health (one or a few days in advance) can be automatically inferred (Shen et al., 2015). After identifying a risk threshold, these models would make it possible to plan interventions (or involve the therapist) in advance, that is, before the patient's affective state reaches a critical state.

We should, however, recognize that the use of EMAs and EMIs has some limitations. These approaches are time-consuming and may be perceived as invasive by users. Patients are required to complete multiple assessments throughout a day, and protocols often last weeks. Moreover, people might not be willing to share personal information. Finally, in terms of more ecological validity, they may be advantageous for clinical purposes, but disadvantageous for research aims, because they imply less experimental control. Because the data are collected during everyday life and in naturalistic environments, it becomes hard or even impossible to have complete control over the setting, and, therefore, it is not possible to rule out the role of confounding variables. Nevertheless, due to the implementation of novel statistical procedures, a balance between research necessities and clinical utility could be achieved (Lin, Mermelstein, & Hedeker, 2018). If this were the case in the near future, EMAs and EMIs would undoubtedly transform the field of mental health, greatly contributing to the bridging of science and practice (Fernández-Álvarez, Fernández-Álvarez, & Castonguay, 2018; Goldfried, 2010).

Overall, this systematic review clearly shows the emergence of ecological assessment and intervention as a promising avenue for clinical psychology. The focus of the review was limited to a specific clinical population. Still, promising results have been already shown also regarding the application of EMA and EMI to anxiety disorders (Schueller, Aguilera, & Mohr, 2017; Walz, Nauta, & aan het Rot, 2014) and stress-related disorders (Gee, Griffiths, & Gulliver, 2016; Yoshiuchi, Yamamoto, & Akabayashi, 2008), highlighting the potential of these tools to provide psychological support in daily life and to investigate symptoms fluctuations across time. However, similar limitations and burning issues were also evidenced, including the need for more high-quality trials, the gap between the clinical and research field, and the importance of making EMAs and EMIs as more engaging and tailored as possible. Altogether, there is evidence showing the feasibility and preliminary efficacy of these approaches, but much more research should be conducted before drawing definite conclusions.

AUTHOR CONTRIBUTIONS

Conceptualization, D.C., J.F.A., A.G.P. and C.B.; methodology: D.C., J.F.A., M.S. and C.B.; writing-original draft preparation: D.C., J.F.A. and A.P.; writing-review and editing: C.B., A.G.P., P.C., M.K. and G.R.

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CONFLICTS OF INTEREST

The authors declare that no competing interests exist.

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CHAPTER 4

The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment

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The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment

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ABSTRACT

In recent decades, emotion regulation (ER) has been one of the most widely studied constructs within the psychological field. Nevertheless, laboratory experiments and retrospective assessments have been the two most common strands of ER research, thus leaving open several crucial questions about ER antecedents and consequences in daily life. Beyond traditional methods, ecological momentary assessment (EMA) has the potential to capture ER dynamics during the flow of daily experiences, in real-life settings and through repeated measurements. Here, we discuss what we currently know about ER antecedents and consequences. We will compare findings from previous literature to findings from EMA studies, pointing out both similarities and differences, as well as questions that can be answered better with the EMA approach.

Keywords: Emotion Regulation; Ecological Momentary Assessment; Emotion Regulation Antecedents; Emotion Regulation Consequences

INTRODUCTION

Emotion regulation (ER) is a process that every individual explicitly or implicitly implements in order to downregulate or upregulate emotional states and achieve personal goals (Gross, 2015). ER can be conceptualized as a complex process with physiological underpinnings, behavioral responses, and affective and cognitive correlates. Adding to this complexity, the preponderant role played by contextual and momentary factors is increasingly emerging, suggesting the dynamic and situational nature of this process (Aldao, 2013).

To date, research into ER has mostly been based on laboratory experiments, thus leaving situated and momentary aspects relatively understudied. Additionally, most studies have relied on retrospective questionnaires, that consider ER to be a trait (i.e. a relatively stable and cross-situational tendency of an individual). However, trait measures only modestly correlate with ER in daily life (Brockman, Ciarrochi, Parker, & Kashdan, 2017), which supports the need for a more ecological approach to the investigation of this process.

An alternative strategy to laboratory experiments and retrospective assessments can be found in ecological momentary assessment (EMA), a procedure that makes it possible to collect repeated inputs of thoughts, feelings and behaviors close in time to the experience and in real-life contexts. The past few years have seen a surge in studies using EMA due to the increased availability of mobile applications (Colombo, Fernandez Alvarez, Palacios, et al., 2019) for both subjective (Suso-Ribera et al., 2018) and objective (Marzano et al., 2015) data collection, and this method has already significantly increased our knowledge about ER outside laboratory settings (Bylsma & Rottenberg, 2011). In fact, a more complex representation of the way people regulate emotions is emerging that emphasizes the importance of capturing this process in the context where emotions are regulated.

In the present paper, we will provide an overview of the available literature on ER antecedents and consequences. To do so, we will relate EMA findings to the broader literature based on laboratory and retrospective studies, pointing out both similarities and differences, as well as questions that can be better answered with the EMA approach. We will suggest EMA as a suitable methodology to extend our understanding of ER, and we will propose a technology-based model to concurrently explore the affective, physiological, and behavioral concomitants of ER.

WHAT ARE THE ANTECEDENTS OF ER?

Beyond individual differences (John & Gross, 2007), ER can be understood as the result of a complex interplay among contextual and situational factors, momentary affect, and situation-specific goals.

Contextual and situational factors

Existing research has revealed the importance of the social context in ER, showing that both rapid changes in the social context (McRae, Heller, John, & Gross, 2011) and stable contextual transactions (Srivastava, Tamir, McGonigal, John, & Gross, 2009) influence this process. Additionally, context controllability has been shown to be critical for ER. Accordingly, Troy and colleagues demonstrated that higher reappraisal ability (i.e. the ability to down-regulate negative emotions) is associated with lower levels of depression after the exposure to an uncontrollable stressor, but it is associated with higher subsequent depression in the context of a controllable stressor (Troy, Shallcross, & Mauss, 2013). Finally, the general context where the emotions are regulated can significantly impact ER. For example, one study shows that people are more likely to choose distraction in high-intensity negative situations, whereas in low-intensity negative situations people are more likely to adopt cognitive reappraisal, which involves rethinking the meaning of a stimulus in order to change its emotional impact (Sheppes, Scheibe, Suri, & Gross, 2011).

EMA studies have confirmed the role of both the social context and context controllability in ER. Suppression, that is the inhibition of ongoing emotion-expressive behaviors, is more frequently adopted when other people are present in the environment (English, Lee, John, & Gross, 2017) and it is used less frequently in situations where people feel high in social hierarchy (Catterson, Eldesouky, & John, 2016). Additionally, individuals with higher well-being report greater reappraisal adoption in situations that are low in controllability (Haines et al., 2016). Beyond these results, EMA studies also extended the previous literature about contextual determinants of ER. The identification of the trigger for one's emotions has been shown to affect ER and, more specifically, to be tied to the use of certain strategies, such as reappraisal and savoring (i.e. the attempt to maintain and up-regulate positive emotions) (Heiy & Cheavens, 2014). Furthermore, the type of emotion targeted also influences this process, so that people concurrently use more strategies in response to certain emotions, such as excitement and pride (Heiy & Cheavens, 2014).

Momentary affect

According to the broaden-and-build theory, the experience of positive emotions fosters people's repertoires of thoughts and actions and encourages the development of new coping skills (Fredrickson, 2001). Evidence supporting this theory comes, for example, from a longitudinal study, showing that higher PA levels predict increased positive coping skills eight weeks later (Burns et al., 2008).

Nonetheless, most of the previous literature only relied on retrospective measurements of ER, which made it difficult to explore real-life relationships between momentary affect and ER. Fortunately, in recent years there has been a surge in research using the EMA approach for the exploration of affective antecedents. For example, high levels of momentary self-esteem, psychological adjustment, and PA have been found to trigger the use of cognitive reappraisal (Nezlek & Kuppens, 2008). High levels of PA also predict greater adoption of problem solving (Pavani, Le Vigouroux, Kop, Congard, & Dauvier, 2016) and mindfulness (Brockman et al., 2017), whereas momentary NA has been associated with greater use of suppression (Brockman et al., 2017) and rumination, which refers to the process of persistently thinking about one's feelings (Li et al., 2017; Pavani et al., 2016). Interestingly, momentary affect also appears to influence the number of strategies adopted, so that the use of different concurrent ER strategies increases in the presence of high levels of momentary NA compared to PA (Brans, Koval, Verduyn, Lim, & Kuppens, 2013).

Situation-specific goals

Along with the aforementioned contextual and affective factors, situation-specific goals have also been shown to influence ER. Overall, the previous literature has shown that individuals who frequently reappraise and distract tend to pursue prosocial and pro-hedonic goals more often, whereas people who habitually suppress tend to pursue contrahedonic and impression management goals more frequently (Eldesouky & English, 2018).

These results are consistent with the EMA literature, which has revealed that distraction and cognitive reappraisal are used more frequently when hedonic goals are pursued, whereas suppression is more likely to be implemented when achieving instrumental goals (English et al., 2017).

WHAT ARE THE CONSEQUENCES OF ER?

In the previous section, we explained that ER can be understood as the outcome of a number of antecedents. However, ER also has multiple consequences on people's lives. In the following paragraphs, we will discuss two important outcomes that can be influenced by ER, namely affective and physiological states.

Momentary affect

A large amount of evidence from previous literature shows an influence of ER on subsequent affective states, and most of the research concludes that cognitive reappraisal has a more adaptive profile in terms of affective consequences, compared to suppression. Reappraisal is indeed related to experiencing less subsequent NA and more PA, whereas suppression leads to experiencing less PA and more NA (Gross & John, 2003). Furthermore, frequent use of savoring has been associated with greater happiness and well-being (Quoidbach, Berry, Hansenne, & Mikolajczak, 2010), whereas recurrent use of rumination (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008) and dampening (i.e. the tendency to decrease positive emotional experiences) (Wood, Heimpel, & Michela, 2003) have been related to increased and prolonged NA.

Similarly, the body of research on affective consequences employing EMA is also extensive. The EMA literature has confirmed previous findings regarding savoring (Jose, Lim, & Bryant, 2012) and dampening (Li et al., 2017). However, contrasting results were observed for other strategies. For instance, cognitive reappraisal has been found to be related to increased PA (Richardson, 2017), which is consistent with previous research, but some studies failed to replicate its relationship with decreased NA (Brans et al., 2013; Brockman et al., 2017; Nezlek & Kuppens, 2008; Pavani et al., 2016). Similarly, many

EMA studies confirmed the association between suppression and subsequent increased NA and decreased PA (Brans et al., 2013; Brockman et al., 2017). Nevertheless, Richardson and colleagues observed no effects of suppression on NA (Richardson, 2017), and Heiy et al. found that suppression did not predict subsequent affect (Heiy & Cheavens, 2014). Finally, the EMA literature confirmed the association between rumination and subsequent decreased PA and increased NA (Brans et al., 2013; Li et al., 2017; Pavani et al., 2016), albeit with mixed results (Genet & Siemer, 2012; Heiy & Cheavens, 2014).

Physiological responses

In addition to its influence on affective states, ER has also been shown to entail physiological concomitants. Thus far, rumination and its physiological effects have been widely investigated, showing that high rumination is associated with heightened activation of the hypothalamic–pituitary–adrenal axis (HPAA) and decreased heart rate variability (HRV) (Ottaviani et al., 2016). Moreover, suppression has been associated with increased sympathetic activation (Gross, 1998), whereas cognitive reappraisal has been linked to reduced physiological response (i.e. skin conductance) (Gruber, Hay, & Gross, 2014). Finally, acceptance has been related to decreased electrodermal reactivity (Dunn, Billotti, Murphy, & Dalgleish, 2009).

A limitation of existent physiological research is that most studies have been conducted in laboratory settings with very few exceptions, such as the study by Brosschot and colleagues, which confirmed the association between rumination and lower HRV using a daily ecological experiment (Brosschot, Van Dijk, & Thayer, 2007).

ADDITIONAL CONTRIBUTIONS OF THE EMA APPROACH TO THE ER LITERATURE: RECIPROCAL INTERPLAY, MODERATION, AND ER STRATEGY USE OVER TIME

In addition to replicating traditional research, the implementation of EMA methodologies has shed light on important gaps in the previous ER literature, that would have been difficult to address with non-ecological research.

According to the EMA literature, not only can ER influence outcomes, but outcomes can also affect subsequent ER processes, thus closing the circle. Momentary affect and

ER, for example, have been shown to reciprocally influence each other at a given point in time (Pavani et al., 2016); similarly, well-being has been shown to be both a predictor (Haines et al., 2016) and an outcome (Quoidbach et al., 2010) of ER. From a theoretical point of view, these findings provide further support for the need to ecologically and momentarily evaluate ER and related variables.

The use of EMA has also allowed for the exploration of moderators in the ER-to-outcomes relationship in real-life settings. The results so far suggest that the effects of ER on subsequent outcomes are not linear, but rather affected by contextual factors or by ER itself. In relation to the former, research has indicated that, on days when people experience fewer positive events, momentary savoring (Jose et al., 2012) and positive rumination (Li et al., 2017) are more relevant in increasing PA levels, whereas suppression is more strongly associated with subsequent lower PA on more stressful days (Richardson, 2017). Regarding the moderating role of ER strategies, a study found that rumination moderates the association between negative events and NA levels, so that unpleasant events predict higher NA when rumination use is high, but not when it is low (Genet & Siemer, 2012).

Another contribution of the EMA approach is the exploration of the concurrent use of ER strategies over time. Heiy and colleagues showed that individuals use, on average, seven strategies to regulate each experienced emotion, which suggests that interactions among strategies may produce different outcomes (Heiy & Cheavens, 2014). In this direction, McMahon and colleagues analyzed the concurrent use of reappraisal, suppression, and rumination, and they showed that reappraisal compensates for the negative effects of suppression and rumination on anxiety and depressive symptoms (McMahon & Naragon-Gainey, 2018).

Finally, a key contribution of the EMA approach has been the exploration of the way ER strategy use is sequenced over time. Emerging evidence suggests that certain strategies are likely to affect subsequent strategy selection. For example, daily reappraisal has been shown to be associated with increased daily suppression (Brockman et al., 2017). Furthermore, ER strategies can affect subsequent antecedent-focused and response-focused ER processes over time. An example of the way ER can affect subsequent situation selection comes from the study by Farmer and colleagues, showing that suppression of positive emotions leads to higher engagement in positive social events on the following days (Farmer & Kashdan, 2012). Moreover, there is evidence suggesting that the adoption of certain strategies affects response modulation (i.e. the attempt to modify the experiential, physiological, or behavioral components of the emotional response). Weiss et al., for example, revealed that the adoption of distraction, cognitive reappraisal, and problem-solving predicts a reduction in marijuana consumption on the following days (Weiss, Bold, Sullivan, Armeli, & Tennen, 2017). Likewise, the adoption of disengagement (e.g., denial, avoidance, wishful thinking, escape or inaction) and involuntary engagement strategies (e.g., rumination, impulsive or involuntary action) has been shown to lead to more problematic behaviors over time, such as lying or stealing (Silk, Steinberg, & Morris, 2003).

CONCLUSIONS AND FUTURE DIRECTIONS

Decades of experimental and observational research have resulted in a relatively comprehensive understanding of ER. Important milestones have already been achieved, such as identification of important antecedents (i.e., contextual and situational factors, affect, and personal goals) and consequences (i.e., affect and physiological states) associated with ER. Although the previous literature has clearly contributed to our understanding of ER, in this paper we argue that the implementation of EMA is fundamental in order to move the ER research forward. ER is a dynamic and complex process with elements that are likely to reciprocally interact with each other, so that antecedents eventually become consequences and vice-versa. Capturing such a complex process is challenging, especially when using laboratory experiments and retrospective ER measurements. Additionally, although laboratory studies are and will be important for ER and clearly facilitate the manipulation of a large number of elements in a controlled setting, the study of ER in real-life settings where multiple factors occur simultaneously is also necessary, because these scenarios are where people implement ER in their daily lives.

So far, the EMA literature has confirmed many of the findings achieved by laboratory experiments, again confirming that the current knowledge about ER is quite robust. Added to the existing literature, EMA research has provided important insights about the reciprocal nature of the relationship between ER and its antecedents and consequences, the potential role of ER and situational factors as moderators in the implementation of ER, and the key role of momentary ER in the study of subsequent ER implementation over time.

In sum, the implementation of EMA allows researchers to explore new dynamics of this process. However, this method could also make it possible to study ER through a multimodal approach that includes concurrent behavioral, physiological, and cognitive concomitants. Although interesting findings have already been achieved with this approach, further advances will require combining more objective and passive data collection methods with traditional EMA self-reports (Colombo, Fernandez Alvarez, Garcia-Palacios, et al., 2019). For example, behavioral information (i.e., sleep patterns, physical activity, social interactions, or social media use) can be obtained with smartphone embedded-sensors, and comfortable wrist-watches or wearable chest-straps can easily monitor and record physiological parameters in ecological settings, thus achieving a more comprehensive understanding of ER in daily life could be achieved (see **Figure 4.1**).

While acknowledging the aforementioned important contributions of EMA research on ER, this methodology is not without limitations. For instance, standardized and ad-hoc items to assess ER via EMA are currently not available, which makes it difficult to compare results across studies. Furthermore, this approach is more time-consuming for participants (Colombo et al., 2018) and, because the data are collected in naturalistic environments, it becomes harder to have complete control over the setting (as opposed to laboratory studies). Considering the strengths and weaknesses of both methods, a combination of approaches should ideally be pursued in order to fully comprehend the complexity of ER. Several milestones have already been achieved, but the promising integration of different methods and technologies could provide a more comprehensive understanding of ER.

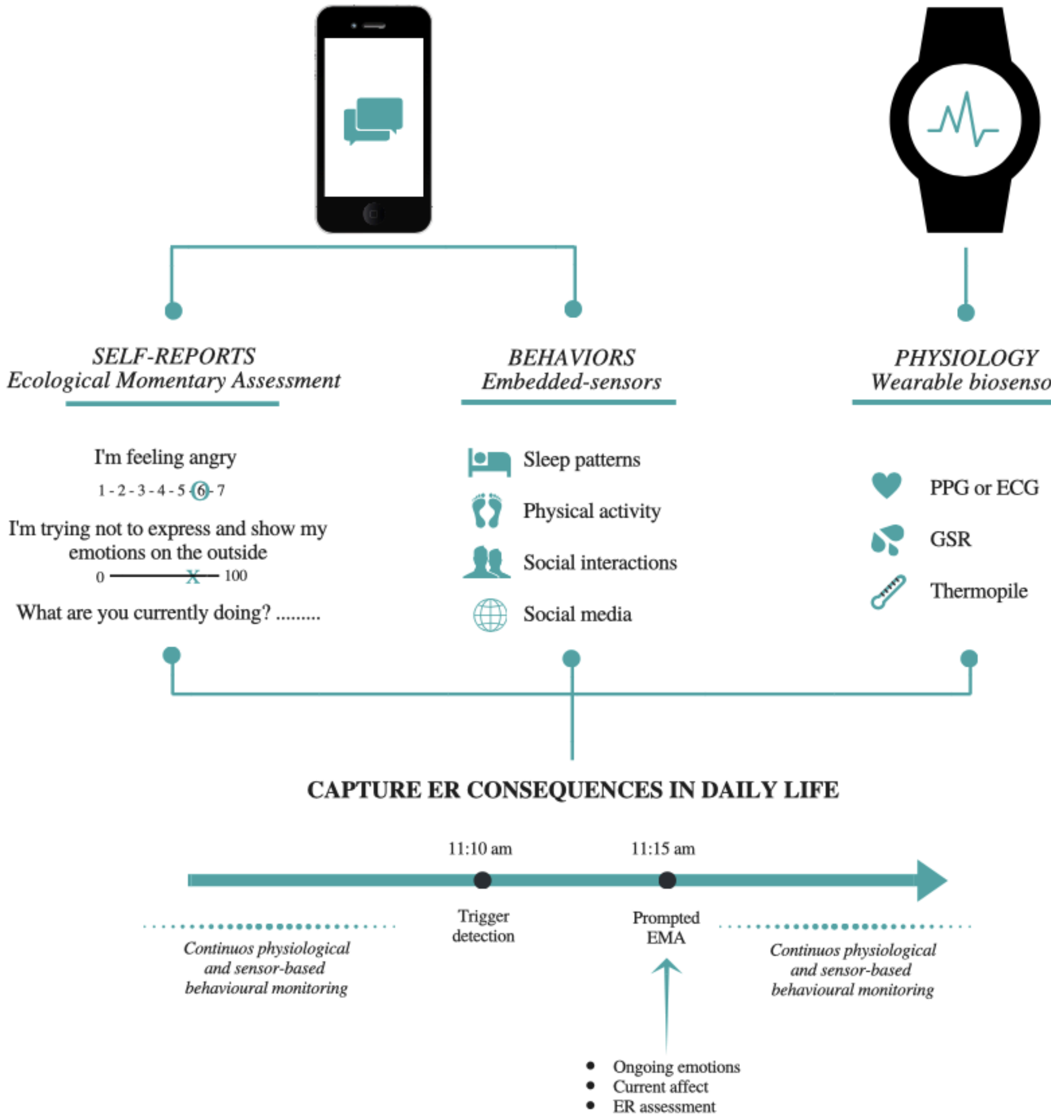

Figure 4.1: Integration of smartphones and wearable biosensors to capture ER in daily life. *At the top*: Repeated daily self-reports about affect, behaviors and ER can be collected through smartphones, together with behavioral information derived from embedded sensors such as physical activity or social interactions. Physiological parameters can be collected through wearable biosensors, like PPG, ECG (to derive HRV), GSR or temperature. *At the bottom*: An example of how to combine these technologies to grasp ER in daily life. The wearable biosensor detects the occurrence of a trigger from the physiological activation. An EMA is therefore triggered in order to collect self-reports regarding ongoing emotions, behaviors, and adopted ER strategies. In-between, a continuous physiological and behavioral monitoring is performed in order to explore ER consequences. *PPG: photoplethysmogram; ECG: electrocardiogram; GSR: galvanic skin response; HRV: heart rate variability*

Clinical implications of a more ecological, momentary, and technology-assisted approach to ER are also worth mentioning. EMA could indeed change the way we assess ER in psychopathology by helping us to understand the dynamics of this process in different emotional disorders, as well as the impact of emotion dysregulation on patients' lives. In turn, this could help clinicians to assess patients' ER directly in daily life in order to recognize specific strategies that need to be targeted in the therapeutic process and provide therapeutic feedback to patients, which has been shown to be a valuable practice (Delgadillo et al., 2018). Using sensors to capture physiological responses or a person's behavior would further augment EMA's potential. The analysis of such multi-modal data can provide some insights into the interplay among emotions, physiology, and behavior, and systems that utilize these principles can enable the practical application of data-driven approaches. Particularly, machine learning algorithms are inherently attuned to interpreting complex interdependent information. Such algorithms have the advantage of continuously learning from observations, and they can be personalized for a specific user. This ambitious, technology-assisted implementation of EMA could, for instance, help us to identify person- or population-wide predictors of emotional states which, in turn, would foster the personalization of treatments and therapy plans.

RECOMMENDATIONS FOR ADDITIONAL READING

1. (Aldao, Sheppes, & Gross, 2015): In this study, Aldao and colleagues discuss the relationship between ER, goals, and context, and they delve into the concept of ER flexibility, i.e. the ability to regulate emotions taking into account situational and contextual demands. Interestingly, specific recommendations to investigate this construct by means of EMA are provided.

2. (Gaggioli et al., 2013): Psychlog is an example of a mobile phone platform that can concurrently collect psychological (i.e. self-reports), physiological (HR monitoring), and activity (i.e. three-axial accelerometer) information in naturalistic settings.

3. (Ottaviani et al., 2015): Ottaviani and colleagues concurrently investigated the three dimensions of ER through an ecological approach. More specifically, cognitive, behavioral, and physiological correlates of rumination were explored in real-life for 24h, using a smartphone-based electronic diary and an ambulatory HR device.

4. (Blanke et al., 2019): Using data from four experience-sampling studies, Blanke and colleagues investigated the importance of the context on ER. According to their results, ER strategies are not adaptive or maladaptive; instead, adaptiveness is the result of the variability in choosing strategies based on situational demands.

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CHAPTER 5

Biased affective forecasting: A potential mechanism that enhances resilience and well-being

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Biased affective forecasting: A potential mechanism that enhances resilience and well-being

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ABSTRACT

According to a growing body of studies, people's ability to forecast future emotional experiences is generally biased. Nonetheless, the existing literature has mainly explored affective forecasting in relation to specific events, whereas little is still known about the ability to make general estimations of future emotional states. Based on existing evidence suggesting future-oriented disposition as a key factor for mental health, the aims of the current study were (1) to investigate the relationship between negative (NA) and positive (PA) affective forecasting biases and perceived psychological well-being, and (2) to explore whether positively biased predictions are associated with resilience and foster one's skills to cope with stressful events. To do so, we asked 85 undergraduate students to forecast PA and NA over two weeks, as well as to report their daily affect through a web-based Ecological Momentary Assessment. According to the results, positively biased PA forecasting (i.e., overestimating positive emotional states) was associated with greater perceived psychological well-being and higher resilience. When high levels of stress were experienced, participants holding an optimistic, yet biased, estimation of future PA were more likely to successfully manage stressors, thus maintaining lower levels of NA and higher levels of positive emotions. We suggest that positively biased PA forecasting is an adaptive cognitive distortion that boosts people's resilience and mental health, thus opening new avenues for the promotion of psychological well-being.

Keywords: Affective forecasting, cognitive bias, ecological momentary assessment, psychological well-being, resilience.

INTRODUCTION

As terms draws to a close and summer vacations stretch out ahead, people start to mentally imagine the upcoming holidays. For instance, they visualize themselves sleeping until late, having a brunch with some friends or leaving for a tropical destination. Beyond envisioning activities, people spontaneously imagine their own future emotions (Staats & Skowronski, 1992). That is, how happy and relaxed they will feel while taking a break from work, or the excitement they will experience while visiting a new place. As evidenced by a long tradition of research, people are indeed used to mentally time travel, and they always try to imagine and predict future emotional experiences (Gilbert, Driver-Linn, & Wilson, 2002; Gilbert & Wilson, 2009; Kahneman & Snell, 1990).

Despite some sort of insight is likely to exist (Buehler & McFarland, 2001; Wirtz, Kruger, Scollon, & Diener, 2003), research generally suggests that inaccuracy between forecasted emotional states and future experiences is frequent: People are not good at forecasting feelings, and the affective states they anticipate do not match the actual future experience (Wilson & Gilbert, 2003). Sources of errors in affective forecasting may be connected either to the time at which the prediction is made or to the actual experience (Wilson & Gilbert, 2003). Regardless of the type of error, the result is a bias in affective forecasts. In this sense, the literature has shown that, while people are usually quite accurate at forecasting the valence of future emotional experiences (i.e., negative or positive) or the specific emotions they will experience (e.g. anger or fear) (Wilson & Gilbert, 2003), they are quite biased at estimating emotional intensity and duration, thus leading to the so-called durability bias (i.e. the tendency to overestimate the duration of an emotional reaction) (Gilbert, Wilson, Pinel, Blumberg, & Wheatley, 1998) and impact bias (i.e. the tendency to overestimate the impact of a future event) (Gilbert et al., 2002; Wilson, Gilbert, & Centerbar, 2003).

To date, a body of studies supports the idea that affective forecasting represents an important cognitive process, and predicting future feelings is an essential source of information to drive behaviours (Crawford, McConnell, Lewis, & Sherman, 2002; DeWall, Baumeister, Chester, & Bushman, 2014; Mellers, Schwartz, Ho, & Ritov, 1997). Accordingly, people use affective information to make judgments and take decisions about the future (Colombo, Fernandez-Alvarez, et al., 2020; Schwarz & Clore, 1983;

Taquet et al., 2016a). In addition, there is also evidence supporting that affective forecasting is a regulatory process, that might serve as a resilience source in the presence of difficulties. Specifically, anticipating future feelings would be a future-oriented strategy to regulate emotions (Goodhart, 1985), which would lead people to directly or indirectly behave in order to match or change the forecasted emotional experience (Persson & Sjöberg, 1985). In that direction, Totterdell et al. (1997) asked thirty participants to predict daily and weekly mood, as well as to annotate daily affect at the end of the day. Results showed that, regardless of the presence of daily hassles, mood was more likely to improve when participants expected it to improve (i.e. when they predicted that they would have experienced a better mood), thus supporting the hypothesis of affective forecasting as a regulatory process and suggesting that mood forecasts may be considered "[…] *as part of a process that exerts some mental control over mood"* (Totterdell et al., 1997).

Based on the previous literature, it seems plausible that the way people anticipate affective states can have repercussions on different aspects of life, such as happiness and well-being (Buchanan, Buchanan, & Kadey, 2019; Elizabeth W. Dunn, Biesanz, Human, & Finn, 2007; Gilbert & Wilson, 2009; Nasso, Vanderhasselt, Demeyer, & Raedt, 2019), physical and mental health (Riis et al., 2005; Sieff, Dawes, & Loewenstein, 1999), and interpersonal relations (Dunn & Laham, 2006). Consequently, biases in affective forecasting, either positive or negative, may entail several consequences for mental health. Indeed, positive illusions such as favorable self-evaluations, exaggerated perception of control, and unrealistic optimism have been shown to boost happiness and well-being (Brookings & Serratelli, 2007; Taylor & Brown, 1988; Taylor & Brown, 1994). These cognitive biases are likely to increase the perception of owning successful copying skills (Brown, 1993), which in turn enhances motivation and enthusiasm while carrying out actions (Taylor & Gollwitzer, 1995). Similarly, a positive future-oriented disposition and openness to the future (i.e., having positive expectations and a general disposition of acceptance towards the future*)* have been shown to be protective factors for mental health and to be positively associated with well-being (Mikus et al., 2017; Weinstein, 1980; Botella et al., 2018).

In the present study, we aimed to explore affective forecasting in a sample of undergraduate students. Contrary to the previous literature that mainly focused on predicting emotions in relation to a specific future event, we explored affective forecasting as a future-oriented disposition in healthy individuals by asking for general future affective estimations. The main objective was to disentangle the association of affective forecasting with well-being and resilience. To do so, we asked 85 participants to forecast positive (PA) and negative (NA) affect over two weeks, and we monitored experienced daily mood by means of a web-based Ecological Momentary Assessment (EMA) design, which has been shown to be an adequate methodology to capture emotional dynamics in daily life (Colombo, Fernández-Álvarez, et al., 2019; Colombo, Fernandez Alvarez, et al., 2019).

First, we hypothesized that people with a more optimistic view of future affect and who tend to overestimate PA will show greater well-being. No significant association is expected in relation to NA forecasts, because overestimating negatively-valenced emotions is known to be either an evolutionary rather than maladaptive copying mechanism (Miron-Shatz, Stone, & Kahneman, 2009), or the consequence of a negative bias associated with anxiety and depressive conditions (Mathersul & Ruscio, 2019), which were excluded from the current study. Second, and in line with the previous hypothesis, we expected that PA but not NA forecasts will be associated with resilience. More specifically, we hypothesized that PA under-estimators would be less resilient than PA over-estimators. Finally, we hypothesized that biased PA forecasts would moderate the impact of stress on affect, consistent with the idea that holding positive expectations about the future represents a further source of resilience to cope with daily events.

METHODS

We reported how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study (Simmons, Nelson, & Simonsohn, 2012).

Sample

The sample size was calculated considering the correlations as the main analyses of the study. Assuming an overall moderate effect size of .3 (correlation), a significance level of 5%, a statistical power of 80%, and a bilateral contrast, the sample size calculation resulted in a sample of n = 82. Calculations were made with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007).

In total, 91 undergraduate students were recruited via online advertisements at the Jaume I University (Castellon, Spain). Participants with a score above 14 on the Patient Health Questionnaire (PHQ-9) (Kroenke, Spitzer, & Williams, 2001) and/or the Generalized Anxiety Disorder (GAD-7) (Spitzer, Kroenke, Williams, & Löwe, 2006) were excluded from the study (i.e., individuals with moderate/severe clinical conditions). Accordingly, there is evidencing showing that patients suffering from Major Depressive Disorder (MDD) or Generalized Anxiety Disorder (GAD) are negatively biased in affective forecasting (Mathersul & Ruscio, 2019; Wenze, Gunthert, & German, 2012), which would make their inclusion together with non-clinical individuals problematic. Accordingly, 6 participants were excluded, thus leading to a final sample of n=85. The sample was composed of 72 females and 13 males, and their mean age was 20.81 years (SD=2.26). In our sample, the PHQ-9's internal consistency was α=.73, whereas the GAD-7's internal consistency was α=.82.

This study was approved by the ethics committee of the Jaume I University (Spain) (certificate number: CD/57/2019; reference: 41EA95C7D3C8747F0A37), and informed consent was obtained from all participants.

Measures

Forecasted positive and negative affect: Participants were administrated the Spanish adaptation (Díaz-García et al., 2020) of the Positive and Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegen, 1988). The PANAS is composed of 10 items to measure PA and 10 items to assess NA. Previous research has shown the validity and reliability of the questionnaire (Sandín et al., 1999). In the present study, the original instructions "*Indicate the extent you have felt this way over the past week*" were changed to "*Indicate the extent you think you will feel over the next two weeks*" to evaluate forecasted as opposed to retrospective affect. In our sample, both the PA and the NA subscales showed good internal consistency (PA: α=.91; NA: α=.78).

Psychological well-being: Psychological well-being was assessed using the Spanish adaptation (Díaz-García et al., 2020) of the Ryff's Psychological Well-Being Scale (Ryff, 2005; Ryff & Keyes, 1995), which explores six different dimensions of psychological well-being: Autonomy (i.e., independence from external judgments and social prejudices:

"I have confidence in my opinions, even if they are contrary to the general consensus"; "I judge myself by what I think is important, not by the values of what others think is important"), environmental mastery (i.e., the ability to take advantage of the environment to achieve personal goals: "I am quite good at managing the many responsibilities of my daily life"; "In general, I feel I am in charge of the situation in which I live"), personal growth (i.e., the sense of continuous self-improvements thanks to life experiences: "For me, life has been a continuous process of learning, changing, and growth"; "I have the sense that I have developed a lot as a person over time"), purpose in life (i.e., the sense of meaning in life, owning clear personal values and life goals: "I have a sense of direction and purpose in life"; "I enjoy making plans for the future and working to make them a reality"), positive relations (i.e., satisfactory and trusting relationships, as well as empathetic and warm attitude towards others: "People would describe me as a giving person, willing to share my time with others"; "I know that I can trust my friends, and they know they can trust me"), and self-acceptance (i.e., positive attitude toward the current and past self, as well as acceptance of both positive and negative personal qualities: "When I look at the story of my life, I am pleased with how things have turned out"; "When I compare myself to friends and acquaintances, it makes me feel good about who I am"). This scale has shown good psychometric properties (van Dierendonck, 2004). In our sample, all subscales demonstrated good internal consistency, except for autonomy and environmental mastery (self-acceptance: α=.87; positive relation: α=.83; autonomy: α=.64; environmental mastery: α=.67; personal growth: α=.83; purpose in life: α=.78).

Resilience: Resilience was assessed using the Spanish adaptation (Notario-Pacheco et al., 2011) of the 10-item Connor-Davidson Resilience Scale (CD-RISC10) (Campbell-Sills & Stein, 2007), a self-report scale with good psychometric properties (Shin et al., 2018; Singh & Yu, 2017) that measures resilience over the previous 30 days ("I can deal with whatever comes my way"; "I think of myself as a strong person when dealing with life's challenges and difficulties"). In our sample, the CD-RISC10 showed high internal consistency (α=.85).

Openness to Future: The Openness to the Future Scale (OFS) is a 10-item self-report questionnaire that measures orientation toward the future, including positive expectations, a sense of competence to cope with daily events, and the acceptance of what can't be predicted. Some examples include: "I calmly accept that good and bad things will happen to me in life"; "I am very excited about future opportunities and challenges"; "I feel hopeful about what the future may bring". This scale has shown good psychometric properties both in community and clinical samples (Botella et al., 2018). In our sample, the OFS showed good internal consistency (α=.80).

Ecological Momentary Affect (EMA) measures

At each daily evaluation, participants were asked to complete three 100-point numerical scales (0=not at all; 100=extremely) evaluating momentary PA ("*To what extent are you experiencing positive emotions at this moment?*"), momentary NA ("*To what extent are you experiencing negative emotions at this moment*?"), and momentary stress ("*How would you rate your current level of stress?*"). Participants were also asked to rate the momentary level of seven positive emotions (happiness, fun, hope, serenity, excitement, pride, gratitude) using a 1-5 Likert scale, ("*To what extent are you experiencing the following positive emotions at this moment?;* 1=not at all; 5=extremely). The sum of the seven scales reflected the momentary level of positive emotions.

Procedure

Participants were recruited via poster advertisements at the Jaume I University (Castellon, Spain). Students interested in the study were invited to the laboratory in order to receive more information about the investigation. Participants who met the inclusion criteria were invited to sign the informed consent and to complete the affective forecasting measure with the PANAS.

Repeated daily assessments were collected by means of Qualtrics, a web-based platform that allows to create and send customized online surveys at specific time points during the day. In the present study, participants were semi-randomly prompted three times a day for two weeks (between 9:30 – 14:00; 14:00 – 18:30; and 18:30 – 23:00) by means of an email. After receiving the notification, participants had sixty minutes to enter the weblink and complete the evaluation.

At the end of the study, participants returned to the laboratory and completed the following questionnaires: The Ryff's Psychological Well-being Scale, the CD-RISC and the OFS. Additionally, participants were asked whether something significant unexpectedly happened in the previous two weeks. This included any sudden and unforeseen positive and/or negative event that significantly affected their mood, thoughts, or behaviors. This question was introduced in order to exclude participants that, during the study, experienced an event that was impossible to anticipate (such as a sentimental breakup, the death of a closer person, or being hired at a new job), thus creating a biased mismatch between the predicted and experienced affect. However, no participant reported such significant events and there was no need for exclusion. A remuneration of 10 euros was given to participants who completed more than 60% of the EMA assessments.

Data analysis

Table 5.1: Summary of all the variables included in the analysis and their abbreviations.

Abbreviation	Variable
Forecasted PA	Anticipated PA – PANAS at baseline
Forecasted NA	Anticipated NA – PANAS at baseline
Experienced PA	Global average of EMA-PA assessments
Experienced NA	Global average of EMA-NA assessments
EMA-PA	PA repeated EMA assessments
EMA-NA	NA repeated EMA assessments
EMA-Stress	Stress repeated EMA assessments
EMA-positive emotions	Positive emotions repeated EMA assessments
Delta PA	(Forecasted PA – Experienced PA)
Delta NA	(Forecasted NA – Experienced NA)

A summary of all the variables included in the analysis and their abbreviations is reported in **Table 5.1**.

Forecasted affect refers to the PANAS-PA and PANAS-NA subscale scores collected at baseline. Experienced affect refers to mean PA and NA levels experienced during the two-week EMA, and it was obtained by calculating the mean of the 42 possible PA and NA assessments for each participant. Besides, EMA scores refer to the 42 possible NA, PA, positive emotions and stress repeated assessments collected throughout the 2-week study.

To distinguish between future affect overestimation or underestimation, delta scores were computed. To have the same range of scores for forecasted (PANAS: 1-to-5 Likert scale) and experienced affect measures (EMA: 0-100 scale), PANAS values were transformed to Percent of Maximum Possible (POMP) Scores (Cohen, Cohen, Aiken, & West, 1999; Fischer & L. Milfont, 2010). POMP scores express raw scores in terms of the maximum possible score and can range between 0 and 100, thus facilitating the comparison of data when scales and scoring methods are not consistent. POMP scores are calculated as follows: *100 * (raw-min) / (max-min),* with min and max indicating the lowest and highest scores possible according to the scale adopted. POMP scores of forecasted affect were calculated as follows: POMP scores: *100 * (raw-10) / (50-10)*. Delta scores were therefore computed as follows: *Delta = (POMP forecasted affect – experienced affect*). Positive scores reflected future affect overestimation, whereas negative scores reflected future affect underestimation.

Correlation analyses were conducted to explore the association between forecasted and experienced NA, and between forecasted and experienced PA. Moreover, Generalized Estimating Equations (GEEs) with an unstructured correlation matrix structure and Huber–White standard error estimates were used, introducing forecasted PA and NA as predictors of daily EMA-NA and EMA-PA scores. GEEs are designed to examine longitudinal repeated-measures data. Furthermore, GEEs are adequate to draw inferences by considering not only variations in affective experience over time within individuals, but also variations in affective experience between individuals (Liang & Zeger, 1986; Pavani, Le Vigouroux, Kop, Congard, & Dauvier, 2016). Forecasted and experienced PA (Paired sample t-test) and NA scores (Wilcoxon Signed Ranks Test) were compared to test the participants' ability to predict future affect. Also, delta scores distribution was explored, and their association with depressive and anxiety symptoms was investigated.

To confirm the first hypothesis, correlation analyses were conducted to explore the association between forecasted/experienced affect, delta scores, well-being, and openness to the future. GEEs with an unstructured correlation matrix structure were used introducing forecasted NA, forecasted PA, daily EMA-PA and daily EMA-NA simultaneously as predictors of psychological well-being.

To explore the association between affective forecasting and resilience, correlation analyses were conducted. Besides, multiple linear regressions were performed using well-being measures as dependent variables and resilience as the independent variable; in a second block, delta scores were included to explore significant improvements in the model.

Consistent with the third hypothesis, we performed GEEs with an unstructured correlation matrix structure and Huber–White standard error estimates including delta scores, daily EMA-stress scores and the interaction term as predictors of daily affect.

RESULTS

Forecasted and experienced affect

An overview of the recruited sample is reported in **Table 5.2**. Overall, high compliance was obtained (M=80.47%; SD=18.44%), considering previous research exploring the extent to which participants tend to answer EMAs (Colombo et al., 2018; Van Genugten et al., 2020). Compliance was associated with depressive ($r=-.21$, $p=.05$) and anxiety symptoms ($r=-.21$, $p<.05$), but not with age ($r=.18$, $p=.11$).

Forecasted and experienced PA ($r=.45$, $p<.001$) and NA levels ($r=.43$, $p<.001$) were significantly correlated, thus indicating a good degree of participants' self-insight about future affect. Forecasted PA significantly predicted EMA-PA scores (B=1.27, SD=.18, 95% CI [.91, 1.63]; $p<.001$); similarly, forecasted NA significantly predicted EMA-NA scores (B=.94, SD=.18, 95% CI [.58, 1.30]; $p<.001$).

Participants forecasted lower levels of PA than what they experienced (forecasted PA-POMP: mean=50.21, SD=±18.48; experienced PA: mean=55.60, SD=±18.46; $t(84)=-2.57$, $p<.05$). Similarly, a significant difference was observed between forecasted NA and experienced NA scores (forecasted NA-POMP: mean=18.71, SD=±11.76; experienced NA: mean=22.06, SD=±12.26; $Z=-2.60$, $p<.01$). Mean delta PA was -5.40 (SD=19.37), whereas mean delta NA was -3.35 (SD=13.29), thus indicating a general tendency to underestimate future affective states. No significant correlation was observed between delta PA and delta NA ($r=-.13$, $p=.25$).

Table 5.2: Detailed information about the recruited sample and affect measures (*GAD-7: Generalized Anxiety Disorder; PHQ-9: Patient Health Questionnaire)*

SAMPLE (n=85)	
Demographics	
Age	20.81 (± 2.26)
Sex	72 female / 13 male
GAD-7	5.12 (± 3.47)
PHQ-9	5.69 (± 2.93)
Compliance (%)	80.47 (±18.44)
Affect	
Forecasted PA-pomp	50.21 (± 18.48)
Forecasted NA-pomp	18.71 (±11.76)
Experienced PA	55.60 (±.18.46)
Experienced NA	22.06 (±12.26)

Participants with higher depressive symptoms anticipated to experience higher NA (r=.36, p<.001) and lower PA levels (r=-21, p=.05). However, delta values were not significantly associated with PHQ-9 scores (delta PA: r=-.11, p=.30; delta NA: r=.20, p=.07), thus indicating that individuals with higher depressive symptoms forecasted and actually experienced lower levels of PA and higher levels of NA. Differently, forecasted NA (r=.65, p<.001) was significantly associated with anxiety symptoms, and delta NA significantly correlated with (r=.28, p<.01) and predicted delta NA (R^2=.11; F(1, 83)=10.30; B=0.83, SE=.03, 95% CI [.03, .14]; p<.01), highlighting greater overestimation of future NA in the presence of increased anxiety symptoms.

Affective forecasting and well-being

Table 5.3 shows the association between psychological well-being measures and forecasted/experienced affect.

Table 5.3: Correlations among all the variables included in the analyses. Forecasted PA, experienced PA, delta NA, delta PA, Ryff autonomy, Ryff environmental mastery and OFS were normally distributed, and correlations were calculated with Pearson correlations. The remaining associations were calculated using Spearman correlations. *p<.05, ** p<.01, ***p<.001. (PHQ-9: Patient Health Questionnaire; GAD-7: Generalized Anxiety Disorder; *OFS: Openness to Future Scale; CD-RISC: Connor-Davidson Resilience Scale*)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.Forecasted NA	1.00															
2.Forecasted PA	-.12	1.00														
3.Experienced NA	.43***	-.15	1.00													
4.Experienced PA	.04	.45***	-.22*	1.00												
5.Delta NA	.48***	-.02	.51***	.20	1.00											
6.Delta PA	-.16	.53***	-.0	-.52***	-.13	1.00										
7.PHQ-9	.36***	-.21*	.13	-.02	.20	-.12	1.00									
8.GAD-7	.65***	-.16	.30**	-.06	.28*	-.19	.68***	1.00								
9.Self-acceptance	-.37***	.53***	-.16	.13	-.16	.33**	-.43**	-.45***	1.00							
10.Positive relations	-.19	.32**	-.01	.00	-.16	.28**	-.18	-.23*	.49***	1.00						
11.Autonomy	-.27*	.43***	-.16	.16	-.13	.38***	-.28**	-25*	.53***	.45***	1.00					
12.Environment mastery	-.33**	.44***	-.08	.08	-.18	.26*	-.37***	-.41***	.72***	.57***	.41***	1.00				
13.Personal growth	-.23*	.42***	-.05	.06	-.14	.28*	-.04	-.07	.54***	.33***	.45***	.48***	1.00			
14.Purpose in life	-.16	.42***	.01	.07	-.12	.33**	-.19	-.24*	.66***	.47***	.38***	.74***	.61***	1.00		
15.OFS	-.21*	.47***	-.10	.20	-.06	.25*	-.30**	-.20	.59***	.32***	.40***	.54***	.47***	.64***	1.00	
16.CD-RISC	-.27*	.62***	-.27*	.19	.05	.37***	-.14	-.24*	.53***	.36***	.46***	.58***	.55***	.57***	.60***	1.00

Forecasted PA (self-acceptance: $r=.53$, $p<.001$; positive relations: $r=.32$, $p<.01$; autonomy: $r=.43$, $p<.001$; environmental mastery: $r=.44$, $p<.001$; personal growth: $r=.42$, $p<.001$; purpose in life: $r=.42$, $p<.001$) but not experienced PA significantly correlated with all Ryff's subscales, revealing that participants holding more optimistic predictions of future PA reported greater psychological well-being. Additionally, forecasted NA showed a significant negative association with Ryff's subscales of self-acceptance ($r=-.37$, $p<.001$), autonomy ($r=-.27$, $p<.05$), environmental mastery ($r=-.33$, $p<.01$), and personal grow ($r=-.23$, $p<.01$), while experienced NA did not correlate with any of the well-being measures. **Table 5.3** also shows the association between biased affective forecasting and psychological well-being. Delta PA was significantly correlated with all Ryff's psychological well-being measures (self-acceptance: $r=.33$, $p<.01$; positive relations: $r=.28$, $p<.01$; autonomy: $r=.38$, $p<.001$; environmental mastery: $r=.26$, $p<.05$; personal growth: $r=.28$, $p<.05$; purpose in life: $r=.33$, $p<.01$): That is, positively biased PA forecasting was associated with enhanced perceived well-being. Consistently with our hypothesis, delta NA did not correlate with any of the well-being measures.

When simultaneously included in a regression model to predict psychological well-being, delta PA was the only significant predictor of self-acceptance ($R^2=.11$; $F(1, 82)=5.21$; delta PA: $B=0.10$, $SE=.03$, 95% CI [.03, .16]; $p<.01$; delta NA: $B=-0.19$, $SE=.04$, 95% CI [-.11, .07]; $p=.70$), positive relations ($R^2=.11$; $F(1, 82)=5.11$; delta PA: $B=0.09$, $SE=.03$, 95% CI [.02, .15]; $p<.05$; delta NA: $B=-0.07$, $SE=.05$, 95% CI [-.17, .02]; $p=.13$), autonomy ($R^2=.14$; $F(1, 82)=6.91$; delta PA: $B=0.10$, $SE=.03$, 95% CI [.04, .16]; $p<.001$; delta NA: $B=-0.02$, $SE=.04$, 95% CI [-.10, .06]; $p=.64$), environmental mastery ($R^2=.09$; $F(1, 82)=3.97$; delta PA: $B=0.05$, $SE=.02$, 95% CI [.01, .10]; $p<.05$; delta NA: $B=-0.4$, $SE=.03$, 95% CI [-.11, .02]; $p=.19$), personal growth ($R^2=.10$; $F(1, 82)=4.53$; delta PA: $B=0.08$, $SE=.03$, 95% CI [.03, .13]; $p<.01$; delta NA: $B=-0.01$, $SE=.04$, 95% CI [-.09, .07]; $p=.81$), and purpose in life ($R^2=.11$; $F(1, 82)=4.94$; delta PA: $B=0.09$, $SE=.03$, 95% CI [.03, .15]; $p<.01$; delta NA: $B=-0.01$, $SE=.04$, 95% CI [-.09, .06]; $p=.78$). Besides, forecasted PA (forecasted PA: $r=.47$, $p<.001$), and forecasted NA ($r=-.21$, $p=.05$) were significantly associated with OFS. Additionally, only delta PA was significantly associated with OFS ($r=.25$, $p<.05$), suggesting that participants who overestimated future PA were more likely to report greater openness to the future.

Table 5.4: Generalized Estimating Equation (GEE) models introducing forecasted PA, forecasted NA, daily EMA-PA and daily EMA-NA as predictors of well-being subscales. B= unstandardized regression coefficient; *p<.05, ** p<.01, ***p<.001. (*PA: Positive affect; NA: Negative affect*)

	Self-acceptance		**Positive relations**		**Autonomy**		**Environmental mastery**		**Personal growth**		**Purpose in life**	
	B	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*
Coefficients												
Forecasted PA	.39***	.06	.25**	.08	.28***	.07	.24***	.05	.27***	.06	.31***	.07
Forecasted NA	-.33***	.09	-.24	.14	-.24*	.11	-.29**	.09	-.16	.09	-.15	.11
Daily PA	.000	.002	-.001	.001	-.001	.001	.001	.0003	.000	.001	-.001	.001
Daily NA	-.002	.002	.000	.001	.000	.001	<.001	.0002	-.001	.001	.000	.001

Using GEEs, forecasted affect and EMA affect scores were simultaneously included as predictors of Ryff's well-being measures (**Table 5.4**).

Forecasted PA was the only significant predictor of positive relations (B=0.54, SE=.08, 95% CI [.09, .42]; p<.01), personal growth (B=0.27, SE=.06, 95% CI [.14, .39]; p<.001), and purpose in life (B=0.31, SE=.07, 95% CI [.17, .45]; p<.001), whereas both forecasted NA and forecasted PA significantly predicted self-acceptance (forecasted PA: B=0.39, SE=.06, 95% CI [.27, .51]; p<.001; forecasted NA: B=-0.33, SE=.09, 95% CI [-.51, -.15]; p<.001), autonomy (forecasted PA: B=0.28, SE=.07, 95% CI [.15, .41]; p<.001; forecasted NA: B=-0.24, SE=.11, 95%CI [-.45, -.02]; p<.05), and environmental mastery (forecasted PA: B=0.24, SE=.05, 95% CI [.14, .34]; p<.001; forecasted NA: B=-0.29, SE=.09, 95% CI [-.47, -.11]; p<.01). Interestingly, experienced daily affect did not predict any of the well-being measures.

Affective forecasting, resilience and stress

Forecasted PA (r=.62, p<.001) and delta PA (r=.37, p<.001) but not experienced PA (r=.19, p=.08) significantly correlated with CD-RISC. That is, holding optimistic expectations regarding the future and overestimating PA were associated with higher levels of resilience. Besides, forecasted (r=-.27, p=<.05) and experienced NA (r=-.27, p<.05) but not delta NA (r=.05, p=.67) did show a significant association with resilience (**Table 5.3**).

Resilience was a significant positive predictor of psychological well-being (self-acceptance: R^2=.32; F(1, 83)=39.87; B=0.48, SE=.08, 95% CI [.33, .63]; p<.001; positive relations: R^2=.14; F(1, 83)=13.54; B=0.34, SE=.09, 95% CI [.16, .52]; p<.001; autonomy: R^2=.21; F(1, 83)=21.82; B=0.35, SE=.07, 95% CI [.20, .50]; p<.001; environmental mastery: R^2=.36; F(1, 83)=46.93; B=0.38, SE=.06, 95% CI [.27, .49]; p<.001; personal growth: R^2=.28; F(1, 83)=32.22; B=0.38, SE=.07, 95% CI [.28, .52]; p<.001; purpose in life: R^2=.35; F(1, 83)=44.22; B=0.46, SE=.07, 95% CI [.32, .59]; p<.001). The inclusion of delta PA significantly increased the variance explained by the model for autonomy (R^2=.62, ΔR2=.05, F (2, 82)=14.57, CD-RISC: B=0.28, SD=.08, 95% CI [.13, .44]; p<.001; delta PA: B=0.07, SD=.03, 95% CI [.01, .12]; p<.05), and a close-to-significance trend was observed in the model predicting positive relations (R^2=.17, ΔR2=.03, F (2,

82)=8.40, CD-RISC: B=0.28, SD=.10, 95% CI [.09, .47]; p<.001; delta PA: B=0.06, SD=.03, 95% CI [-.01, .13]; p=.08).

Finally, GEE analyses were conducted to explore whether EMA-stress scores and delta PA significantly predicted EMA-affect. EMA-NA was significantly predicted by EMA-stress level but not by delta PA (EMA-stress: B=0.46, SD=.02, 95% CI [.42, .51]; p<.001; Delta PA: B=-0.04, SD=.04, 95% CI [-.11, .03]; p=.26), thus underlying the fundamental role of stress on NA affect ratings (i.e. the experience of higher stress was associated with higher levels of perceived NA). Similarly, EMA-stress scores but not delta PA significantly predicted positive emotion level (stress: B=-0.09, SD=.01, 95% CI [-.11, -.08], p<.001; Delta PA: B=-0.02, SD=.02, 95% CI [-.07, .03], p=.46). Notably, a significantly different association between EMA-NA and stress was observed as a function of delta values (stress: B=0.45, SD=.02, 95% CI [.40, .50], p<.001; Delta PA: B=0.02, SD=.04, 95% CI [-.05, .09], p=.60; interaction: B=-0.003, SD=.001, 95% CI [-.01, .00]; p<.05). As indicated by the negative beta coefficient of the interaction (Suso-Ribera, Camacho-Guerrero, Osma, Suso-Vergara, & Gallardo-Pujol, 2019), as delta PA becomes more positive (i.e., future PA is overestimated), the contribution of stress on NA is reduced. A significantly different association between EMA-positive emotion and stress was also observed as a function of PA delta values (stress: B=-0.09, SD=.01, 95% CI [-.10, -.07], p<.001; Delta PA: B=-0.04, SD=.03, 95% CI [-.09, .01], p=.12; interaction: B=0.001, SD=.0003, 95% CI [.001, .002]; p<.001). As the interactive effect of delta PA and stress on positive emotion level is positive, this means that, as delta PA becomes more negative (i.e., forecasting becomes more negatively biased and future PA is underestimated), stress becomes more deleterious for positive emotions. In other words, it is possible to suggest that, despite the increase in experienced stress, subjects with positively biased PA forecasting (i.e., those who overestimated future positive affective states) reported lower NA levels and higher positive emotions.

Regarding delta NA, EMA-PA (stress: B=-0.36, SD=.03, 95% CI [-.42, -.30], p<.001; Delta NA: B=0.14, SD=.11, , 95% CI [-.07, .36], p=.19) was significantly predicted by EMA-stress but not delta NA, whereas EMA-positive emotions were significantly predicted by both stress level and delta NA (stress: B=-0.14, SD=.02, 95% CI [-.18, -.09], p<.001; Delta NA: B=0.51, SD=.16, 95% CI [.83, .19], p<.01). No significant interaction effect was observed.

DISCUSSION

So far, a growing body of literature has explored people's ability to forecast emotional experiences in relation to specific future events. In the current study, instead, we investigated affective forecasting as a future-oriented disposition, asking participants to estimate their affect during a two-week period.

The main aim of the present study was to explore whether biased affective forecasting was associated with perceived psychological well-being, consistently with the hypothesis that the ability to estimate future emotional experiences constitutes a future-oriented strategy to regulate emotions (Goodhart, 1985; Totterdell et al., 1997).

Aligned with the previous literature (Buehler & McFarland, 2001; Wirtz et al., 2003), participants in the present study showed a good degree of insight about their future PA and NA levels. A significant discrepancy between forecasted and experienced affect was also observed, and participants showed a somewhat pessimistic view of the future. These results diverge from what has been revealed by a growing body of literature exploring affective forecasting in relation to specific future events. People would indeed overestimate the impact of both positive and negative future events (Wilson & Gilbert, 2003), due to an excessive focus on a single event in isolation without considering the general context and background distractions (Wilson, Wheatley, Meyers, Gilbert, & Axsom, 2000). This phenomenon, called *focalism*, does not occur when forecasting general emotional states, which could explain the dissimilar results observed in this study. Besides, our results confirmed the role played by depressive and anxiety symptoms on affective forecasting (Wenze et al., 2012), and the presence of mild symptoms was associated with a negative bias, which is consistent with the previous literature (Colombo et al., 2019; Craske & Pontillo, 2001; Gotlib & Joormann, 2010). Specifically, depressive symptoms were associated with future NA overestimation and PA underestimation, whereas anxiety symptoms only significantly correlated with future NA overestimation. As evidenced by the tripartite model, indeed, depression and anxiety share the same pattern of enhanced NA, whereas low levels of PA and anhedonia are only typical of depressive conditions (Clark & Watson, 1991).

Coherently with the first hypothesis, participants holding more positive estimations of future PA and positively biased PA forecasting reported greater psychological well-being on almost all Ryff's subscales. Results also confirmed the hypothesis that biased NA estimations (i.e., underestimating or overestimating NA) were not significantly associated with well-being, which supports the idea that a bias in negative affective forecasting does not affect psychological well-being. Besides, it is of particular interest that psychological well-being was significantly predicted by forecasted but not experienced affect. In other words, our results suggest that psychological well-being is a grounded dimension: Rather than momentary affect and daily events, psychological well-being seems to be more strongly associated with resilience and coping skills, such as holding an optimistic, even if distorted, vision of the future. Accordingly, delta PA but not delta NA was significantly associated with OFS, which in turn has been found to be associated with better mental health (Botella et al., 2018).

Our results also confirmed the second hypothesis. Contrary to delta NA, forecasted PA as well as delta PA were strongly associated with resilience, and participants holding more positive estimations of future PA and overestimating future PA were found to be more resilient. The multiple regression analyses also showed that delta PA in addition to resilience improved the prediction of some well-being dimensions, thus confirming the idea that positively biased affective forecasting may constitute a coping skill that increases individuals' abilities to deal with daily hassles. Consistently, and confirming our third hypothesis, delta PA significantly moderated the impact of daily stress on daily affect. This means that, when experiencing high levels of stress, subjects who tended to overestimate future PA reported lower NA and higher positive emotions than subjects who showed a tendency to underestimate it. A positive attitude toward the future seems therefore to be an adaptive coping resource in highly stressful situations, allowing to maintain better levels of momentary affect despite the presence of intense stressors.

Even though a long tradition of research considered cognitive distortions as maladaptive mechanisms associated with worse mental health (Jahoda, 1953), there is now increasing evidence revealing that, in certain circumstances, cognitive biases may rather be adaptive (Taylor & Brown, 1988). Specifically, people's perception of the future has been shown to affect mental health (Mikus et al., 2017; Weinstein, 1980), and openness to the future has been associated with higher positive emotions, psychological well-being, and self-esteem (Botella et al., 2018). This seems to be strictly connected to the construct of optimism, defined as "[…] *a mood or attitude associated with an* *expectation about the social or material future*" (Tiger, 1979), which has been shown to increase people's skills to deal with challenging events (Carver, Scheier, Miller, & Fulford, 2012) and to be associated with higher subjective well-being, health and life success (Forgeard & Seligman, 2012). Beyond the conceptualization of optimism as an explanatory style (Seligman, 1991), the definition of optimism as one's disposition to hold favorable or unfavorable expectations and beliefs about the future seems to be more coherent with our results (Carver & Scheier, 2014). In this regard, we suggest that positively biased affective forecasting may in part reflect one's dispositional optimism, and it may constitute a mechanism that increases people's skills to deal with daily events, thus having a positive impact on psychological well-being.

Although optimism toward the future is likely to foster coping skills and promote well-being, it is important to note that holding a positively biased view of reality can also be maladaptive in certain circumstances (Chang, Chang, & Sanna, 2009). For instance, there is evidence showing that optimistic individuals are more likely to show gambling behaviors (Gibson & Sanbonmatsu, 2004) or to report lower motivation when trying to quit smoking (Weinstein, Slovic, & Gibson, 2004). As suggested by Forgeard et al. (2012), "*the most adaptive outlook seems therefore to be mostly optimistic, tempered with small doses of realistic pessimism when needed*": For example, to avoid disappointment when idealizing something that it is quite improbable to achieve. A flexible rather than rigid positively biased perspective seems therefore to be the key of well-being. Future research should investigate the potential role of flexibility on affective forecasting and health-related outcomes.

Besides, the findings of the current study have to be considered in light of some limitations. In the present study, we excluded individuals with clinically relevant depressive and anxiety symptoms in order to control for the confounding effect of a pathological negative bias (Mathersul & Ruscio, 2019; Wenze, Gunthert, & German, 2012). However, there are other individual factors, which have been shown to play a fundamental role in affective forecasting abilities. For example, personality has been found to explain 30% of the concordance between anticipated and experienced emotional experiences (Hoerger, Chapman, & Duberstein, 2016; Zelenski et al., 2013), and introverted as compared to extroverted individuals tend to anticipate more unpleasant emotions and less positive emotional states. Furthermore, there is evidence showing that people who are high in emotional intelligence are more accurate at encoding and predicting their emotional reactions (Dunn, Brackett, Ashton-James, Schneiderman, & Salovey, 2007; Hoerger, Chapman, Epstein, & Duberstein, 2012). Altogether, these results suggest that affective forecasting is a complex cognitive phenomenon, in which many different factors are likely to reciprocally interact with each other. In addition to the previous, it is also possible to hypothesize that an individual's response style to positive emotional states (Feldman, Joormann, & Johnson, 2008) could be an additional element that influences positive affective forecasting. Accordingly, habitual positive ruminators (i.e., those who tend to reflect on positive events, self-qualities, and pleasant emotions) might be more likely to be positively biased toward their future emotional states, as a result of an over-focus on positive emotional experiences and/or qualities. Future research is needed to prove this hypothesis and, more generally, to build a broader framework in which all the aforementioned factors are concurrently considered.

It is also important to note that the sample was mainly composed of undergraduate female students. Future research should investigate whether other factors such as sex or age may entail different effects on affective forecasting. To date, elderly people as compared to young individuals have been shown to recall more positive than negative information, a phenomenon called positivity effect (Carstensen & DeLiema, 2018; Reed & Carstensen, 2012). However, this positivity effect does not seem to influence elderly's affective forecasting (Nielsen, Knutson, & Carstensen, 2008), who have been shown to be accurate rather than positively biased in the estimation of future affective states, thus suggesting that "[…] *people may correct for this bias as they age*". Accordingly, the results observed in our study may not be generalizable to all populations, and it is possible that positively biased estimations of future states are more common in young-to-middle adulthood.

Additionally, the methodological nature of this study only allows to draw correlational conclusions, and more evidence is needed to clarify the potential causal role of biased forecasting on perceived well-being and resilience. Hence, experimental designs could complement existing evidence assuming causal inferences. Future studies should also consider the potential consequences of this cognitive bias on behaviours, exploring whether holding positive expectations about future emotions may also affect people's decisions in daily life. It might be possible, indeed, that biased affect predictions influence daily behavioural attitudes (such as avoiding or joining specific situations), which in turn may influence well-being. Finally, the use of single items to measure EMA-PA and EMA-NA might not capture the complexity of momentary affect, as opposed to the use of the PANAS for the assessment of affective forecasting. However, we decided to use single items in order to reduce participants' burden and increase adherence rates (Colombo et al., 2018; Colombo et al., 2019), similarly to previous studies (Suso-Ribera et al., 2018). Besides, the autonomy and environmental mastery Ryff's subscales showed low internal consistency, and analyses including both measures have to be taken with caution.

To conclude, the benefits of enhancing PA as a way to promote mental health and well-being has been widely supported (Pressman, Jenkins, & Moskowitz, 2018), thus suggesting the importance of developing specific interventions to potentiate people's strategies to regulate positive emotions. In particular, it is of utmost importance to clearly determine the importance of developing a positive bias as well as an optimistic rather than pessimistic attitude toward the future. Besides, it is arguable that the complex dynamic of emotional and cognitive processes that intrinsically conform the regulatory process of individuals does not need evaluative precision but rather intrinsic coherence that the future will be possible to cope with.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF at https://doi.org/10.17605/OSF.IO/JFS3K.

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ETHICS STATEMENT

This study was approved by the ethics committee of the Jaume I University (Spain) (certificate number: CD/57/2019; reference: 41EA95C7D3C8747F0A37), and informed consent was obtained from all participants. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DC contributed to the conception and design of the work; the acquisition, analysis and interpretation of data; and the drafting the manuscript. JF-Á and CS-R equally contributed to the critical revision of the work. PC, AG-P, CB, and GR contributed to writing—review processes, editing and supervision.

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CHAPTER 6

Savoring the present: The reciprocal influence between positive emotions and positive emotion regulation in everyday life

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Savoring the present: The reciprocal influence between positive emotions and positive emotion regulation in everyday life

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ABSTRACT

A growing body of research has investigated the regulation of negative emotions in ecological settings, but little is known about the mechanisms underlying positive emotion regulation in everyday life. Although some evidence suggests that adopting positive strategies is beneficial for emotional well-being, the literature is inconsistent about the effects of positive emotions on subsequent regulatory processes. In the present study, we adopted a two-week ecological momentary assessment to explore the association between positive emotions and positive emotion regulation in daily life. According to our results, the less individuals felt positive emotions at one point in time, the more they tended to enhance their use of positive strategies from this point in time to the next, which in turn resulted in subsequent higher levels of positive affect. This prototype of positive regulation can be seen as a highly adaptive mechanism that makes it possible to compensate for a lack of positive emotions by enhancing the deployment of positive strategies. The theoretical and clinical implications of these findings are discussed.

Keywords: Positive emotions; positive emotion regulation; ecological momentary assessment.

INTRODUCTION

The pursuit of happiness is considered one of the most important life goals of individuals (Diener, 2000), who intensely seek to create pleasant experiences throughout their lives. Positive emotions (PE) are a core component of well-being because they are not limited to pleasant sensations, but rather produce short- and long-term psychological benefits and improve both physical and mental health (Diener & Seligman, 2002; Gruber et al., 2013; Lyubomirsky et al., 2005; Tugade & Fredrickson, 2007). More specifically, PE temporarily extend the scope of attention, cognition, and action (Barbara L. Fredrickson, 1998), which in turn promotes resilience and psychological well-being (Barbara L. Fredrickson & Joiner, 2002). Accordingly, people spend most of their time trying to downregulate negative emotions and upregulate positive ones (Gross et al., 2006).

Emotion regulation is a process through which individuals try to influence their emotional state in order to achieve personal goals (Gross, 1998a). To date, most of the literature has focused on the regulation of negative emotional states. Nevertheless, there is increasing evidence highlighting the crucial role of positive emotion regulation (Bryant, 2003; Quoidbach et al., 2015), that is, the set of strategies people implement to create, maintain, and enhance PE for two main purposes. First, people upregulate PE for its own sake, that is, to experience pleasurable affective states and increase happiness (Livingstone & Srivastava, 2012). Second, the upregulation of PE has been recognised as a mood repair mechanism, i.e. a process that helps individuals to reduce negative affect and recover from stressful events (Folkman & Moskowitz, 2000; Tugade & Fredrickson, 2004).

Although originally conceptualized for negative emotion, Gross' extended model (2015) has also been used to understand positive emotion regulation (Quoidbach et al., 2015). Accordingly, different types of positive strategies can be deployed in different stages of the emotion generation process: 1) by selecting a situation that is expected to improve affect (situation selection); 2) by actively changing a situation in order to get the most out of it (situation modification); 3) by redirecting the attention towards specific features or details of a situation (attentional deployment); 4) by changing the appraisal of an emotion-eliciting stimulus (cognitive change); and 5) by experientially, physiologically, or behaviourally expressing the ongoing emotion (response modulation). These strategies are not only implemented during the experience of a positive emotional state (Quoidbach et al., 2015). They might also be used before (i.e., while anticipating a positive event) (Colombo, Fernandez Alvarez, et al., 2020) or after (i.e., while recalling a positive memory) (Colombo, Suso-Ribera, et al., 2020) the emotion-generative process (Bryant, 2003; Quoidbach et al., 2015). For the purposes of the present study, however, we will mainly focus on the available literature exploring PE regulation in the present.

The implementation of positive emotion regulation has been shown to be beneficial for mental health. In fact, people who frequently adopt strategies to intensify and prolong positive experiences (i.e., savoring; Bryant & Veroff, 2017) show enhanced emotional well-being (Jose et al., 2012; Quoidbach et al., 2010) and more sustained PE over time (Gentzler et al., 2013). Similarly, a more extensive use of positive strategies, such as counting blessings or sharing, leads to greater levels of happiness, despite experiencing fewer daily positive events (Jose et al., 2012). In another study, Langstone et al. (1994) found that capitalizing on positive events further increases the experience of positive affect. Furthermore, intense use of mindfulness has been shown to predict higher levels of daily autonomy (Brown & Ryan, 2003), whereas positive reappraisal has been associated with greater self-esteem and well-being (Nezlek & Kuppens, 2008). In sum, there is a growing body of evidence that highlights the important affective outcomes associated with the use of positive emotion regulation in daily life.

However, not only can emotion regulation influence affective outcomes, but affect can also determine subsequent emotion regulation processes (Colombo, Fernandez-Alvarez, et al., 2020). This hypothesis is further confirmed by the evidence showing that momentary mood predicts subsequent affect levels (Pettersson et al., 2013), which suggests that emotion regulation might be partly determined by an individual's momentary affective state (Pavani et al., 2016). Nonetheless, the previous literature has been inconsistent about the association between PE and positive emotion regulation.

On the one hand, the broaden-and-build theory states that the experience of PE enhances one's attentional scope and thought-action repertoire, leading to cognitive and behavioural broadening mechanisms (B L Fredrickson, 2001; Barbara L. Fredrickson & Joiner, 2002) such as increased creativity or cognitive flexibility (Davis, 2009; Lin et al., 2014). These mechanisms have been hypothesized to affect emotion regulation processes as well. Thus, positive emotions are likely to encourage the adoption of adaptive, broadminded strategies that further enhance positive affect (Burns et al., 2008; Barbara L. Fredrickson & Joiner, 2002). Consistent with this theory, the momentary experience of high levels of PA has been found to predict greater subsequent adoption of adaptive strategies such as problem solving (Pavani et al., 2016) and mindfulness (Brockman et al., 2017).

On the other hand, pro-hedonic theories, such as the hedonic flexibility principle, suggest that people are likely to implement behavioural strategies based on their momentary mood in order to minimize negative affect and maximize positive affect (Quoidbach, Sugitani, et al., 2019; Simon, 1967). More specifically, the experience of low positive emotions is supposed to motivate actions and behaviours to enhance mood. Thus, individuals are likely to increase their attempts to upregulate PE when experiencing a low rather than high level of PE. Recent studies have demonstrated that, when experiencing bad moods, people are more likely to engage in mood-enhancing activities, such as doing sport, going out in nature, or chatting with a friend, whereas useful but mood-decreasing activities are pursued when the current mood is already high (Quoidbach, Sugitani, et al., 2019; Taquet et al., 2016). In another study, individuals were found to seek pleasant social relationships when feeling bad and prefer solitude or less pleasant social interactions when feeling good (Quoidbach, Taquet, et al., 2019).

In sum, despite the growing evidence highlighting the importance of PE in mental health, there are still many unanswered questions about the regulatory mechanisms underlying positive states. Although positive emotion regulation has received increasing attention in the past decade, the effects of its momentary use are still unexplored. More specifically, whereas the findings about the affective outcomes of positive emotion regulation are quite consistent, the effect of momentary PE on subsequent strategy implementation is still largely unknown. Importantly, momentary PE not only reflect the experience of a pleasant state, but they also represent an important source of information that drives regulatory mechanisms. Thus, exploring the reciprocal influences between PE and positive emotion regulation is important, in order to disentangle the factors determining past, present, and future positive affective experiences.

The current study

The aim of the current study was to explore the reciprocal interconnection between PE and positive emotion regulation in daily life. To do so, we asked 85 undergraduate students to use a two-week Ecological Momentary Assessment (EMA) to report their momentary levels of PE and rate their adoption of positive strategies to regulate ongoing PE. Based on Gross' extended model (Gross, 2015) and its application to the regulation of ongoing PE (Quoidbach et al., 2015), three categories of strategies were explored: Attentional deployment (AD), cognitive change (CC), and response modulation (RM).

The first objective of this study was to explore which of the two aforementioned theories best explains the association between PE and positive emotion regulation. According to the broaden-and-build theory, the experience of intense PE fosters broadening mechanisms and the use of broad-minded positive strategies. In this case, and consistent with previous findings, high levels of PE should determine an increase in the subsequent use of positive strategies. In contrast, the hedonic flexible principle states that low mood, compared to high mood, predicts the implementation of strategies to enhance momentary affect. Thus, a lower level of PE at one point in time should predict an increase in the use of positive emotion regulation from that time to the next.

The second objective of this study was to explore the unique impact of six positive emotion regulation strategies on subsequent PE. Consistent with the ample evidence showing the beneficial affective outcomes of positive regulation, we expected to find that increased use of positive strategies at one point in time predicted enhanced PE in the following assessment.

Finally, we investigated whether the reciprocal influence between PE and positive emotion regulation changed significantly depending on the strategy category (AD, CC, RM).

MATERIAL AND METHODS

Inclusion criteria and sample

In order to exclude the potential confounding effect of depression, which has been shown to be associated with impaired use of savouring strategies and increased adoption of dampening strategies (i.e., the tendency to decrease the intensity of ongoing PE) (Li et al., 2017; J. V. Wood et al., 2003), individuals with a score above 14 on the Patient Health Questionnaire (PHQ-9) (Kroenke et al., 2001) were excluded from the study (i.e., individuals with moderate to severe depressive conditions) (n=6). The final sample included 85 undergraduate students recruited at Jaume I University (Castellon, Spain). The sample was composed of 67 females (77.9%) and 19 males (22.1%), and their ages ranged between 18 and 36 years (M: 22.07; SD:3.45).

This study was approved by the ethics committee of Jaume I University (Spain) (certificate number: CD/57/2019), and informed consent was obtained from each participant.

Material

Participants were prompted three times a day for two weeks to complete a brief questionnaire on their smartphone, reaching a total of 42 potential observations for each participant. Consistent with previous studies, this sampling frequency has been shown to be adequate for the assessment of daily emotion regulation patterns (Heiy & Cheavens, 2014), and it leads to good compliance levels (Colombo, Fernandez Alvarez, et al., 2020; Colombo, Suso-Ribera, et al., 2020). In the present study, 2726 out of 3570 possible assessments were obtained, thus revealing a mean compliance of 76.34% (SD=18.12), ranging between 33% and 100%.

At each prompt, participants were first asked to rate the momentary intensity of seven PE on a Likert scale from 1 to 5 (1 = Not at all, 5 = A lot). The seven emotions were selected in order to include both low- (hope, serenity, pride, gratitude) and high-arousal (happiness, amusement, excitement) positive emotions (Russell, 1980), which is consistent with the evidence showing the influence of positive regulation on both active and de-active positive affect (Nezlek & Kuppens, 2008). To obtain a general indicator of PE, the seven positive emotions rated at each assessment were averaged. The composite score obtained showed high internal consistency at both the between- (□=.96) and within-individual levels (□=.86).

Participants were also asked to rate the momentary adoption of six positive strategies on a 0-100 scale (0= no adoption; 100= high adoption). Strategies were selected based on Gross' extended model (Gross, 2015b; Quoidbach et al., 2015), with the aim of exploring three categories of positive emotion regulation: AD, CC, and RM. Due to the lack of validated questionnaires to assess positive strategies, ad-hoc single items were created, as is common in ecological studies exploring emotion regulation (see for example: Brans et al., 2013; Brockman et al., 2017; Pavani et al., 2016; Quoidbach, Sugitani, et al., 2019). These items were mostly inspired by a previous study (Heiy & Cheavens, 2014).

AD refers to the set of strategies specifically designed to direct one's attention in order to savour a pleasant emotional state. In the present study, participants were asked to rate the momentary use of mindfulness, i.e., focusing the attention on the present situation ("I'm trying to be focused on the present and concentrate on how good I feel"), and stimulus control, i.e., avoiding other negative thoughts to focus on the pleasant affective state ("I'm trying to avoid all negative thoughts and stressors in order to focus and make the most of my positive emotions"). According to the previous literature, both strategies can play a role in daily positive affect. Indeed, a growing body of literature has found mindfulness use to be associated with more intense and frequent positive emotions (Brown & Ryan, 2003; Erisman & Roemer, 2010; Quoidbach et al., 2010), which in turn has been shown to increase next day mindfulness levels (Brockman et al., 2017). Furthermore, Heiy et al. (2014) recently found stimulus control to be a frequently adopted strategy that positively impacts general mood.

CC refers to the attempt to influence the meaning of a positive stimulus, for instance, by reappraising a positive situation as a special moment or by increasing the value attributed to a positive event. Generally, previous research has shown that reappraising a positive stimulus (Giuliani et al., 2008; Wang et al., 2014) and increasing the perceived value of a positive experience (Plassmann et al., 2008) are associated with enhanced levels of positive emotions. Accordingly, we assessed participants' use of broadening, i.e., thinking about the current pleasant state as part of a worthy life ("I'm thinking about all the good things I have and that are happening in my life as well"), and counting one's blessings, i.e. thinking about the special moments by not taking them for granted ("I'm thinking about how lucky I am to live in this moment and feel so good"). Whereas one's perceived satisfaction and fulfilment in different aspects of life have been found to significantly affect emotional well-being (Frisch, 2006), Wood et al. (2010) showed the significant effect of counting one's blessings on increasing positive emotions.

Finally, RM includes strategies to influence the physiological, experiential, or behavioural response to a positive state, which usually involve expressing the emotion either physically or verbally. Indeed, the accumulated literature has suggested that expressing positive emotions both physically (e.g., facial display, (Mori & Mori, 2009; Neuhoff & Schaefer, 2002)) and verbally (Gable et al., 2004a; Langston, 1994) can boost the experience of the associated positive state. Consistently, participants were asked to rate the momentary use of emotion expression ("I'm trying to express and emphasize my emotions on the outside by showing them") and sharing ("I'm sharing my positive emotions with other people, for example, with my friends, partner, and/or family").

Change scores were calculated for each emotion regulation strategy, indicating whether a strategy was used more or less at a point in time (t1), compared to the previous assessment (t0). These scores were calculated to analyse to what extent PE at t0 influenced positive emotion regulation at t1. Change scores were computed through linear mixed-effects models with maximum likelihood by taking the residuals of a model in which the strategy at t1 was regressed on itself at t0. In addition, strategy type was also taken into account in the analyses in order to further explore the relationship between PE and positive regulation depending on the intrinsic nature of the strategies adopted. To do so, strategies were averaged based on their category. This made it possible to obtain three new variables that reflected the intensity of use of each type of strategy. Correlations for each pair of strategies were performed at the within-individual level to assess the internal consistency of the new variables (AD: $r=.556$, $p<.001$; CC: $r=.732$, $p<.001$; RM: $r=.630$, $p<.001$).

Procedure

Participants were recruited via social media and poster advertisements placed in different buildings at the university. Students willing to participate were invited to visit the laboratory to receive more details about the study design and sign the informed consent.

The EMA phase lasted 14 days. Participants received three daily semi-random prompts (between 9:30 - 14:00; 14:00 - 18:30; and 18:30 - 23:00) to complete the momentary assessment through the data collection program Qualtrics. To prevent backfilling, participants were given sixty minutes to access the survey; after that period of time, the assessment was marked as missing. During the entire study, participants could contact a researcher on the team to resolve technical issues.

At the end of the study, participants were invited to return to the laboratory for a debriefing session. Participants who replied to at least 65% of the total EMA assessments received a monetary remuneration of 10 euros.

Statistical analyses

The datasets of the analyses and the R code are contained in an open-access file available in OFS at https://doi.org/10.17605/OSF.IO/TEUBR. The data analytic strategy followed three steps that are similar to the steps found in previous ecological momentary assessment studies on reciprocal influences between emotions and actions (Brans et al., 2013; Pavani et al., 2016; Quoidbach, Sugitani, et al., 2019).

In an initial data preparation step, all the variables of interest were person-mean-centred to enable the examination of within-individual processes. Then, to analyse the relationships between variables assessed at two consecutive time points (t0 and t1), data were lagged. This meant deleting assessments that were not directly preceded or followed by another completed assessment (n=558). Consequently, each row of the data frame analysed contained participants' responses to two consecutive assessments (see the "Data.csv" file at https://doi.org/10.17605/OSF.IO/TEUBR).

The second step in the analytic strategy was to examine the effect of the PE felt at a given time on the subsequent implementation of positive strategies. To this end, a series of linear mixed-effects models containing one random intercept per participant were estimated using maximum likelihood with the R "lmerTest" package (Kuznetsova et al., 2017). Linear mixed-effects models were computed to take into account the hierarchical nature of the data (i.e., several assessments completed by several individuals). In this step, six models were computed (i.e., one per strategy). The dependent variable entered in each model was the change in the strategy of interest from t0 to t1, whereas the main independent variable was PE at t0. Two other independent variables were also included to neutralize their possible confounding effects: the use of each strategy at t0 and PE at t1. The inclusion of this latter control variable makes it possible to capture the part of the effect of PE at t0 on subsequent behaviours that is not attributable to the effect of PE at t0 on subsequent levels of PE.

The third step was to examine the reciprocal effect of strategy use on PE. To this end, another linear mixed-effects model was computed that contained PE at t1 as the dependent variable and change in the use of each strategy from t0 to t1 as independent variables. PE at t0 was also included as a control variable to neutralize the so-called regression towards the mean effect. Taken together, the second and third steps made it possible to analyse similar phenomena to those analysed in previous studies on reciprocal influences between emotions and actions in everyday life (i.e., the effect of emotions at one time on the actions occurring between this time and a following time, and the effect of the actions performed within this time interval on concurrent emotional changes (e.g., Brans et al., 2013; Pavani et al., 2016; Quoidbach, Sugitani, et al., 2019), without resorting to their semi-retrospective assessment of strategy use.

We also explored whether the relationships between PE and positive emotion regulation significantly changed depending on the type of strategy. To this end, the dataset on which our analyses were based was restructured to obtain a data frame where each row contained a participant's responses to two consecutive assessments for one strategy type (e.g., AD). In this restructured data frame, each pair of consecutive assessments completed consisted of three rows (i.e., one for the intensity of the use of AD strategies, one for the intensity of the use of CC strategies, and one for the intensity of the use of RM strategies, see the "Data_ST.csv" file at https://doi.org/10.17605/OSF.IO/TEUBR). Then, the two types of linear mixed-effects models mentioned for the second and third steps were computed again, but with slight modifications. A first model was designed to examine whether the effect of PE at t0 on the change in strategy use depended on the type of strategy considered. The dependent variable was change in strategy use from t0 to t1, whereas the independent variables were PE at t0 and the interaction with strategy type (i.e., a categorical variable with three modalities: AD, CC, and RM), with PE at t1 as a control variable. A second model was designed to examine the effects of change in strategy use on subsequent PE depending on the type of strategy considered. This model included PE at t1 as the dependent variable, whereas the independent variables were change in strategy intensity, its interaction with strategy type, and PE at t0.

RESULTS

Descriptive statistics

Table 6.1 shows correlations between the within-subject variables of interest in order to provide an initial general overview of the association between PE and positive emotion regulation.

A moderate level of PE throughout the two-week study was reported (*M*=2.76, *SD*=.75). Descriptively, mindfulness was the most widely used strategy (*M*=55.37, *SD*=20.26), followed by stimulus control (*M*=51.88, *SD*=21.47), broadening (*M*=50.96, *SD*=21.77), counting blessings (*M*=50.66, *SD*=21.49), emotional expression (*M*=46.11, *SD*=22.48), and sharing (*M*=44.13, *SD*=23.53). AD strategies (*M*=53.63, *SD*=20.24) were adopted to a greater extent than CC (*M*=50.80, *SD*=21.55) and RM strategies (*M*=45.14, *SD*=22.62). Overall, a more intense adoption of positive strategies was associated with higher levels of experienced PE.

Table 6.1: Correlations between strategy use and PE an the within-individual level. (PE: positive emotions; AD: attentional deployment; CC: cognitive change; RM: response modulation). *p<.05, ** p<.01, ***p<.001

	1	2	3	4	5	6	7	8	9
1. PE	1.00								
2. Mindfulness	.538***	1.00							
3. Stimulus control	.400***	.556***	1.00						
4. Broadening	.489***	.601***	.565***	1.00					
5. Count blessings	.504***	.625***	.558***	.732***	1.00				
6. Emotion expression	.422***	.462***	.368***	.474***	.463***	1.00			
7. Sharing	.406***	.422***	.377***	.468***	.452***	.630***	1.00		
8. AD	.520***	.854***	.891***	.646***	.650***	.454***	.444***	1.00	
9. CC	.527***	.653***	.591***	.923***	.931***	.497***	.489***	.686***	1.00
10. RM	.454***	.487***	.409***	.514***	.500***	.896***	.899***	.494***	.539***

The influence of experienced positive emotions on positive emotion regulation

The first aim of the study was to explore the effects of PE on positive emotion regulation. In a series of linear mixed-effects models (**Table 6.2**), we therefore examined how PE at t0 influenced changes in each of the strategies at t1, controlling for the use of each strategy at t0 and for PE at t1.

Results showed that the effects were all negative and significant. In other words, the less individuals felt positive emotions at t0, the more they tended to enhance the use of mindfulness (b=-0.16, SE=.023, p<.001), stimulus control (b=-0.105, SE=.025, p<.001), broadening (b=-0.075, SE=.024, p<.01), counting blessings (b=-0.124, SE=.023, p<.001), emotion expression (b=-6.47e-02, SE=2.5e-02, p<.001), and sharing (b=-6.9e-02, SE=2.5e-02, p<.001) from this time to the next. Therefore, our results seem to confirm the hypothesis postulated by the hedonic flexibility principle, suggesting that the experience of low PE is likely to motivate individuals to subsequently increase the use of positive strategies in order to upregulate positive affective states.

The influence of positive emotion regulation on experienced positive emotions

The second aim of the study was to explore the affective outcomes of positive emotion regulation. We hypothesized that strategy change at t0 would predict PE at t1 and, more specifically, that an increase in the use of positive strategies would be associated with a greater experience of PE in the subsequent assessment.

To test this hypothesis, a linear mixed-effects model was performed that included PE at t1 as the dependent variable. Confirming our hypothesis, all the strategies were found to positively predict PE at t1, and, thus, an increase in the use of positive strategies at one time enhanced the experience of PE in the subsequent assessment (mindfulness: b=2.84e-01, SE=2.24e-02, p<.001; stimulus control: b=4.46e-02, SE=2.10e-02, p<.05; broadening: b=2.27e-02, SE=2.43e-02, p<.001; counting blessings: b=1.25e-01, SE=2.56e-02, p<.001; emotion expression: b=1.92e-01, SE=2.18e-02, p<.001; sharing: b=9.26e-02, SE=2.17e-02, p<.001), controlling for PE at t0 (b=2.1e-01, SE=1.6-02, p<.001).

Table 6.2: Results of the six linear mixed-effects models predicting change in strategy use from PE at t0. (PE: positive emotions). **p*<.05, ** *p*<.01, ****p*<.001

	Mindfulness		Broadening		Stimulus control		Counting blessings		Emotion expression		Sharing	
	b	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
FIXED EFFECTS												
PE (t0)	-.16***	.023	-.11***	.025	-.075**	.023	-.123***	.023	-6.5e-02**	2.5e-02	-6.9e-02**	2.5e-02
Mindfulness (t0)	-.082**	.025	.038	.027	.054*	.026	.020	.026	5.06e-02	2.7e-02	2.9e-02	2.8e-02
Stimulus control (t0)	.012	.023	-.067**	.025	.043	.024	.024	.023	3.9e-03	2.5e-02	2.9e-02	2.49e-02
Broadening (t0)	.069*	.028	.024	.03	-.14***	.028	.096***	.028	2.7e-02	3.1e-02	-9.7e-03	3.1e-02
Counting blessings (t0)	.034	.028	.032	.031	.04	.029	-.124***	.029	-1.9e-02	3e-02	-1.4e-02	3.1e-02
Emotion expression (t0)	.038	.023	-.007	.025	.051*	.024	.025	.024	-7.2e-02**	2.5e-02	1.8e-02	2.5e-02
Sharing (t0)	.014	.023	.023	.025	-.016	.024	.027	.024	5.4e-02*	2.5e-02	-3.4e-02	2.5e-02
PE (t1)	.55***	.019	.40***	.02	.48***	.019	.502***	.019	4.4e-01***	2.03e-02	4.1e-0***	2.05e-02

The moderating role of strategy type

We finally explored whether the association between PE and positive emotion regulation significantly changed depending on the type of strategy used.

A first linear mixed-effects model investigated whether the type of strategy affected the impact of PE at t0 on strategy use at t1 (**Table 6.3**). However, no significant interactions were observed.

Table 6.3: Results of the linear mixed-effect model predicting the effect of positive emotions at t0 on change in strategy use at t1, moderated by the type of strategy (PE: positive emotions; CC: cognitive change; RM: response modulation). *p<.05, ** p<.01, ***p<.001

	b	*SE*	*df*	*t*
FIXED EFFECTS				
PE (t0)	-.174***	.019	6546	-9.31
CC	-.103***	.024	6546	-4,29
RM	-.283***	.025	6546	-11.53
Strategy intensity (t0)	-.010	.011	6546	-.91
PE (t1)	.464***	.011	6546	43.37
PE (t0) * CC	.028	.025	6546	1.13
PE (t0) * RM	.045	.025	6546	1.83

We, therefore, examined whether strategy type influenced the effect of change in strategy use on subsequent levels of PE (**Table 6.4**).

Table 6.4: Results of the linear mixed-effect model predicting the effect of change in strategy intensity at t0 on PE at t1, moderated by the type of strategy (PE=positive emotions; CC=cognitive change; RM=response modulation). *p<.05, ** p<.01, ***p<.001

	b	*SE*	*df*	*t*
FIXED EFFECTS				
Change in use intensity (t1)	.564***	.021	6486.91	26.89
CC	.058*	.025	6439.02	2.36
RM	.132***	.024	6440.36	5.33
PE (t0)	.252***	.01	6538.48	4.06
Change in use intensity (t1) *CC	-.054	.029	6524.83	-1.89
Change in use intensity (t1) * RM	-.161***	.027	5933.7	-5.92

Interestingly, results revealed that the type of strategy moderated the association between the change in strategy use and PE. More specifically, there was a significant interaction between change in strategy use and RM (b=-0.161, SE=.027, p<.001), and a close-to-significance trend in the interaction between change in strategy intensity and CC (b=-0.054, SE=.027, p=.059). As **Figure 6.1** shows, the use of RM to enhance PE was less effective than the adoption of AD strategies.

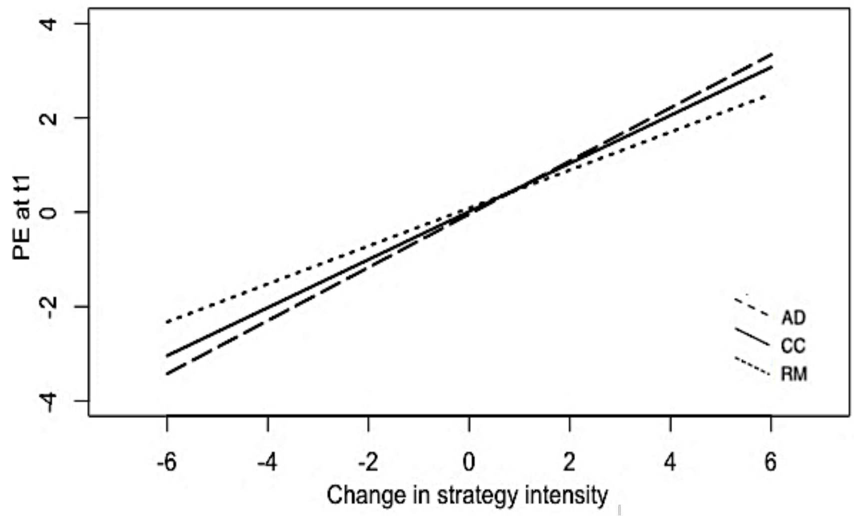

Figure 6.1: Graphical representation of the effect of change in strategy use on subsequent positive emotions as moderated by the type of strategy (PE=positive emotions; AD=attentional deployment; CC=cognitive change; RM=response modulation)

DISCUSSION

To date, although the use of strategies to regulate negative emotions has been extensively explored, the regulation of positive emotional states in everyday life has received little attention. The aim of the current study was to deepen our knowledge about PE and its underlying regulatory mechanisms. Overall, we showed that PE determines positive emotion regulation, which in turn affects subsequent levels of PE, thus confirming the existence of a reciprocal influence between momentary PE and positive emotion regulation.

First, the results showed that PE at t0 predicted positive emotion regulation at t1 and, more specifically, that the less individuals felt PE at one time, the more they tended to increase the use of positive strategies from this point in time to the next. Experiencing low levels of PE is, therefore, likely to shift one's efforts towards implementing strategies to reach a more positive emotional state. These findings are consistent with the hedonic flexibility principle (Quoidbach, Sugitani, et al., 2019; Simon, 1967), suggesting that individuals are likely to be motivated to upregulate PE as a consequence of low momentary affect. This regulatory mechanism might be seen as a highly adaptive process that can compensate for the lack of PE through an increased use of positive strategies, regardless of their nature (i.e., attentional, cognitive, or behavioural).

Moreover, the findings of the present study might also be understood in light of the affective baseline theory (Kuppens et al., 2010), which postulates the existence of a baseline functioning of an individual's affective system. According to this theory, although fluctuations around the home-base are the natural consequence of internal and external life events, affect is constantly brought back to the baseline by an attractive component consisting of regulatory mechanisms. Thus, the experience of low PE might encourage individuals to implement strategies that induce a return to the baseline, which has been shown to be defined by a slightly positive valence (Cacioppo & Berntson, 1999).

In spite of being coherent with the hedonic theories, our results diverge from previous studies that showed increased implementation of positive strategies as a consequence of high levels of positive affect (Brans et al., 2013; Heiy & Cheavens, 2014; Pavani et al., 2016). A possible explanation for these divergent results might be found in the EMA design. All the previous studies adopted a momentary evaluation of the affective state, but a partially retrospective assessment of emotion regulation, asking participants to rate the strategies used since the last prompt (i.e., in the previous few hours). Thus, when analysing the effect of emotions at one point in time on subsequent strategy use, emotion regulation strategies were closer in time to the emotions than in our study, which assessed emotion regulation at exactly the same time as PE. In fact, there is evidence showing that soon after an emotion, mood-congruent processes take place, whereas mood-incongruent processes tend to follow (Forgas & Ciarrochi, 2002). Furthermore, the two theories suggested by the previous literature could be reconciled. The broaden-and-build theory states that the experience of PE encourages the building of adaptive resources and boosts the creation of coping skills, which in turn foster well-being. Accordingly, this "resource-building process" might involve mechanisms that help to enhance affect when experiencing low PE and maintain a positive mood (i.e., consistent with hedonic theories), which in turn would promote psychological well-being and resilience in the long term.

The second aim of the study was to explore the unique affective outcomes of positive emotion regulation. Confirming our hypothesis, an increase in the use of all six strategies resulted in enhanced PE in the subsequent assessment. In previous studies, trait savouring was found to be associated with greater happiness and well-being (Quoidbach et al., 2010), whereas state savouring was shown to predict increased positive affect (Jose et al., 2012). Therefore, these results are consistent with the previous literature and support the adaptive role of positive emotion regulation in emotional well-being. Interestingly, the tendency to adopt positive strategies to increase PE was less effective when using RM strategies (e.g., sharing and emotional expression).

Sharing positive experiences has been shown to improve one's perception in the eyes of others, leading to increased self-esteem (Gable et al., 2004b) and life satisfaction (Quoidbach et al., 2010). This strategy might, therefore, indirectly increase PE by mainly targeting other dimensions of an individual's well-being. Furthermore, the benefits of sharing have been shown to depend on how the recipient responds to the news (actively/constructively or passively/destructively) (Gable et al., 2004b), which could further justify the mitigated effects of this strategy on momentary PE found in our study. In contrast, emotional expression refers to the verbal or nonverbal expression of an ongoing emotion (Gross, 1998b), which makes it possible to rapidly and adaptively react to environmental threats and opportunities (Ekman, 1992). Emotional expression may foster PE, especially in the short term (i.e., soon after the emotion is produced), thus showing reduced effects in the long term. As suggested in a previous study (Quoidbach et al., 2010), positive emotion regulation might not only increase PE. Instead, each strategy may target different dimensions of the person's emotional well-being, thus involving different affective outcomes. However, further studies are needed to disentangle the unique affective consequences of positive emotion regulation.

Although this study sheds new light on the mechanisms underlying the experience of PE, we acknowledge several limitations that could be addressed by future research. First, our study involved a sample of 85 healthy undergraduate individuals, and future studies are needed to explore the reciprocal influence between PE and positive emotion regulation in a more diverse sample. Second, we excluded participants who presented moderate-to-severe depressive symptoms. It is possible that the affective patterns observed in the present study cannot be extended to samples of patients suffering from an emotional disorder (Carl et al., 2013), who are typically prone to dampening rather than savouring PE (Li et al., 2017; J. V. Wood et al., 2003). Reasonably, an abnormal functioning of this mechanism might be observed in this population, which could be defined by a lack of motivation or capacity to implement positive strategies despite experiencing low PE, or by reduced efficacy in using positive strategies to increase PE levels. Future studies should confirm this hypothesis. Third, our study specifically focused on PE, without studying the role of negative affect on positive emotion regulation. A growing body of evidence shows that positive and negative affect do not lie on two opposite ends of a bipolar scale; instead, they can be experienced simultaneously (Berrios et al., 2015; Larsen & McGraw, 2011). In our study, we found that the experience of low PE was associated with a greater use of positive strategies, which might suggest that upregulating PE also serves as a mechanism to repair mood (Folkman & Moskowitz, 2004). Nevertheless, the absence of a variable assessing momentary negative emotions keeps us from confirming this hypothesis, which should be addressed in future studies. Fourth, the daily EMA only included the assessment of six positive strategies. On the one hand, there is evidence that people's repertoire for dealing with PE includes a wider range of strategies that were not explored in this study (Cheavens, 2014). On the other hand, the use of maladaptive strategies in response to positive states (e.g., dampening) was not taken into consideration, thus limiting the findings of the present study to the mechanisms underlying the upregulation of PE. Finally, the use of ad-hoc single items to assess a multifaceted construct such as emotion regulation might not fully capture the complexity of this process. In addition to the fact that the use of ad-hoc items is common in EMA studies (see for example: Brans et al., 2013; Brockman et al., 2017; Pavani et al., 2016; Quoidbach, Sugitani, et al., 2019), the validated questionnaires available to assess positive emotion regulation mainly measure an individual's tendency to savour positive emotions (see for example (Bryant, 2003; Feldman et al., 2008; Nelis et al., 2011)), rather than measuring to what extent specific strategies are adopted. The lack of validated items for the assessment of momentary positive regulation led us to create our own single items. Moreover, there is evidence that long EMA questionnaires usually lead to higher perceived burden (Eisele et al., 2020), which further supports the decision to include only a few items to assess emotion regulation. Indeed, the inclusion of a broader set of items could have resulted in decreased compliance and increased participant burden, thus affecting the quality of the data collected. As Trull and Ebner-Premier (2020) recently stated, EMA is still a field with several methodological aspects that remain unclear. The guidelines presented by these authors represent an inflection point to more accurately design future studies.

Despite these limitations, our research adds to the previous literature by extending our knowledge about PE and the underlying regulatory mechanisms. More specifically, we showed that low levels of PE determine an increase in the use of strategies to upregulate PE, which in turn results in increased mood. Although further studies are needed to confirm these findings, our study sheds new light on the importance of PE for emotional well-being, and it opens up new avenues to understand the dysfunctional regulation of positive affective states in emotional disorders.

DISCLOSURE STATEMENT

No potential competing interest was reported by the authors.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF at https://doi.org/10.17605/OSF.IO/TEUBR.

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CHAPTER 7

Affect recall bias: Being resilient by distorting reality

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Affect recall bias: Being resilient by distorting reality

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ABSTRACT

Background: According to a growing body of literature, people are quite inaccurate in recalling past affective experiences. Nevertheless, the mechanism underlying this recall bias (i.e., the tendency to overestimate and/or underestimate positive or negative past emotional experiences) remains unclear, and its association with mental health has not been studied yet. Methods: We adopted a smartphone-based Ecological Momentary Assessment (EMA) to monitor daily affect (n=92) and investigate the association between affect recall bias, mental health and resilience. Results: While the tendency to overestimate negative affective (NA) experiences was observed in participants reporting mild depressive symptoms, positive affect (PA) overestimation as compared to PA underestimation was associated with better mental health (i.e. higher psychological well-being and lower depressive and anxiety symptoms) through the enhancement of resilience. Furthermore, positively biased participants (i.e. PA overestimators) benefited from greater well-being, even when compared to accurate individuals. Conclusions: While people appear to use retrospective PA overestimation as a strategy to enhance well-being and resilience, they are not likely to underestimate past negative experiences to feel better. Accordingly, owning an optimistic vision of the past may represent an adaptive "distortion" of reality that fosters people's mental health. The clinical implications of cultivating PA and learning strategies to regulate both negative and positive emotions are discussed.

Keywords: Cognitive bias; affect recall bias; ecological momentary assessment; well-being

INTRODUCTION

In recent decades, one of the most studied constructs in the psychological field has been represented by emotion regulation (ER)(Fernández-Álvarez, Cipresso, Colombo, Botella, & Riva, 2018), which refers to the process of down-regulating or up-regulating ongoing emotions in order to achieve desirable states (Gross, 1998, 2015). Although the previous literature mainly investigated ER in relation to negative emotions, there is now increasing evidence showing the importance of positive affect (PA) in many aspects of our life (Colombo et al., 2020), and highlighting the importance of cultivating positive emotions (Carl, Soskin, Kerns, & Barlow, 2013; Diener & Seligman, 2002; Lyubomirsky, King, & Diener, 2005; Tugade & Fredrickson, 2007). Accordingly, people adopt up to five different categories of strategies to regulate positive emotions (Gross, 2015), which can be implemented either before, during or after the emotion-generation process (Quoidbach, Mikolajczak, & Gross, 2015). More specifically, the use of strategies to increase PA after the occurrence of an event has been extensively supported, and it is now widely accepted that recalling positive memories is an effective strategy to upregulate positive emotions (Mitchell, Thompson, Peterson, & Cronk, 1997; Wilson & Ross, 2003), enhance emotional well-being, and increase happiness (Bryant, Smart, & King, 2005; Quoidbach, Berry, Hansenne, & Mikolajczak, 2010).

Nonetheless, the emotions experienced during an event do not necessarily match with the emotions prompted by the associated memory: The intense sadness experienced after losing a job, for instance, might be remembered less intensely (i.e. underestimation) or more intensely (i.e. overestimation) sometime later. This phenomenon, called recall bias, has received increasing attention in recent decades because of its correlates with adjustment to life events (Skoronski, 2010; Walker & Skowronski, 2009). Hedges and colleagues (1985) first showed that people tend to overestimate experienced levels of PA and negative affect (NA) when asked to retrospectively recall their general mood (i.e., not in relation to a specific event). In recent years, different studies have confirmed this overestimation bias in recalling past affect (Ben-Zeev, Young, & Madsen, 2009; Colombo et al., 2019; Kardum & Tićac Daskijević, 2001; Thomas & Diener, 1990; Wirtz, Kruger, Scollon, & Diener, 2003), and they have pointed to different factors affecting this mechanism, including beliefs, event reappraisal, contextual information, and personality traits (Levine, Prohaska, Burgess, Rice, & Laulhere, 2001; Robinson & Clore, 2002; Safer, Levine, & Drapalski, 2002). Whereas the tendency to overestimate negatively-valenced emotions has been interpreted as an adaptive evolutionary mechanism to increase the salience of threatening events, which is essential for survival (Miron-Shatz, Stone, & Kahneman, 2009), it is still not clear whether the presence of a bias in recalling positive emotional experiences may play a role for mental health.

According to the Positive Illusion Theory, enhanced self-evaluations, exaggerated perceptions of control, and unrealistic optimism are adaptive mechanisms that improve people's happiness, satisfaction in life, and well-being (Brookings & Serratelli, 2007; Taylor & Brown, 1988; Taylor & Brown, 1994). Indeed, holding positive illusions is likely to increase the perceived abilities to deal with stressors, thus enhancing motivation and enthusiasm while carrying out actions (Taylor & Gollwitzer, 1995). This, in turn, would make it easier to reappraise negative events and implement successful coping strategies (Brown, 1993). Likewise, holding an optimistic past-oriented disposition (i.e., overestimating past affective experiences) may represent a sort of strategy to maintain and upregulate positive emotions over time (Bryant, 1989), which in turn could increase people's resilience and perceived coping skills: That is, the set of personal qualities that enable an individual to thrive in the face of adversity (Connor & Davidson, 2003). The cultivation of positive emotions has been widely found to be an essential coping skill that helps people to deal with daily stressors, with important implications for mental health (Tugade & Fredrickson, 2007). Accordingly, the habitual use of savoring strategies has been associated with higher levels of happiness and well-being (Jose, Lim, & Bryant, 2012; Quoidbach et al., 2010), whereas dampening (i.e. the use of strategies to downregulate positive affective experiences) has been linked to prolonged NA levels (Li et al., 2017; Wood et al., 2003). This could also explain the tendency of depressed patients to retrospectively underestimate PA (Ben-Zeev et al., 2009; Colombo et al., 2019), which may arguably reflect the inability of these individuals to recall positive experiences and upregulate positive emotions (Bryant, 2003).

Together, there is evidence suggesting that people's past-oriented disposition and, more specifically, the way people recall experienced PA, may in itself be a tool to regulate current emotions. Consequently, the presence of a recall bias may have direct consequences for present affective states and, therefore, individuals' mental health status and well-being. In the present study, we explored the potential effects of PA recall bias (i.e. the tendency to retrospectively overestimate or underestimate positive affective experiences) and NA recall bias (i.e. the tendency to retrospectively overestimate or underestimate negative affective experiences) on mental health outcomes (depressive symptoms, anxiety symptoms, and psychological well-being), and we investigated resilience as a potential mechanism (i.e., mediator) explaining this relationship. To do so, we asked participants to self-report their mood during a two-week Ecological Momentary Assessment (EMA) study, and we subsequently asked them to retrospectively recall the experienced PA and NA levels. We anticipate that PA overestimation will positively contribute to well-being and will be associated with increased resilience. More specifically, we hypothesize PA overestimation to positively impact mental health through the enhancement of an individual's resources to cope with daily stressors. Conversely, and consistently with the previous literature (Miron-Shatz et al., 2009), we expect NA overestimation to be an evolutionary rather than coping mechanism and, therefore, not be associated with well-being.

METHODS

Sample

The sample size was calculated considering the correlations as main analyses. Assuming an overall moderate effect size of 0.3, a significance level of 5%, a statistical power of 80%, and a bilateral contrast, the sample size calculation resulted in a sample of n = 82. This study was approved by the ethics committee of Jaume I University (Spain), and informed consent was obtained from all participants.

Data were collected from 97 undergraduate students who were recruited via online advertisements at Jaume I University (Castellon, Spain). In order to exclude possible confounding effects in recalling affective experiences associated with the presence of clinical conditions of depression and/or anxiety, which have been shown to be associated with a negative bias (Wenze, Gunthert, & German, 2012), we excluded participants with a score above 14 on the Patient Health Questionnaire-9 (PHQ-9) (Kroenke, Spitzer, & Williams, 2001) and/or the Generalized Anxiety Disorder-7 (GAD-7) (Spitzer, Kroenke, Williams, & Löwe, 2006), i.e. participants with moderately severe disorders.

Accordingly, 5 participants were excluded from the study, thus resulting in a final sample of n=92. The sample was composed of 69 females (75%) and 23 males (25%). Their mean age was 21.98 years (min=18, max=36; SD=3.41).

Measures

Depressive symptoms: Participants' depressive symptoms were assessed with the Spanish adaptation of the PHQ-9 (Diez-Quevedo, Rangil, Sanchez-Planell, Kroenke, & Spitzer, 2001; Kroenke et al., 2001). The PHQ-9 is a 9-item self-report depression screening measure, that has been shown to have good psychometric properties (Wittkampf, Naeije, Schene, Huyser, & van Weert, 2007). A score above 15 indicates moderately severe to severe depression. In our sample, PHQ-9 internal consistency was α=.797.

Anxiety symptoms: Anxiety symptoms were assessed with the Spanish adaptation of GAD-7 (García-Campayo et al., 2010; Spitzer et al., 2006). The GAD-7 is a quick self-report questionnaire used to identify the presence of minimal, mild, moderate or severe anxiety. This scale has shown good internal consistency and test–retest reliability, as well as convergent, construct, criterion, procedural, and factorial validity (Löwe et al., 2008). In our sample, GAD-7 internal consistency was α=.845.

Retrospective positive and negative affect: Participants were administered the Spanish adaptation (Díaz-García et al., 2020) of the Positive and Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegen, 1988) in order to retrospectively obtain the experienced PA and NA levels during the 2-week EMA study. The PANAS is composed of 10 items to assess PA and 10 items to measure NA. Scores on each scale can range from 10 to 50. The PANAS has been shown to have good construct validity and reliability (Sandín et al., 1999). This scale was administrated at the end of the study and referred to the previous two weeks, i.e. the time during which the daily EMA measures were being collected. In our sample, both PA and NA subscales showed high internal consistency (PA: α=.918; NA: α=.873).

Resilience: Resilience was assessed using the Spanish adaptation (Notario-Pacheco et al., 2011) of the 10-item Connor-Davidson Resilience Scale (CD-RISC-10) (Campbell-Sills & Stein, 2007). This scale is composed of 10 statements to be rated on a 5-point

Likert agreement scale, which aim at measuring resilience during the last 30 days. Higher total scores indicate greater resilience. The CD-RISC10 has been shown to have good internal consistency (Shin et al., 2018; Singh & Yu, 2017). In our sample, the CD-RISC-10 showed high internal consistency (α=.843).

Psychological well-being: Psychological well-being was assessed using the Spanish adaptation (Díaz-García et al., 2020) of Ryff's Psychological Well-Being Scale (Ryff, 2005; Ryff & Keyes, 1995). This scale explores six different constructs of psychological well-being, namely: Autonomy (i.e. an individual's independence from external judgments and social pressures), environmental mastery (i.e. one's ability to take advantage of the environment, opportunities, and activities to achieve personal needs and goals), personal growth (i.e. the sense of continuous self-improvement thanks to life experiences), purpose in life (i.e. the sense of meaning in life, which is defined by clear beliefs, personal values, and aims), positive relations with others (i.e. having satisfactory and trusting relationships, as well as owning an empathetic and warm attitude towards others), and self-acceptance (i.e. a positive attitude toward the current and past self, as well as acceptance of both positive and negative personal qualities). This scale has been shown to have good psychometric properties (van Dierendonck, 2004). In our sample, all subscales demonstrated good internal consistency (self-acceptance: =.810; positive relation: α=.840; autonomy: α=.758; environmental mastery: α=.717; personal growth: α=.785; purpose in life: α=.709).

Ecological Momentary Affect (EMA) measures

Two items about momentary affect were rated on the participant's smartphones using "EMA Móvil", a mobile application that allows to administer ecological assessments via smartphones, and that can easily be monitored and programmed with a web platform (i.e., no programming skills are needed).

At each evaluation, participants were asked to complete two 1-5 point Likert scales (1=not at all; 5=extremely), one evaluating momentary PA ("*To what extent are you experiencing positive emotions at this moment?*") and one evaluating NA ("*To what extent are you experiencing negative emotions at this moment*?").

Procedure

Participants were recruited via poster advertisements placed in different buildings at the university. Students interested in the study were invited to visit the laboratory to receive more information about the investigation. During this first face-to-face meeting, a researcher administered the PHQ-9 and the GAD-7 in order to verify that the candidates met the inclusion criteria. Students who met the eligibility criteria were invited to sign the informed consent to participate in the study. Subsequently, each participant was provided with an identification number to download and access the app.

Over the following 14 days, the mobile application "EMA Móvil" prompted three daily assessments of momentary PA and NA. Participants received one random prompt between 9:30 am and 2:00 pm, one between 2:00 pm and 6:30 pm, and one between 6:30 pm and 11:00 pm (semi-random design). To prevent backfilling, participants were given sixty minutes to open the notification on their smartphone and complete the evaluation. After that period of time, the assessment was marked as missing. Participants were provided with an email to contact the researchers if they needed technical support to use the app.

At the end of the study, participants returned to the laboratory and completed the PANAS, Ryff's Psychological Well-Being Scale and the CD-RISC-10. Participants who completed more than 65% of the total EMA assessments received a compensation of 10 euros. Overall compliance (i.e., percentage of completed assessments) was 77.8% (SD=14.12), and 76 out of 92 participants received the remuneration. Participants who were not remunerated showed compliance rates included between 45% and 65%. No dropouts were observed.

Data analysis

The mean EMA affect score was obtained by calculating the means of the PA ("*experienced PA*") and NA item scores ("*experienced NA*") across the study (42 possible assessments for each participant). To have the same range of scores on the EMA affect measures (each scale has a 1-5 point range) and the PANAS recall measures (each scale originally had a 10-to-50 point range), PANAS recall values were divided by the number of items on the scale (i.e., 10). Thus, the score ranges for both forms of assessment (two weeks of daily, single-item assessments with an app and a single retrospective evaluation using the full-length scale at the end of the study) were the same (1 = lowest affect to 5 = highest affect). In the manuscript, we will use the terms "*recalled PA*" and "*recalled NA*" to refer to the PANAS retrospective scores. To explore affect recall bias and distinguish retrospective affect overestimation from underestimation, delta scores between experienced and recalled PA ("*PA bias*") and between experienced and recalled NA ("*NA bias*") were calculated (bias = recalled affect – experienced affect). Positive delta scores reflected affect overestimation during the retrospective assessment, whereas negative delta values reflected retrospective affect underestimation.

Kolmogorov-Smirnov test was used to assess normality, suggesting that delta PA ($D(89)=0.042$, $p=.200$), Ryff's autonomy subscale ($D(89)=0.072$, $p=.200$) and Ryff's environmental mastery subscale ($D(89)=0.069$, $p=.200$) were normally distributed. Parametric or non-parametric analyses were adopted, accordingly.

To test the construct validity of the EMA affect items, Spearman correlations between experienced and recalled PA, and between experienced and recalled NA were performed. Furthermore, Generalized Estimating Equations (GEE) (Liang & Zeger, 1986) with an unstructured correlation matrix structure and Huber–White standard error estimates were used, which are designed to analyze longitudinal repeated-measures data, and to draw inferences by considering not only variations in affective experience over time within individuals, but also variations in affective experience between individuals. More specifically, PANAS scores were used as predictors of EMA repeated measures.

Experienced and recalled PA and NA scores were compared (Wilcoxon Signed Ranks Test) to test the participants' ability to estimate PA and NA retrospectively. Besides, PA and NA delta scores were compared using a Wilcoxon's Signed Ranks Test.

Correlations analyses were computed between bias scores and mental health outcomes (psychological mental well-being, depression, and anxiety). Linear regressions were also performed to identify PA and NA biases as significant predictors of mental health outcomes.

Mediation models were examined using the PROCESS macro for SPSS (version 23, model 4) which utilizes a bootstrap approach to test the hypothesized indirect effect of the mediators (Hayes, 2012). Each analysis utilized 5000 bootstrap re-samples and significance was determined based on 95% bias-corrected confidence intervals. The models tested included PA bias scores (independent variables) and mental health related outcomes (dependent variables) mediated by resilience. We provide estimates of the indirect effects and associated confidence intervals for each mediator.

Finally, A Two-Step Cluster Analysis was performed in order to identify possible subgroupings based on PA and NA biases. Cluster distance was determined using the log-likelihood measure and the number of clusters was determined automatically using Schwarz's Bayesian Criterion (BIC). The average silhouette measure of cohesion and separation was used to indicate overall goodness of fit, and ANOVA analysis was performed to further confirm the significant differences in PA and NA biases scores among the clusters. A multivariate analysis of variance (MANOVA) was conducted to explore differences in mental health related outcomes among the clusters obtained, and Tukey HSD post-hoc analyses were conducted to explore significant differences.

RESULTS

Affect recall bias and mental health

Detailed information about the recruited sample and the collected measures is reported in **Table 7.1**.

Experienced PA (M=2.69, SD=.68) and recalled PA (M=2.76, SD=.73) were significantly correlated (r=.233, p<.05), as well as experienced (M=1.51, SD=.35) and recalled NA (M=1.92, SD=.65; r=.532, p<.001). Similarly, the NA-PANAS scores significantly predicted NA-EMA repeated measures (B=0.032, SD=.005, 95% CI [.022, .041], p<.001), while the PA-PANAS scores significantly predicted PA-EMA repeated assessments (B=0.033, SD=.008, 95% CI [.018, .049], p<.001).

The comparison of experienced and recalled NA showed a significant mean difference in scores (Z = -6.13, p < .001), revealing higher NA scores in the retrospective assessments (i.e., NA overestimation during the retrospective evaluation). No significant difference was observed when comparing experienced and recalled PA (Z = -.68, p =.496). These and the previous findings support the idea that the bias might take different forms (i.e., interindividual order or average scores) depending on the variable of interest (i.e., PA or NA).

Table 7.1. Frequencies, means, and standard deviations of demographics, compliance and study measures. PA: Positive Affect; NA: Negative Affect; *RYFF'S= Ryff's Psychological Well-Being Scale; GAD-7: Generalized Anxiety Disorder-7; PHQ-9= Patient Health Questionnaire-9; CD-RISC-10= Connor-Davidson Resilience Scale-10*.

Demographics	**n=92**
Age	22.10 (± 3.58)
Sex	69 female / 23 male
Compliance (%)	77.8 (±14.12)
Measures	
Recalled PA	2.76 (± .73)
Recalled NA	1.92 (± .65)
Experienced PA	2.69 (±.68)
Experienced NA	1.51 (±.35)
RYFF'S Self-acceptance	26.53 (± 5.07)
RYFF'S Positive relations	27.69 (± 6.03)
RYFF'S Autonomy	33.26 (± 6.61)
RYFF'S Environmental mastery	26.30 (± 4.81)
RYFF'S Personal growth	34.46 (± 4.50)
RYFF'S Purpose in life	27.19 (± 4.81)
GAD-7	6.52 (± 3.89)
PHQ-9	6.66 (± 3.88)
CD-RISC-10	27.53 (± 7.11)

Statistically significant differences in rank scores were observed between PA bias (M=.074, SD=.85) and NA bias scores (M=.415, SD=.55; Z = -2.94, p < .01). Specifically, PA bias scores were equally distributed below (i.e., PA retrospective underestimation: n=49, M=.701, SD=.568) and above 0 (i.e., PA retrospective overestimation: n=43, M=.641, SD=.465), whereas NA bias scores were more frequently distributed above 0 (i.e., NA retrospective overestimation: n=71, M=.607, SD=.474; NA retrospective underestimation: n=21, M=-.235, SD=.212).

Table 7.2. Bivariate correlations between PA and NA bias and related mental health outcomes. Note that positive bias scores reflect affect overestimation, whereas negative bias scores reflect affect underestimation. **p*<.05, ** *p*<.01, ****p*<.001. *PA: Positive Affect; NA: Negative Affect; PHQ-9: Patient Health Questionnaire-9; GAD-7: Generalized Anxiety Disorder-7; CD-RISC-10: Connor-Davidson Resilience Scale-10*.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1. NA bias	1.00										
2. PA bias	-.062	1.00									
3. Self-Acceptance	-.093	.432***	1.00								
4. Positive relations	-.022	.383***	.564***	1.00							
5. Autonomy	-.002	.192	.494***	.323**	1.00						
6. Environment mastery	-.117	.393***	.702***	.411***	.423***	1.00					
7. Personal growth	-.093	.118	.301**	.258*	.329**	.465***	1.00				
8. Purpose in life	-.222*	.241*	.748***	.289**	.489***	.738***	.353***	1.00			
9. PHQ-9	.291***	-.440***	-.551***	-.489***	-.334**	-.528***	-.153	-.497***	1.00		
10. GAD-7	.185	-.411***	-.539***	-.474***	-.403*	-.554***	-.177	-.429***	.747***	1.00	
11. CD-RISC-10	-.195	.306***	.683***	.474***	.497***	.599***	.343***	.613***	-.459***	-.544***	1.00

PA bias was significantly correlated with the PHQ-9 (r=-.440, p<.001) and GAD-7 scores (r=-.411, p<.001), revealing greater PA retrospective overestimation in association with lower depressive and anxiety symptoms (**Table 7.2**). Similarly, delta NA was positively correlated with depression (r=.291, p<.001) but not with anxiety symptoms (r=.185, p=.077); that is, higher NA retrospective overestimation was associated with more severe depressive symptoms. Together, delta PA (β =-0.441, *SE*=.420, 95% CI [-2.85, -1.18]; p<.001) and delta NA (β =0.203, *SE*=.643, 95% CI [.138, 2.69]; p<.05) significantly predicted PHQ-9 scores, explaining 25% of their variance (R^2=.247; F (2, 89) =14.59, p<.001). Delta PA (β =-0.416, *SE*=.433, 95% CI [-2.76, -1.04]; p<.001) but not delta NA (β =0.150, *SE*=.663, 95% CI [-.267, 2.37]; p=.117) significantly predicted GAD-7 scores (R^2=.203; F (2, 89) =11.37, p<.001).

Correlation analyses between affect recall bias and mental health outcomes are shown in **Table 7.2**. Concerning psychological well-being, delta PA positively correlated with self-acceptance (r=.432, p<.001), positive relations (r=.383, p<.001), environmental mastery (r=.393, p<.001), purpose in life (r=.241, p<.05), and significantly predicted several well-being outcomes (self-acceptance: R^2=.17; F(1, 87)=18.28; β=0.417, *SE*=.57, 95% CI [1.31, 3.58]; p<.001; positive relations: R^2=.13; F(1, 87)=13.16; β =0.362, *SE*=.70, 95% CI [1.14, 3.91]; p<.001; environmental mastery: R^2=.16; F(1, 87)=15.9; β=0.393, *SE*=.55, 95% CI [1.97, 3.28]; p<.001; purpose in life: R^2=.07; F(1, 87) =6.57; β=0.265, *SE*=.58, 95% CI [.332, 2.62]; p<.05). Conversely, delta NA only correlated with purpose in life (r=-.222, p<.05), and it did not predict any of the well-being measures. Overall, these results suggest that overestimating past PA is associated with higher psychological well-being.

Underlying mechanism of the relationship between affect recall bias and psychological well-being

As **Table 7.2** shows, PA bias significantly correlated (r=.306, p<.001) and predicted resilience (R^2=.114; F (2, 87) =11.18, β =0.337, *SE*=.830, 95% CI [1.13, 4.43]; p<.001), whereas no significant association was observed between NA bias and CD-RISC-10 scores (r=-.195, p=.07). In other words, people who overestimated past PA, but not those who underestimated past NA, were more resilient. Furthermore, resilience significantly correlated (self-acceptance: r=.683, p<.001; positive relations: r=.474, p<.001; autonomy: r=.497, p<.001; environmental mastery: r=.599, p<.001; personal growth: r=.343, p<.001; purpose in life: r=.613, p<.001) and predicted psychological well-being (self-acceptance: R^2=.42; F(1, 87)=63.73; β=0.650, SE=.06, 95% CI [.349, .580]; p<.001; positive relations: R^2=.22; F(1, 87)=24.45; β =0.468, SE=.08, 95% CI [.238, .557]; p<.001; autonomy: R^2=.25; F(1, 87)=28.67; β =0.498, SE=.09, 95% CI [.291, .635]; p<.001; environmental mastery: R^2=.33; F(1, 87)=42.37; β=0.572, SE=.06, 95% CI [.269, .505]; p<.001; personal growth: R^2=.11; F(1, 87)=11.14; β =0.337, SE=.06, 95% CI [.086, .340]; p<.001; purpose in life: R^2=.35; F(1, 87) =46.14; β=0.589, SE=.06, 95% CI [.282, .516]; p<.001).

As significant correlations were observed between PA bias, CD-RISC-10, and four well-being measures (i.e., self-acceptance, positive relations, environmental mastery, purpose in life), we explored whether resilience significantly mediated the association between PA bias and well-being using the PROCESS macro for SPSS (version 23, model 4), which utilizes a bootstrap approach to test the hypothesized indirect effect of the mediators (Hayes, 2012). Significant indirect effects are represented in **Figure 7.1**.

According to the results, a significant indirect effect of PA bias on psychological well-being through resilience was observed: Self-acceptance (unstandardized indirect effect=1.14, 95% CI [.44, 1.91]), positive relations (unstandardized indirect effect=.92, 95% CI [.34, 1.63]), environmental mastery (unstandardized indirect effect=.093, 95% CI [.38, 1.53]), and purpose in life (unstandardized indirect effect=1.06, 95% CI [.42, 1.79]). Together, these analyses reveal that resilience partially mediates the effect of PA bias on psychological well-being.

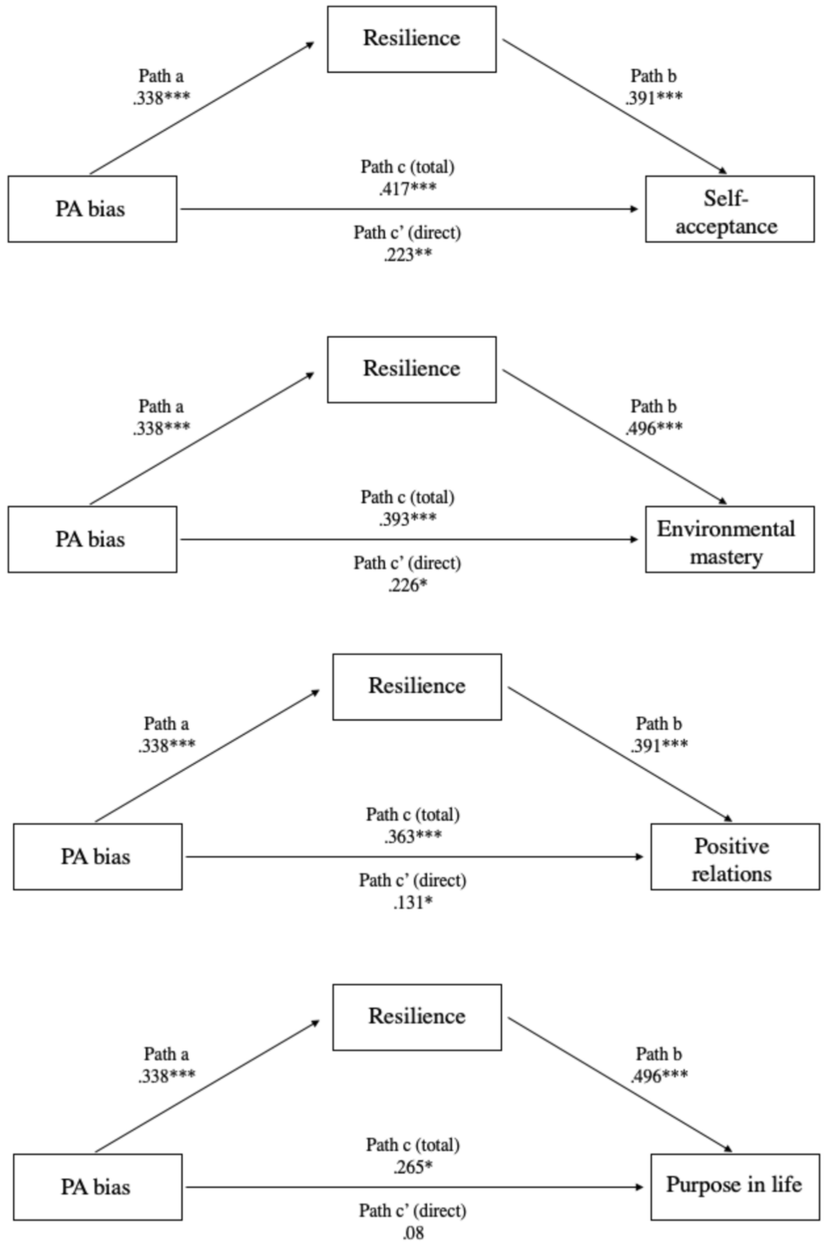

Figure 7.1: Standardized regression coefficients for the relationship between PA bias and well-being measures as mediated by resilience.

The combination of PA and NA recall biases on mental health

A Two-Step Cluster Analysis was conducted to detect potential subgroupings based on PA and NA bias scores (average Silhoutte=0.5). Four clusters were identified, which showed statistically different PA and NA bias values (PA bias: F (3,88) = 89.03, p<.001; NA bias: F (3,88) = 25.31, p<.001): (1) The "*double bias*" cluster (n=19; PA bias=-1.06;

NA bias=.59) included individuals who retrospectively underestimated PA and tended to overestimate NA; (2) the "*negative bias"* cluster (n=30; PA bias=.10; NA bias=.81) included individuals who were quite accurate in retrospectively estimating PA, but overestimated NA; (3) the "*accurate"* cluster (n=21; PA bias=-.06; NA bias=-.18) included individuals who were quite accurate in retrospectively estimating both PA and NA; (4) the "*positive bias"* cluster (n=22; PA bias=1.14; NA bias=.29) included individuals who were quite accurate in retrospectively estimating NA, but that overestimated PA.

MANOVA analyses were performed to explore differences in mental health measures among the four clusters (**Table 7.3**), and a statistically significant effect was observed (Wilks' Lambda=.634, F (24, 226.825) = 1.607, $p < .05$). There were statistically significant differences among the four groups in terms of depressive symptoms (F (3, 93.1) = 7.56, $p<.001$). A Tukey HSD post hoc analysis revealed that the "*positive bias*" group reported significantly lower depression levels compared to the "*double bias*" ($p<.001$) and "*negative bias*" groups ($p<.01$). Significant differences in anxiety scores were also observed among the four groups (F (3, 76.23) = 5.99, $p<.001$). The post hoc analysis indicated that the "*positive bias*" group reported significantly lower anxiety levels than the "*double bias*" (p<.001) and "*negative bias*" clusters ($p<.05$). No significant differences were observed between the "*double bias*" and "*negative bias*" groups.

Besides, significant differences were observed on self-acceptance (F (3, 167.83) = 8.10, $p<.001$), positive relations (F (3, 107.25) = 3.17, $p<.05$), environmental mastery (F (3, 122.39) = 6.25, $p<.001$) and purpose in life (F (3, 77.14) = 3.63, $p<.05$). More specifically, the "*positive bias*" cluster reported significantly higher scores than the "*double bias*" cluster on self-acceptance (p<.001), positive relations (p<.05), environmental mastery (p<.001) and purpose in life (p<.05), and higher values on self-acceptance (p<.05) and environmental mastery (p<.05) when compared to the "*negative bias*" group. Notably, the "*positive bias*" cluster also showed higher well-being scores when compared to the "*accurate group*" on two of the well-being subscales (self-acceptance: p<.01; environmental mastery: p<.01). Again, no significant differences were observed between the "*double bias*" and "*negative bias*" groups.

Table 7.3. MANOVA comparisons of depressive symptoms, anxiety symptoms and psychological well-being in the four clusters. *p<.05, ** p<.01, ***p<.001. *PHQ-9: Patient Health Questionnaire-9; GAD-7: Generalized Anxiety Disorder-7.*

PHQ-9					
			Tukey HSD comparisons (mean difference)		
Group	*Mean*	*SD*	*Double bias*	*Negative bias*	*Accurate*
Double bias	9.00	3.68			
Negative bias	7.18	3.23	-1.82		
Accurate	6.35	3.86	-2.65	-.83	
Positive bias	3.91	3.35	-5.09***	-3.27**	-2.44
GAD-7					
Double bias	8.74	3.91			
Negative bias	6.71	3.46	-2.02		
Accurate	6.30	3.86	-2.44	-.41	
Positive bias	4.05	3.35	-4.69***	-2.67*	-2.25
Self-acceptance					
Double bias	23.42	4.64			
Negative bias	26.71	4.71	3.29		
Accurate	25.25	2.76	1.83	-1.46	
Positive bias	30.14	2.64	6.72***	3.42*	4.89**
Positive relations					
Double bias	25.74	5.76			
Negative bias	27.89	5.67	2.16		
Accurate	26.00	7.63	.26	-1.89	
Positive bias	30.64	3.81	4.90*	2.74	4.64
Autonomy					
Double bias	31.00	6.77			
Negative bias	33.07	5.45	2.07		
Accurate	32.95	7.65	1.95	-.12	
Positive bias	35.73	6.43	4.73	2.66	2.78
Environmental mastery					
Double bias	24.11	3.91			
Negative bias	26.04	4.45	1.93		
Accurate	25.10	5.56	.99	-.94	
Positive bias	29.64	3.57	5.53***	3.60*	4.54**
Personal growth					
Double bias	33.89	4.83			
Negative bias	34.21	4.12	.32		
Accurate	34.35	5.85	.46	.14	
Positive bias	35.3	3.77	1.47	1.15	1.01
Purpose in life					
Double bias	25.32	4.53			
Negative bias	26.54	4.96	1.22		
Accurate	27.00	4.92	1.68	.46	
Positive bias	29.82	3.86	4.50*	3.28	2.82

DISCUSSION

In the present study, we explored affect recall bias by comparing daily to retrospective assessments of affect. Consistent with the previous literature, participants tended to overestimate negative affective experiences. Nevertheless, we did not find the general PA retrospective overestimation that was observed in previous studies (Ben-Zeev et al., 2009; Hedges, Jandorf, & Stone, 1985). Specifically, in our sample, half of the participants were likely to overestimate past PA, but the other half were likely to underestimate it. This divergent result may be due to the novel assessment approach used in the present study (i.e., EMA using a smartphone app) (Colombo, Fernandez Alvarez, Garcia-Palacios, et al., 2019), but also to the characteristics of the recruited sample, which included mildly depressed/anxious students. In relation to the latter, despite reporting a similar NA overestimation pattern, depressed individuals have been shown to overestimate PA to a lesser extent (Ben-Zeev et al., 2009) or even to underestimate it (Colombo et al., 2019). Accordingly, it is possible that the presence of participants with mild symptoms influenced the results observed in this study, increasing the variability of PA bias distribution and leading to an equal number of overestimators and underestimators. This hypothesis cannot be confirmed at this stage and will require further investigation.

An interesting finding in the present study was that PA bias correlated and predicted mental health outcomes. More specifically, PA underestimation was associated with higher depression and anxiety symptoms, which confirms a recent meta-analysis that pointed out no significant differences in the effect sizes of reduced PA levels in depressed and anxious patients (Khazanov & Ruscio, 2016). Additionally, PA overestimation correlated with and predicted higher levels of psychological well-being (self-acceptance, environmental mastery, purpose in life and positive relations), thus supporting the hypothesis that overestimating past positive affective experiences is likely to be an adaptive strategy that positively impacts many dimensions of mental health. Notably, an indirect effect of PA bias on psychological well-being through resilience was observed: In other words, our results suggest that the tendency to overestimate PA does not directly affect mental health, but instead adds up to the set of personal qualities that people use to face adversities (Connor & Davidson, 2003) and indirectly enhances mental health. Consistent with the broaden-and-build theory (Fredrickson & Joiner, 2002; Tugade &

Fredrickson, 2007), these results confirm the idea that cultivating positive emotions is a fundamental tool for the enhancement of resilience (Herrero et al., 2019).

Besides, NA bias correlated with and predicted the presence of mild depressive symptoms. Our results are coherent with a long tradition of research showing the presence of a negative bias in depressed patients, which involves increased elaboration of negative information, recall of more negative memories than positive ones, and difficulties in disengaging from negative information (Gaddy & Ingram, 2014; Gotlib & Joormann, 2010). Accordingly, the tendency to overestimate negative emotional experiences may reflect the negative bias that it is usually reported by depressed people (Craske & Pontillo, 2001), and it may be already observable in individuals with mild symptoms. However, the direction of the association between depression and the negative bias remains an open question, and the correlational nature of our results does not allow to disentangle whether the presence of mild depressive symptoms provokes a negative bias or the other way around. Notably, NA bias only barely correlated with one of the Ryff's well-being dimensions and it was not significantly associated with resilience. In addition, almost all the participants in our sample tended to overestimate past NA, and only a few people underestimated it. In other words, NA bias does not seem to have regulatory or coping functions, but it may rather be a "normal" tendency of individuals. Thus, whereas people appear to overestimate past PA to cope with daily stressors, they are not likely to use NA underestimation to feel better and deal with negative events.

In the present study, we also conducted an exploratory cluster analysis to investigate whether the combination of biases could lead to different associations with the outcome measures. Interestingly, participants in the "*double bias*" cluster (i.e., PA underestimation and NA overestimation) reported the poorest mental health status (in terms of depression, anxiety and psychological well-being). These scores were clearly worse than participants in the "*positive bias*" group (i.e., PA overestimation), but also slightly, yet not significantly worse than participants in the "*negative bias*" group (i.e., NA overestimation, PA accuracy). Although the latter differences were not statistically significant, these results and the marked differences with the "*positive bias"* group suggest that the concurrent overestimation of NA and underestimation of PA might potentially represent an important vulnerability factor for mental health. Due to the small sample size of each cluster, future studies are needed to confirm this hypothesis, which might open new avenues for research, prevention and treatment purposes. Another interesting finding was that people who tended to overestimate past positive emotions benefited from higher psychological well-being (self-acceptance and environmental mastery), even when compared to individuals who were almost accurate in retrieving their affect ("*accurate*" cluster). Despite representing a cognitive bias, we therefore suggest that the overestimation of past positive affective experiences can be considered an adaptive distortion of reality.

For many decades, accurate predictions have been considered a marker of mental health: Cognitive distortions or non-accurate representations of reality were considered vulnerability factors for psychopathology (Jahoda, 1953). Consistent with the information processing perspective, humans were regarded as scientists gathering and elaborating information from the environment with the aim of building realistic and accurate pictures of the world (Fischhoff, 1975). The Positive Illusion Theory offered a divergent perspective, suggesting that cognitive biases are adaptive in many circumstances (Taylor & Brown, 1988), and our results are consistent with this latter idea.

According to Taylor and Brown (1988), people are likely to report three positive biases: Unrealistically positive views of the self, exaggerated perceptions of control, and unrealistic optimism. Rather than representing processing errors, these positive biases have been shown to be protective factors for mental health (i.e., useful resources to maintain and promote well-being and happiness). Consistent with this perspective, a growing body of studies has focused on the importance of a future-oriented disposition (Colombo, Fernandez Alvarez, et al., 2020) and, more specifically, the repercussions that future perception has on mental health (Mikus et al., 2017; Weinstein, 1980). Accordingly, a new construct called "openness to the future" has been proposed, which refers to the "*positive expectations about what life may bring, a sense of competence and ability to cope with events, the anticipation, planning and perseverance to reach an outcome even in the face of adversity, and the acceptance of what cannot be resolved or predicted*". Similar to Taylor's positive biases (1988), openness to the future has been shown to be a protective factor for well-being, and it has been associated with higher PA levels, psychological well-being, and self-esteem, as well as with reduced depressive symptoms, anxiety, and worry (Botella et al., 2018). Here, we propose that also people's past-oriented disposition may represent an important protective factor for mental health.

Building on our results, we showed that the way we perceive and recall our past experiences is associated with many mental health related dimensions. More specifically, overestimating past affective experiences is likely to be a protective factor associated with greater well-being. Conversely, the tendency to underestimate PA and strongly overestimate NA might potentially represent a risk factor for mental health, although the direction of this association cannot be clarified due to the observational nature of the design.

In relation to the previous, there is evidence suggesting that, while experiencing both positive and negative emotional states is adaptive and essential for survival, dysregulated NA levels along with reduced PA can be associated with the onset of many emotional disorders (Hofmann, Sawyer, Fang, & Asnaani, 2012). From an evolutionary perspective, NA entails the implementation of avoidance or withdrawal behaviors in the face of challenging and dangerous situations, whereas PA fosters approach behaviors and the exploration of novel situations (Cacioppo & Berntson, 1999). It is therefore possible to hypothesize that owning distorted emotional representations could affect an individual's behaviors and attitude towards the external world. Accordingly, the concurrent overestimation of NA and underestimation of PA may lead to avoid new experiences and to focus more on negative rather than positive stimuli, which in turn may discourage positive attitudes such as exploration and curiosity.

From a clinical point of view, these results might have some important implications. Reduced PA is indeed a core component of anhedonia, which in turn is a vulnerability factor for mental health. Furthermore, altered levels of both NA and PA has been found to account for the onset and maintenance of many emotional disorders (Brown, 2007; Brown & Barlow, 2009). However, the primary focus of most of the available interventions has been placed on the reduction of symptoms and on the alleviation of negative emotional states. Considering the growing literature showing the short- and long-terms benefits of PA on health and mental health (Pressman, Jenkins, & Moskowitz, 2018), more efforts should be made in order to create interventions that focus on increasing PA levels and learning strategies to regulate not only negative emotions, but also positive ones. An example in this direction is the Positive Affect Treatment, which focuses specifically on the enhancement of PA. In a recent randomized controlled trial, the authors revealed better clinical outcomes in terms of depression, affect, anxiety, stress, and suicidal ideation in the group of patients receiving Positive Affect Treatment, compared to a Negative Affect Treatment (Craske, Treanor, Dour, Meuret, & Ritz, 2019). Additionally, a possible future line of research could lie in the self-monitoring of daily affect and ER deployment in relation to positive emotions by means of a smartphone based EMA similar to the one used in the present investigation. Symptom self-monitoring has already been shown to be an efficacious tool to increase awareness and self-empowerment in depressed patients, leading to decreased symptoms and fewer maladaptive behaviors (Simons et al., 2015; Snippe et al., 2016). Consistently, it is possible that monitoring daily affect and related emotion regulation strategies increases people's awareness of experienced positive and negative emotions. Along this line, Sharot (2011) showed that individuals tend to update their predictions when provided with a piece of information that is positive rather than negative (i.e., when the information provides a more optimistic perspective on the prediction made). This updating process appears to produce optimism that is resistant to change. Similarly, providing a feedback about daily experienced emotions may lead habitual PA underestimators to update their predictions to more closely match the real affect experienced, thus reducing the PA bias.

Although this study deepens our knowledge about affect bias and its relationship with mental health, we acknowledge several limitations that could be addressed in future research. An important aspect that needs to be considered is content validity. Although the single items we used to assess PA and NA via EMA significantly correlated with and predicted affect scores, it would be necessary to replicate this finding in a larger population in order to guarantee content validity. In addition, the PANAS consists of 10 items to assess PA and 10 items to evaluate NA. Conversely, we used single items to collect momentary measures of PA and NA because of the daily, repeated nature of the ecological assessments. It is possible that a complex construct like affect might be grasped differently when using 10 items as opposed to one item. While acknowledging this, it is important to note that it would have been too demanding for users to complete the 20 items on the PANAS three times a day for 2 weeks. Similar to other studies (Suso-Ribera et al., 2018), we decided to use single items in order to manage the difficulties in obtaining high adherence rates when dealing with EMA research (Colombo et al., 2018). Additionally, the indirect effects of recall bias on mental well-being observed in this study should be considered with caution, considering the cross-sectional nature of data

(Maxwell & Cole, 2007). Further studies are needed to confirm the causal role of PA bias on Ryff's measures through resilience. Finally, further limitations are related to the nature of our sample, which was mainly female and composed of undergraduate students, and that also included individuals with mild depressive symptoms. An important goal for future research would include investigating whether affect recall is affected by sex and whether different patterns can be observed in relation to age. According to the "positivity effect", indeed, old individuals as compared to younger ones are likely to recall more positive than negative information (Carstensen & DeLiema, 2018; Reed & Carstensen, 2012). It would be therefore important to explore whether the benefits of holding biased representations of past emotional experiences entail the same implications in different populations.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by DC, CS-R and JFÁ. The first draft of the manuscript was written by DC, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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DATA AVAILABILITY

All data analysed during this study are included in this published article as supplementary information file.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

Desirée Colombo, Carlos Suso-Ribera, Javier Fernández-Álvarez, Pietro Cipresso, Azucena Garcia-Palacios, Giuseppe Riva and Cristina Botella declares that they have no conflict of interest.

Consent to Publish

Patients signed informed consent regarding publishing their data.

Ethical Approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Jaume I University (Spain).

Informed Consent

Informed consent was obtained from all participants included in the study.

Animal Rights Statements

No animal studies were carried out by the authors for this article.

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CHAPTER 8

General discussion

CHAPTER 8: GENERAL DISCUSSION

Although a long tradition of research mainly focused on the study of negative affect, in the last decades there has been an increasing interest in exploring the mechanisms underlying the experience of positive emotions. As a matter of fact, positive emotions are a core component of people's lives, improving both physical and psychological health, and leading to greater well-being and quality of life (Fredrickson & Joiner, 2002; Kok et al., 2013; Tugade & Fredrickson, 2007). Understanding the processes underlying the experience and regulation of positive states is therefore critically important to comprehend human's positive functioning and open new avenues for the promotion of well-being.

The broad aim of the present dissertation was to extend our knowledge about the mechanisms underlying the regulation of positive emotions. To do so, we attempted to provide a comprehensive perspective on positive regulation by considering three different temporal perspectives: The anticipation of positive emotional states, the savoring of ongoing positive emotions, and the recall of past positive experiences. By adopting an ecological approach, we explored the regulation of positive emotions within each frame and we investigated the association between positive regulation and well-being.

In this chapter, we will first provide an overview of the key findings of the present dissertation, which will be summarized starting from the research questions posed in the introduction. Furthermore, the limitations of this research work will be outlined, and the most salient directions for future research will be pointed out.

KEY FINDINGS

The present dissertation was built around three main research questions. Whereas the first three chapters were meant to provide the methodological and theoretical evidence that justifies the approach adopted throughout this thesis (**Chapter 2, Chapter 3** and **Chapter 4**), the subsequent chapters (**Chapter 5, Chapter 6** and **Chapter 7**) attempted to answer each of the questions posed in the introduction.

Anticipation of positive emotional states

Does affective forecasting play a role for well-being? Does one's future-oriented disposition influence resilience, thus enhancing and/or decreasing one's resources to deal with stressors?

The regulation of positive emotions entails anticipating future positive experiences. Forecasting future emotional states has been shown to play a key role in people's lives, driving decisions and behaviours (Crawford, McConnell, Lewis, & Sherman, 2002; Mellers, Schwartz, Ho, & Ritov, 1997). Most importantly, affecting forecasting is considered an effective strategy to regulate positive emotions (Quoidbach, Mikolajczak, & Gross, 2015), and imaging future positive experiences has been shown to positively impact mood by increasing current levels of positive affect and emotional well-being (Bryant, 2003; Westermann, Spies, Stahl, & Hesse, 1996).

Nevertheless, people are quite inaccurate at forecasting future emotions (Wilson & Gilbert, 2003). Biased expectations about the future might entail important consequences for well-being. Consistent with these premises, we explored the association between affective forecasting abilities and mental health, and we hypothesized that the presence of negatively distorted expectations about future positive experiences could be associated with reduced psychological well-being.

First, our results showed that individuals holding positively biased expectations about positive emotional states (i.e., participants who forecasted higher levels of positive emotions than what experienced) reported higher psychological well-being and resilience. Interestingly, psychological well-being was significantly predicted by forecasted but not experienced affect, thus suggesting the fundamental role of future-oriented disposition for mental health.

Second, our results revealed that, when experiencing high levels of stress, individuals who tended to overestimate future positive emotions concurrently reported lower negative affect and higher positive affect than subjects who showed a tendency to underestimate it. In other words, positively biased participants could maintain a better mood despite the presence of intense stressors, thus supporting the potential association between positively biased affective forecasting and resilience.

Together, our study showed that holding optimistic, yet distorted, expectations about future positive emotions is likely to foster psychological well-being and enhance resilience. As evidenced by the previous literature (Bryant, 2003; Westermann, Spies, Stahl, & Hesse, 1996), and consistent with the exaggerated optimism towards the future identified as a fundamental positive illusion by Taylor et al. (1988, 1994), imaging a "positive and pleasant future", regardless of what will actually happen in the real life, may serve to upregulate positive emotions in the present, which in turn might promote psychological well-being and increase one's skills to deal with daily stressors. These results are in line with the previous literature, showing that a more positive future-oriented disposition and greater openness to the future are associated with better mental health and greater well-being (Mikus et al., 2017; Weinstein, 1980; Botella et al., 2018). Notably, positively biased affective forecasting might also partially reflect one's dispositional optimism, defined as the tendency to hold favorable expectations and beliefs about the future (Carver and Scheier, 2014). However, our study does not allow to draw such a conclusion, due to the lack of measures about participants' optimism.

Savoring of positive emotional states

> *Which is the association between positive emotions and subsequent positive emotion regulation in daily life? Is positive emotion regulation fostered by the experience of high levels of positive emotions (i.e., consistent with the Broaden and Build theory) or by the presence of low levels of positive emotions (i.e., consistent with the hedonic flexibility principle)?*

Momentary affect and emotion regulation are reciprocally interconnected (Colombo et al., 2020): That is, the implementation of regulatory processes influences momentary affect, which in turn shapes the subsequent emotion regulation process. Whereas this reciprocal influence has been deeply explored in the case of negative affective states, the dynamics underlying the regulation of positive emotions in daily life has received less attention.

So far, there is increasing evidence showing the beneficial effects of using savoring strategies, which have been shown to improve the experience of positive emotions and/or reduce negative affect levels (Brans, Koval, Verduyn, Lim, & Kuppens, 2013; Heiy & Cheavens, 2014; Nezlek & Kuppens, 2008; Pavani, Le Vigouroux, Kop, Congard, &

Dauvier, 2016; Quoidbach et al., 2015). However, the previous literature was inconsistent regarding the effects of experienced positive emotions on subsequent positive regulation. On the one hand, and consistent with the Broaden and Build theory (Burns et al., 2008; Fredrickson & Joiner, 2002), the experience of high levels of positive affect has been shown to encourage the adoption of positive strategies that further increase positive emotions (see for example Pavani et al., 2016). On the other hand, and coherent with the hedonic flexibility principle (Simon, 1967; Taquet, Quoidbach, de Montjoye, Desseilles, & Gross, 2016), experiencing low levels of positive emotions is supposed to enhance the subsequent adoption of positive strategies in order to repair mood and increase positive affect (see for example Quoidbach, Taquet, Desseilles, de Montjoye, & Gross, 2019). In our study, we monitored positive emotions and positive regulation over 14 days in a sample of undergraduate students, with the aim of shading lights on the dynamics underlying the regulation of positive states.

First, and consistent with the previous literature, our results confirmed the beneficial consequences of positive emotion regulation for emotional well-being. More specifically, our study showed that an increase in the adoption of positive strategies at one time (namely, mindfulness, stimulus control, count blessing, broadening, emotion expression, and sharing) predicted enhanced positive emotions at the subsequent assessment.

Second, our results showed that the less individuals felt positive emotions at one time, the more they tended to increase the use of positive strategies from this time to the next, which is in line with the hedonic flexibility principle. This prototype of positive regulation might be considered a highly adaptive mechanism, that encourages people to behave in order to increase positive affect, when needed (i.e., when momentary affect is low). Despite apparently divergent, we suggest that the Broaden and Build theory and the hedonic flexibility principle might be seen as complementary processes in the regulation of positive emotions. That is, the experience of low positive emotions might encourage an increase in the adoption of positive strategies to repair mood in the short term (consistent with hedonic theories), which in turn might lead to greater psychological well-being and resilience in the long term (consistent with the Broaden and Build theory).

To resume, our results revealed that positive emotions and positive emotion regulation are reciprocally determined in everyday life. Furthermore, the important role of positive regulation on emotional well-being emerged, thus underlying the fundamental function of positive emotions for mental health.

Recall of positive emotional states

> *Which are the mechanisms underlying the bias in recalling past positive experiences? Does holding a biased, yet optimistic, past-oriented disposition boost well-being and resilience?*

Pleasant memories are an important source of positive emotions. Accordingly, people retrieve past positive events in order to re-experience the associated positive emotions and increase current mood (Bryant, Smart, & King, 2005; Quoidbach, Berry, Hansenne, & Mikolajczak, 2010).

Similar to the biases observed in affective forecasting abilities, there is consistent evidence showing that people are not accurate at recalling past emotional experiences and, more specifically, that they tend to retrospectively overestimate past levels of positive and negative emotions (Colombo et al., 2019; Hedges, Jandorf, & Stone, 1985; Thomas & Diener, 1990). However, the mechanisms underlying these biases are still understudied. Differences in how people retrieve the past may entail important consequence for mental health, and holding an optimistic, yet biased, past-oriented disposition (i.e., overestimating past affective experiences) may represent an adaptive strategy that helps to maintain and up-regulate positive emotions over time.

First, our results showed a significant association between the tendency to overestimate past positive affective experiences and mental health, including lower depressive and anxiety symptoms, higher psychological well-being and enhanced resilience. More specifically, mediation analyses revealed that the tendency to overestimate past positive emotions does not directly improve mental health: Rather, it positively impacts on resilience, which in turn is likely to enhance different dimensions of psychological well-being.

Second, our results revealed that positively biased participants (i.e., participants who overestimated past positive emotions) compared to accurate ones (i.e., participants who could accurately retrieve past affective experiences) were likely to benefit from higher psychological well-being. In other words, being highly accurate at recalling past positive emotions was not associated with better mental health. Rather, the presence of a positive bias emerged as a potential protective factor for psychological well-being.

Together, we suggest that holding an optimistic, yet biased, mental representation of one's past affective experiences is likely to constitute an adaptive mechanism that positively impacts well-being through the enhancement of resilience. According to the Positive Illusion theory (Taylor & Brown, 1988; Taylor & Brown, 1994), healthy people are likely to hold three "unrealistic" and favorable beliefs to improve happiness, satisfaction in life, and well-being, namely: 1) A heightened evaluation of the Self, which includes the overestimation of one's abilities and qualities; 2) An amplified perception of control over the environment; and 3) An exaggerated optimism, especially towards the future. Consistently, overestimating past positive experiences might be considered a sort of positive illusion, that allows to maintain high levels of emotional well-being over time.

LIMITATIONS

The results of the three experimental studies exposed in the present dissertation should be interpreted in light of some limitations, as listed below.

Anticipation of positive emotional states

In **Chapter 5**, we explored biased affective forecasting and its association with resilience and well-being. The limitations of this study are the following:

1. There is evidence showing that individual factors, such as emotional intelligence or personality traits, are likely to strongly influence affective forecasting abilities (Hoerger et al., 2016; Hoerger et al., 2012). These factors were not taken into account in our study.
2. The sample was composed of undergraduate students, and most of the participants were female. It is therefore possible that the results observed in our study are not generalizable to all populations. For example, there is evidence showing that the elderly tend to be more accurate in forecasting future emotions than younger individuals (Nielsen, Knutson, & Carstensen, 2008). Future studies are needed to clarify the role of confounding variables such as age or gender on these results, and to replicate our findings in a more representative population.

3. The results of our study have a correlational nature. It is therefore not possible to draw causal conclusions, as well as disentangle the direction of the association between biased forecasting and mental health.
4. Daily affect was measured by means of ad-hoc single items, which might have not completely captured one's momentary emotional state. However, and similarly to other ecological studies, we decided to use single items rather than long questionnaires in order to reduce participants' burden and increase adherence rate (Colombo et al., 2018; Colombo et al., 2019). This choice was made across all three studies.

Savoring of positive emotional states

In **Chapter 6**, we conducted an EMA study to explore the dynamics of positive emotion regulation in daily life and deepen our knowledge about savoring mechanisms. Despite the interesting findings, this study should be considered in light of some limitations.

1. The sample was composed of undergraduate students, whose age varied between 18 and 36. It is important to remark that, according to previous studies, age plays a key role in emotion regulation processes and age-specific regulation patterns have been observed (Jazaieri, Urry, & Gross, 2013; Zimmermann & Iwanski, 2014). The results observed in our study might have been influenced by the type of sample recruited, and future studies are needed to identify whether the prototype of positive regulation suggested by our results varies across different age groups.
2. One of the exclusion criteria of the study was the presence of mild to severe depressive symptoms. Notably, the regulation of positive emotions has been found to be impaired across different emotional disorders, especially depression (Carl, Fairholme, Gallagher, Thompson-Hollands, & Barlow, 2014; Carl, Soskin, Kerns, & Barlow, 2013). The prototype of positive regulation suggested in our study may therefore not work for subclinical or clinical populations. Depressive symptoms might, for instance, influence this emotion regulation prototype.

However, a bigger sample would have been needed to explore the potential moderator role of such clinical factors.

3. Positive emotion regulation was measured by means of ad-hoc single items, which were semi-randomly administered throughout the day. As aforementioned, there's the possibility that the use of single items did not completely grasp the complex construct of emotion regulation. However, to the better of our knowledge, no validated tool to measure momentary positive regulation has been so far developed. Similar to other previous ecological studies (e.g., Brans, Koval, Verduyn, Lim, & Kuppens, 2013; Brockman et al., 2017; Quoidbach, Sugitani, et al., 2019), we therefore developed our own items, which were inspired by a previous work (Heiy & Cheavens, 2014).

Recall of positive emotional states

The last study included in the present dissertation (**Chapter 7**) explored the mechanisms underlying affect recall bias. This study has to be interpreted in light of some limitations.

1. Similar to chapter 5, the findings of this study are correlational. In other words, it is not possible to define the specific direction of the association between affect recall biases and mental health. For instance, we showed a negative association between a past-oriented positive bias and mild depressive symptoms. However, our study does not allow to define whether mild depressive symptoms cause the underestimation of past positive emotional experiences, or the other way around.
2. The mediation analyses proposed in our study allowed to explore the indirect effects of affect recall biases on mental well-being. However, mediation analyses should be considered with caution because of the cross-sectional nature of data (Maxwell & Cole, 2007).
3. The sample was composed of undergraduate students and was not homogeneous in terms of gender. Despite being quite common in psychological research, the use of this specific population might have brought some biases in the results. In the complex field of emotion regulation, many individual factors have been shown to affect emotional dynamics and regulation processes, including age and gender

(Jazaieri et al., 2013; Zimmermann & Iwanski, 2014; Goubet & Chrysikou, 2019; McRae, Ochsner, Mauss, Gabrieli, & Gross, 2008). It would be therefore important for future research to recruit a more diverse sample, not only to explore the replicability of our results, but also to further extend our knowledge about the individual factors shaping positive emotion regulation.

4. FUTURE DIRECTIONS

Besides the aforementioned key findings and limitations, the studies included in the present dissertation might potentially open the way to fascinating future directions of research.

1. From healthy to clinical populations. This dissertation aimed at deepening the mechanisms underlying the regulation of future, present and past positive emotions. Despite the fascinating findings, it is important to underline that all studies involved a sample of healthy individuals. Interesting findings could be revealed when investigating the same processes in clinical populations characterized by difficulties in emotion regulation. The prototype of positive regulation suggested in chapter 6, for instance, could make it possible to better comprehend why patients suffering from abnormal levels of positive affect, such as depression, are poorly able at regulating positive emotions. Interestingly, some significantly different forecasting and recall patterns were observed in relation to mild depressive and/or anxiety symptoms, as measured through validated clinical instruments. For example, a negative bias towards the future was observed in participants showing mild anxiety symptoms (i.e., overestimation of future negative emotions), but not in mild depressed individuals, who were more likely to report a negative bias towards the past (i.e, overestimation of past negative states and underestimation of positive ones). Patients suffering from emotion dysregulation may therefore report significant impairments in the ability to forecast and/or recall emotional states, and our results suggest that such impairments could be frame-specific. A broader framework which concurrently considers the three times frames is needed in order to deeply comprehend the regulation of past, present and future positive emotions in emotional disorders.

2. From observational to experimental designs. The correlational nature of the studies presented in chapter 5 and chapter 7 does not allow to draw causal conclusions. For instance, we have shown that people who tend to overestimate past positive experiences and future positive emotions show higher well-being and resilience. However, better mental health could be the cause of these biases (e.g., people with better mental health tend to be more optimistic towards the past and the future), rather than the result (e.g., being more optimistic towards the past and the future increases one's well-being). Future research should consider adopting an experimental rather than correlation design in order to disentangle the direction of this association. To date, small interventions in the field of mental time travel which aim at making people's predictions more accurate have already been developed (Dunn & Laham, 2006). These procedures could be used to manipulate one's abilities to recall or forecast emotional states, thus observing the potentially causal effects on well-being and resilience. However, this approach would not be able to capture the consequences of a positive bias, which was the main finding of our studies. An important issue for future research would be to test whether it is possible to induce positively biased expectations towards past and future affective states; for example, through specific small interventions that aim at increasing optimism (see for example Sergeant & Mongrain, 2014). Considering the findings described in the present dissertation, inducing optimistic mental representations towards the past and the future could be potentially useful to foster emotional well-being.

3. From ad-hoc items to validated EMA questionnaires. A recurrent methodological limitation of the studies included in the present dissertation and, more generally, of the EMA literature, concerns the lack of validated questionnaires to be used in EMA designs, which led to the adoption of ad-hoc single items. The use of single items not only raises many issues in terms of psychometric properties, but it also makes it difficult to compare results across studies. More specific guidelines to design EMA protocols should be developed, and specific questionnaires should be created to be used in this research field. Notably, state rather than trait emotion regulation questionnaires have recently been developed (Lavender, Tull, DiLillo, Messman-Moore, & Gratz, 2017; Marchetti, Mor, Chiorri, & Koster, 2018), that

represent adequate candidates to be used in EMA studies and that might open the way to the creation of validated EMA instruments in the near future.

From research findings to clinical implications. The results observed in the present dissertation could have some important clinical implications. So far, a growing body of evidence has demonstrated the essential role of positive emotions in people's lives, being associated with greater well-being, happiness and quality of life (Pressman, Jenkins, & Moskowitz, 2018). Nevertheless, positive emotions have so far received little attention in clinical settings, and only a few interventions targeting the regulation (and upregulation) of positive affect have been developed. Importantly, there is evidence supporting the importance to include positive affect components into the treatment of many emotional disorders, characterized by low levels of positive emotions and abnormal regulation of positive affective states (Díaz-García et al., 2017; González-Robles et al., 2015; Craske, Treanor, Dour, Meuret, & Ritz, 2019). The studies included in the present dissertation do not only open new avenues for the understanding of abnormal positive regulation in such clinical populations, but they also further support the importance of cultivating positive emotions for emotional well-being and mental health, encouraging the development of specific interventions which focus on the up-regulation of future, present and past positive emotions. As aforementioned, future studies are needed to explore which time frames are mostly impaired depending on a patient's clinical condition, and which techniques could be applied to improve the regulation of positive emotions within each dimension. More importantly, it would be of utmost importance to clearly determine to what extent positive affect and biased expectations towards the future and past should be potentiated, as an excess in positive affect could also trigger manic episodes (Gruber, Johnson, Oveis, & Keltner, 2008).

CONCLUSIONS

The studies included in the present dissertation represent a valid contribution to the field of positive emotion regulation and, more specifically, they allow to extend our knowledge about the mechanisms underlying the regulation of past, present and future positive affective states. For a long time, cognitive biases have been regarded as vulnerability factors for psychopathology (Jahoda, 1953), being considered the result of incorrect and inaccurate interpretations of reality (Fischhoff, 1975). Here, we showed that holding optimistic, yet biased, estimations of one's past and future positive emotional experiences is associated with enhanced resilience and greater well-being, thus suggesting the potentially adaptive nature of such cognitive illusions. Our results seem therefore to support the hypothesis that anticipating and recalling positive emotional states are efficient strategies to regulate emotions and increase emotional well-being. Furthermore, we bridged the gap existing in the previous literature regarding the mechanisms underlying the reciprocal interconnection between positive emotions and positive emotion regulation in daily life, revealing the existence of a highly adaptive regulatory mechanism that enables healthy individuals to repair negative mood and maintain positive affect over time. A special emphasis has been placed on the use of ecological and momentary methodologies to better grasp emotional dynamics in daily life. The advantages of using such approaches have been strongly underlined by the three theoretical research works included at the beginning of this dissertation, and further supported by their application in the experimental studies about positive emotion regulation.

Despite the limitations mentioned in the previous paragraphs, this research work adds up to the previous literature by extending our knowledge about the regulation of positive emotions, and sheds new light on the importance of positive emotions for mental health. Future studies will be encouraged in testing the role of Positive Illusion Theory on both human wellbeing and human behaviors, thus coming to understand if this positive view of oneself and illusion of control can really play a protective role even towards the adoption of risky behaviors, typically inversely associated with dimensions of well-being.

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APPENDIX (1)

Ethical approvals

UNIVERSITAT
JAUME•I

Beatriz Tomás Mallén, secretaria de la Comisión Deontológica de la Universitat Jaume I de Castelló de la Plana,

CERTIFICO: Que la Comisión Deontológica de la Universitat Jaume I ha emitido informe favorable sobre el proyecto con número de expediente 16/2018 "The role of emotion regulation flexibility on psychological well-being and autobiographical memory: An Ecological Momentary Study" cuya investigadora principal es Cristina Botella Arbona, por considerar que cumple las normas deontológicas exigidas.

UNIVERSITAT
JAUME•I

Castellón de la Plana, 4 de junio de 2018

Beatriz Susana Tomás Mallén, secretaria de la Comisión Deontológica de la Universitat Jaume I de Castellón de la Plana,

CERTIFICO; que la Comisión Deontológica de la Universitat Jaume I ha emitido informe FAVORABLE sobre el proyecto con número de expediente "CD/57/2019" Regulation of positive emotions in daily life: exploring antecedents and consecuences, presentado por Cristina Botella Arbona, por considerar que cumple con las normas deontológicas exigidas.

Castellón de la Plana, 13 de diciembre de 2019

APPENDIX (2)

Co-authors’ agreements

UNIVERSITAT JAUME I
Escola de Doctorat · ED

Castellon, 1st September 2020

I, Cristina Botella, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8*(4), 465.

- Colombo, D., Fernández-Álvarez, J., Garcia Palacios, A., Cipresso, P., Botella, C., & Riva, G. (2019). New technologies for the understanding, assessment, and intervention of emotion regulation. *Frontiers in psychology, 10,* 1261.

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., García-Palacios, A., Riva, G., & Botella, C. (2020). Biased affective forecasting: A potential mechanism that enhances resilience and well-being. *Frontiers in Psychology, 11*.

- Colombo, D., Pavani, J.B., Fernández-Álvarez, J., García-Palacios, A., & Botella, C. (2020). Savoring the present: The reciprocal influence between positive emotions and positive emotion regulation in everyday life. *(submitted)*

- Colombo, D., Suso-Ribera, C., Fernández-Álvarez, J., Cipresso, P., Garcia-Palacios, A., Riva, G., & Botella, C. (2020). Affect Recall Bias: Being Resilient by Distorting Reality. *Cognitive Therapy and Research,* 1-13.

Signed,

In accordance with article 23 of the Regulation of Doctoral Studies, regulated by RD 99/2011, at the Universitat Jaume I (Approved by the Governing Council No. 19 of January 26, 2012, modified by the Governing Council no. 29 of November 27, 2012 and subsequent amendment by the Governing Council No. 37 of July 25, 2013):"(...) "Those doctoral theses that opt for the incorporation of articles (compendium of publications) must include………… the acceptance of the co-authors of the publications that have waived the right to present them as a part of another PhD thesis"

UNIVERSITAT JAUME I
Escola de Doctorat · ED

Castellon, 1st September 2020

I, Azucena García Palacios, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8*(4), 465.

- Colombo, D., Fernández-Álvarez, J., Garcia Palacios, A., Cipresso, P., Botella, C., & Riva, G. (2019). New technologies for the understanding, assessment, and intervention of emotion regulation. *Frontiers in psychology, 10,* 1261.

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., García-Palacios, A., Riva, G., & Botella, C. (2020). Biased affective forecasting: A potential mechanism that enhances resilience and well-being. *Frontiers in Psychology, 11*.

- Colombo, D., Pavani, J.B., Fernández-Álvarez, J., García-Palacios, A., & Botella, C. (2020). Savoring the present: The reciprocal influence between positive emotions and positive emotion regulation in everyday life. *(submitted)*

- Colombo, D., Suso-Ribera, C., Fernández-Álvarez, J., Cipresso, P., Garcia-Palacios, A., Riva, G., & Botella, C. (2020). Affect Recall Bias: Being Resilient by Distorting Reality. *Cognitive Therapy and Research*, 1-13.

Signed, Azucena Garcia-Palacios

In accordance with article 23 of the Regulation of Doctoral Studies, regulated by RD 99/2011, at the Universitat Jaume I (Approved by the Governing Council No. 19 of January 26, 2012, modified by the Governing Council no. 29 of November 27, 2012 and subsequent amendment by the Governing Council No. 37 of July 25, 2013):"(...) "Those doctoral theses that opt for the incorporation of articles (compendium of publications) must include………… the acceptance of the co-authors of the publications that have waived the right to present them as a part of another PhD thesis"

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Castellon, 1st September 2020

I, Pietro Cipresso, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8(*4), 465.

- Colombo, D., Fernández-Álvarez, J., Garcia Palacios, A., Cipresso, P., Botella, C., & Riva, G. (2019). New technologies for the understanding, assessment, and intervention of emotion regulation. *Frontiers in psychology, 10,* 1261.

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., García-Palacios, A., Riva, G., & Botella, C. (2020). Biased affective forecasting: A potential mechanism that enhances resilience and well-being. *Frontiers in Psychology, 11.*

- Colombo, D., Suso-Ribera, C., Fernández-Álvarez, J., Cipresso, P., Garcia-Palacios, A., Riva, G., & Botella, C. (2020). Affect Recall Bias: Being Resilient by Distorting Reality. *Cognitive Therapy and Research,* 1-13.

Signed,

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Castellon, 1st September 2020

I, Giuseppe Riva, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8(*4), 465.

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Signed,

Giuseppe Riva

In accordance with article 23 of the Regulation of Doctoral Studies, regulated by RD 99/2011, at the Universitat Jaume I (Approved by the Governing Council No. 19 of January 26, 2012, modified by the Governing Council no. 29 of November 27, 2012 and subsequent amendment by the Governing Council No. 37 of July 25, 2013):"(...) "Those doctoral theses that opt for the incorporation of articles (compendium of publications) must include……….. the acceptance of the co-authors of the publications that have waived the right to present them as a part of another PhD thesis"

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Castellon, 1st September 2020

I, Carlos Suso-Ribera, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

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- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

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Castellon, 1st September 2020

I, Javier Fernández- Álvarez, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8*(4), 465.

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Castellon, 1st September 2020

I, Marta Kwiatkowska, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8*(4), 465.

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Castellon, 1st September 2020

I, Hristo Valev, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

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Castellon, 1st September 2020

I, Corina Sas, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

Signed,
Corina Sas

Prof Corina Sas
School of Computing and Communications
Lancaster University
Lancaster, UK
Email: c.sas@lancaster.ac.uk

In accordance with article 23 of the Regulation of Doctoral Studies, regulated by RD 99/2011, at the Universitat Jaume I (Approved by the Governing Council No. 19 of January 26, 2012, modified by the Governing Council no. 29 of November 27, 2012 and subsequent amendment by the Governing Council No. 37 of July 25, 2013):"(...) "Those doctoral theses that opt for the incorporation of articles (compendium of publications) must include………… the acceptance of the co-authors of the publications that have waived the right to present them as a part of another PhD thesis"

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Castellon, 1st September 2020

I, Andrea Patané, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine*, *8*(4), 465.

Signed,

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Castellon, 1st September 2020

I, Tim Leufkens, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

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- Colombo, D., Fernández-Álvarez, J., Suso-Ribera, C., Cipresso, P., Valev, H., Leufkens, T., Sas, C., García-Palacios, A., Riva, G., & Botella, C. (2020). The need for change: Understanding emotion regulation antecedents and consequences using ecological momentary assessment. *Emotion, 20*(1), 30.

Signed,

T. Leufkens

In accordance with article 23 of the Regulation of Doctoral Studies, regulated by RD 99/2011, at the Universitat Jaume I (Approved by the Governing Council No. 19 of January 26, 2012, modified by the Governing Council no. 29 of November 27, 2012 and subsequent amendment by the Governing Council No. 37 of July 25, 2013):"(...) "Those doctoral theses that opt for the incorporation of articles (compendium of publications) must include........... the acceptance of the co-authors of the publications that have waived the right to present them as a part of another PhD thesis"

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Castellon, 1st September 2020

I, Michelle Semonella, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Fernández-Álvarez, J., Patané, A., Semonella, M., Kwiatkowska, M., García-Palacios, A., Cipresso, P., Riva, G., & Botella, C. (2019). Current state and future directions of technology-based ecological momentary assessment and intervention for major depressive disorder: A systematic review. *Journal of clinical medicine, 8*(4), 465.

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Escola de Doctorat · ED

Castellon, 1st September 2020

I, Pavani Jean-Baptiste, hereby authorise Desirée Colombo to include the publications listed below in her doctoral thesis. In addition, I waive the right to use those articles as part of any other doctoral thesis.

List of articles:

- Colombo, D., Pavani, J.B., Fernández-Álvarez, J., García-Palacios, A., & Botella, C. (2020). Savoring the present: The reciprocal influence between positive emotions and positive emotion regulation in everyday life. *(Submitted)*

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