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REVIEW

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When all glasses look half empty: a computational model of reference dependent evaluation to explain depression

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ABSTRACT

Computational proposals argue that impairments in evaluation are central to depression. At the same time, contemporary theories of evaluation highlight its reference dependent nature: when attributing value to an outcome, our brain automatically assesses the outcome relative to its context. Yet, reference dependent processes underlying evaluation remain to be explored in the context of depression. To fill this gap, here we develop a computational model of reference dependent evaluation to explain the disorder. The model proposes that early-life stress (combined with genetic predispositions) impairs the ability to adjust to environmental changes. After experiencing stress later in life, such inability to adapt would result in excessive standards to which life outcomes are compared. This model explains diverse affective aberrations observed in the disorder, including low mood, poor self-esteem, reduced controllability, and blunted emotional reactivity. Our proposal raises the possibility that abnormal reference dependent evaluation might be a critical process underlying depression.

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Depression; reference dependent; computational model; reference point; stress

Introduction

Afflicting approximately 20% to 25% of women and 10% to 17% of men in their lifetime, depression is the predominant mental illness worldwide (Kessler et al., 1994). This is characterised by the following symptoms: persistent low mood, loss of interest or pleasure, low self-esteem, lack of energy, disturbed sleep or appetite, and difficulty to concentrate (American Psychiatric Association, 2013). Employing a computational modelling approach (Frank et al., 2016; Montague et al., 2012), recent work has highlighted impairments in evaluation (the process whereby individuals assign positive or negative motivational value to stimuli) as being central to the disorder (Chen et al., 2015; Huys et al., 2015). Aspects of evaluation examined so far include the role of prior beliefs and of model-free versus model-based decision-making strategies (Huys et al., 2015). However, one crucial aspect remains to be explored in relation with depression: the notion that evaluation is inherently reference dependent (Kőszegi & Rabin, 2006; Louie et al., 2013; 2015; Rigoli, 2019; Rigoli et al., 2016a; Stewart, 2009; Stewart et al., 2006; Woodford, 2012). When attributing a value to an outcome, our brain automatically assesses the outcome not in isolation, but relative to its context. As an example, consider an individual who is purchasing a house and who discovers that the price of the house is £10 more than expected. Compare this with someone who, when paying for a coffee, realises that the price is £10 higher than expected. Objectively, both individuals experience an equivalent unforeseen extra-cost of £10. Yet, we would expect the second person to be way more upset than the first. This example stresses the idea that evaluation is reference-dependent, that is, the idea that the subjective value of outcomes strongly depends on the context.

Is the notion of reference dependent evaluation relevant to understand depression? The present paper addresses this question. Our analysis starts with an overview of affective alterations that are central to the disorder. Next, a reference-dependent model of depression (RDMD) will be introduced and

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will be assessed with respect to its ability to explain such affective alterations.

Affective processes in depression

Alterations of mood (reflecting a long-lasting affective state) and emotion (reflecting a more transient, stimulus-driven, affective response) are central to depression (Rottenberg, 2005; 2017; Rottenberg et al., 2005; Rottenberg & Johnson, 2007; Yoon & Rottenberg, 2020). What does research know about these alterations? Low mood is inherent to the definition of the disorder, with poor self-esteem being often one of the causes of low mood (Sowislo & Orth, 2013). Moreover, a vast body of literature has connected low mood with learned helplessness, arising when several negative events occur despite attempts to avoid them (Maier & Seligman, 1976; Seligman, 1974). Such repeated failures would foster a perception of poor controllability, namely, the belief that one's own behaviour is ineffective upon the environment. In turn, this literature posits that low controllability elicits a resigned attitude which results in lack of energy and in pervasive negative mood.

Regarding the role of emotion, a reduced (or even absent) emotional reactivity to positive events (i.e. anhedonia) is well-documented in depression (Pizzagalli, 2014; Rottenberg, 2017). More recent research has asked whether the disorder is also associated with abnormal emotional responses to negative events. Are emotional reactions to these events enhanced or reduced? Recent evidence indicates that, like in the case of positive events, reactivity to negative events is also attenuated (Rottenberg, 2005; 2017; Rottenberg et al., 2005; Rottenberg & Johnson, 2007; Yoon & Rottenberg, 2020). Thus, emotional reactivity appears to be blunted in depression for both positive and negative outcomes.

In short, research points to poor self-esteem, reduced controllability (underlying learned helplessness), low mood, and blunted emotional reactivity as key aspects of depression. Thus, our analysis focuses on explaining these aspects. Specifically, we ask whether the notion of reference dependent evaluation can contribute to explain (i) low mood, (ii) poor self-esteem, (iii) reduced controllability, and (iv) blunted emotional reactivity. To address this question, below we introduce the RDMD.

The model

Our proposal is inspired by contemporary models of reference-dependent evaluation (Kőszegi & Rabin, 2006; Louie et al., 2013; 2015; Rigoli, 2019; Rigoli et al., 2016a; Stewart, 2009; Stewart et al., 2006). Although these differ in important matters, they all share the same fundamental principles. Here we will rely on a specific model (Rigoli, 2019; Rigoli & Pezzulo, 2022; Woodford, 2012); however, similar arguments would arise if different models were adopted. The reason for focusing on this model is that, at least in some domains, this represents one of the major candidates for explaining evaluation (Rigoli, 2019). Moreover, the model is simple, and can easily be applied to depression (see below).

Consider an environment or context (e.g. school) where a set of outcomes (e.g. school marks) can be experienced, each associated with a raw value (e.g. the actual mark). For each outcome, the calculation of the subjective value V_R associated with the raw value R depends on the following logistic function:.

$$V_R = \frac{1}{1 + e^{-\frac{R-\mu}{\sigma}}} \quad (1)$$

This prescribes that the subjective value of a stimulus is $0 < V_R < 1$. The parameters μ and σ (being $\sigma > 0$) are the reference point and the uncertainty associated with the environment, respectively. These parameters capture the reference-dependent nature of evaluation: the subjective value (V_R), which is experienced at a subjective level and drives behaviour, is not equivalent to the raw value (R), but it depends on some reference information. The RDMD proposes that the subjective value can be experienced as either reward or punishment, occurring when $V_R > 0.5$ and $V_R < 0.5$, respectively (a neutral experience occurs when $V_R = 0.5$). Based on this definition, note that reward is experienced when $R > \mu$ and punishment is experienced when $R < \mu$. Therefore, the reference point can be interpreted as the standard to which outcomes are compared to and are evaluated as reward (i.e. better than the standard) or as punishment (i.e. worse than the standard) (Figure 1). For example, the reference point μ might indicate the standard mark at school, implying that a better mark will be perceived as success and a worse mark as failure. The parameter σ can be interpreted as the level of uncertainty about one's own standard, prescribing how much a discrepancy from the reference point will be weighted. In other words, it determines how subjectively good or bad an outcome is when compared to the reference

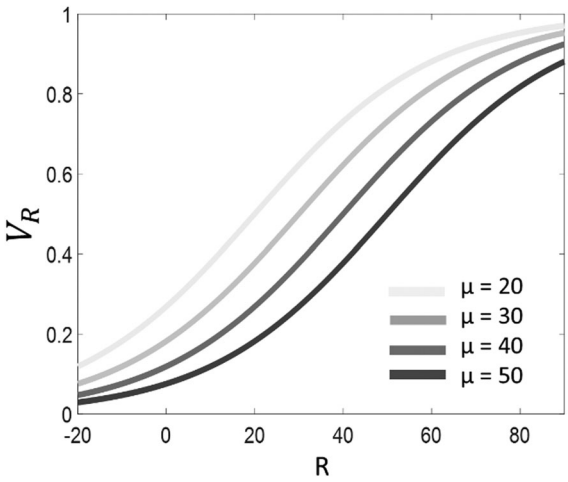

Figure 1. Subjective value as a function of raw value for different reference point μ (σ = 20 for all lines).

point. For example, if one has received a mark above/below the standard, the uncertainty parameter determines how subjectively good/bad the mark is. With high uncertainty, a discrepancy will not be weighted much, minimising the subjective distance from the reference point. Hence, the mark above/below the standard will not be considered too good/bad. Conversely, with low uncertainty, a discrepancy will be weighted heavily, maximising the subjective distance from the reference point. Hence, the mark above/below the standard will be considered as very good/bad.

Based on equation 1, an individual can evaluate a variety of states within a context, such as the current, past, and future state of affair. Three of such evaluations are particularly relevant in our proposal (Rigoli, 2021; Rigoli & Martinelli, 2021): (i) V_{pres}, capturing the subjective value attributed to the current state of affair (e.g. the current performance at school), (ii) V_{act}, capturing the subjective value attributed to the future outcome achievable by performing appropriate actions (e.g. the performance at school achievable with proper commitment), (iii) V_{Noact}, capturing the subjective value attributed to the future outcome expected without performing those appropriate actions (the performance at school expected without much commitment) (note that, by definition, $V_{act} > V_{Noact}$). The RDMD proposes that these three evaluations are at the root of self-esteem and controllability, both fundamental constructs in depression. Self-esteem is commonly interpreted as reflecting the level of satisfaction about the current state of the self (Branden & Archibald, 1982). Based on this, the RDMD defines self-esteem simply as equal to the subjective value associated with the current state of affair (V_{pres}). According to the literature (Dayan, 2012; Maier & Seligman, 1976; Rigoli et al., 2016b; Seligman, 1974), controllability indicates to what degree one expects to achieve goals (or avoid punishments) with appropriate actions. Following this definition, controllability can be formalised as:.

$$C = V_{act} - V_{Noact} \tag{2}$$

This fits with the common definition of controllability as corresponding to the subjective value expected by performing appropriate actions minus the value expected without those actions (Dayan, 2012; Maier & Seligman, 1976; Rigoli et al., 2016b; Seligman, 1974).

In short, thanks to the reference point μ and to the uncertainty parameter σ, the RDMD highlights the reference-dependent nature of subjective value. From this model, a formal definition of self-esteem and controllability can be derived. Below, we will explore how this framework can be applied to explain important aspects of depression.

Applying the model to depression

Consider an example of a context where an agent can experience six possible raw values (10, 20, 30, 40, 50, 60, 70), each with equal probability. The RDMD suggests that, within this context, adaptive evaluation occurs if the reference point μ corresponds to the contextual average (equal to 40 in this example) and the uncertainty parameter σ corresponds to the contextual standard deviation (equal to 20 in this example) (Rigoli, 2019; Rigoli & Pezzulo, 2022). In other words, adaptive evaluation occurs when an individual has a realistic representation of the context and of its statistics, and uses this representation to evaluate each stimulus appropriately. Applying Equation (1) with μ = 40 and σ = 20 (reflecting the true context statistics), the subjective value of the different raw values corresponds to 0.1824, 0.2689, 0.3775, 0.5, 0.6225, 0.7311, 0.8176, respectively (Table 1; Figure 2(a)). Conversely, when the reference point μ or the uncertainty parameter σ do not reflect the true context statistics, evaluation is deemed to be maladaptive according to the RDMD (Rigoli et al., 2021).

We propose that an extremely high reference point μ is at the root of depression. Intuitively, the idea is that, during depression, patients assess

their outcomes compared to standards that are excessively high. The notion that depressed patients entertain unrealistic standards is not new: it is at the centre of several classic theories of the disorder (Abramson & Sackheim, 1977; Arieti & Bemporad, 1978; Beck, 1967; Bibring, 1953; Carver & Scheier, 1990; Freud, 1917; Hyland, 1987).

According to the RDMD, what are the implications of an extremely high reference point μ? Let us consider the example above (describing a context with raw values 10, 20, 30, 40, 50, 60, 70), but now where the reference point μ is equal to 100 (Table 1; Figure 2(b)), namely, much higher than the contextual average (which is 40). Comparing the results for $\mu = 40$ versus $\mu = 100$, two key differences emerge. First, all subjective values are lower when $\mu = 100$ (Table 1; Figure 2(b)), so much so that they are all experienced as punishment (i.e. $V_R < 0.5$ in all cases). The second aspect concerns the distance in subjective value among outcomes that are adjacent in the distribution (e.g. 20 minus 10, or 30 minus 20, or 40 minus 30 etc.) (Table 2; Figure 2(b)). When $\mu = 100$, different outcomes are perceived as more similar, leading to an indiscriminate (and highly negative) affective response to all of them.

We argue that such extremely high reference point can explain the core features of depression highlighted above, including (i) low mood, (ii) poor self-esteem, (iii) reduced controllability, and (iv) blunted emotional reactivity. First, people suffering from depression manifest low mood independent of the outcome they experience (Rottenberg, 2005). According to the RDMD, this occurs because outcomes are compared with an excessive standard (Table 1; Figure 2(b)). This happens also for objectively positive outcomes, explaining why depressed patients often fail to feel pleasure when they experience these outcomes (resulting in anhedonia; Pizzagalli, 2014).

Table 1. Subjective value V_R for different outcomes (reported in rows) and different parameter sets (reported in columns) relative to a context characterised by raw values 10, 20, 30, 40, 50, 60, and 70 (each with equal probability).

	$\mu = 40, \sigma = 20$	$\mu = 100, \sigma = 20$
10	0.1824	0.0110
20	0.2689	0.0180
30	0.3775	0.0293
40	0.5000	0.0474
50	0.6225	0.0759
60	0.7311	0.1192
70	0.8176	0.1824

Second, an excessive reference point μ implies lower subjective value attributed to the current state V_{pres}. Because the latter can be interpreted as reflecting self-esteem (see above), an excessive reference point entails low self-esteem. Intuitively, this simply emerges because evaluation of oneself is more negative when the self is compared with excessive standards (Sowislo & Orth, 2013).

Third, a higher reference point usually entails lower controllability (Maier & Seligman, 1976; Seligman, 1974). To understand why, consider two individuals, one having higher reference point μ than the other. Imagine that both individuals predict that an outcome of 40 can be achieved with the correct behaviour, and that an outcome of 20 will be achieved without that behaviour. According to the RDMD, perceived controllability will be lower for the individual having higher reference point μ, because the distance in subjective value between 40 and 20 (corresponding to the level of controllability; see equation 2) is smaller for this individual. Intuitively, a higher reference point μ implies lower controllability because it entails the expectation that things will remain quite similar independent of whether an appropriate behaviour is performed or not.

Fourth, when the reference point μ is excessive, all outcomes elicit a very similar affective response, even when they are objectively very different (Table 2; Figure 2(b)). This captures the notion of blunted emotional reactivity (Rottenberg, 2005; 2017; Rottenberg et al., 2005; Rottenberg & Johnson, 2007; Yoon & Rottenberg, 2020): people with depression appear to lose the ability to discriminate among different outcomes.

In short, the RDMD is consistent with several core aspects of depression. Notably, this consistency emerges just by postulating an excessive reference point μ, without any further assumption. The next section examines the processes responsible for the development of such excessive reference point μ in the disorder.

Aetiology of depression

The argument developed so far raises a critical question: what are the processes responsible for the formation of an excessive reference point μ, which is proposed to be at the core of depression? To answer this question, it is important to consider empirical research on the aetiology of depression, which highlights two critical factors: genetic

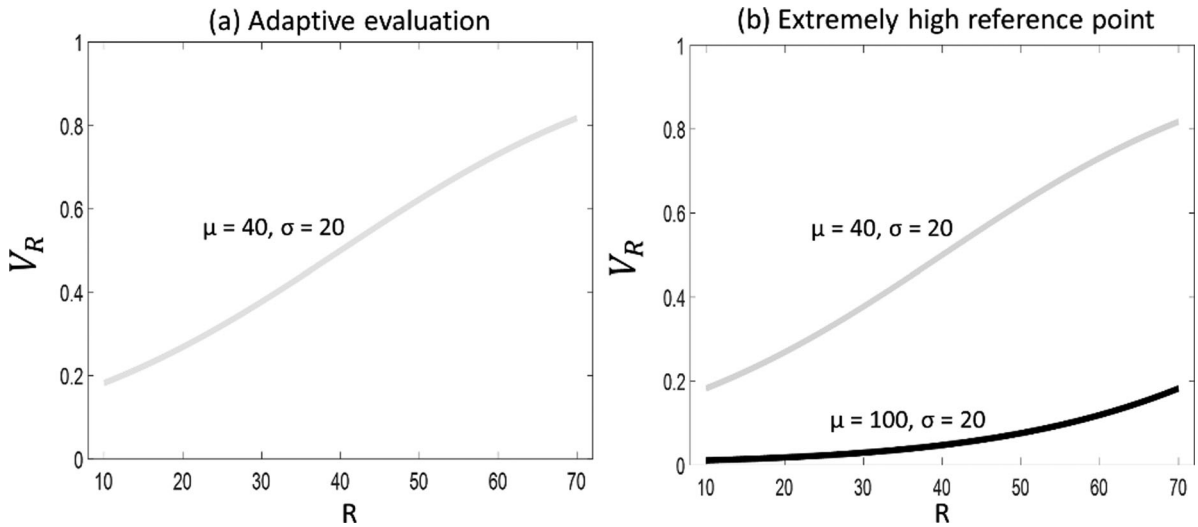

Figure 2. Subjective value as a function of raw value for different parameter sets, plotted for: (a) a case where parameters reflect the true context statistics; (b) a case where parameters reflect the true context statistics and a case where the reference point μ is extremely high.

predisposition (Flint & Kendler, 2014) and stress (Hammen, 2005; Liu & Alloy, 2010). Our analysis will focus on the latter. Evidence shows that the risk for depression increases with both episodic (or acute) and chronic stress, and with both recent and early negative life events (Hammen, 2005; Liu & Alloy, 2010). Moreover, stress appears to be implicated in the first onset of depression, in relapse, in the recurrence of the illness, and in the exacerbation of symptoms (Hammen, 2005; Liu & Alloy, 2010).

This literature urges the RDMD to explain why stress might lead to developing an excessive reference point μ. To begin with, this explanation requires distinguishing negative events (i.e. stress) occurring early in life from those occurring later, the former predisposing an individual to depression and the latter triggering the onset thereof. Let us examine the role of early-life stress (Mandelli et al., 2015). Throughout the life of any individual, the environment (i.e. the distribution of outcomes) changes continuously. For example, while a certain life period might be particularly stressful (i.e. characterised by a series of negative events such as when a family member dies or when a serious illness is contracted), a sequence of positive events might characterise another life period. The RDMD assumes that an individual keeps track of such environmental changes by updating the model parameters (reference point μ and uncertainty σ) according to a learning rate (Behrens et al., 2007). Early life stress might be important in establishing such learning rate: severe stress experienced early in life (combined with a specific genetic profile) might produce alterations of the learning rate, thus leading to either an excessively high or low learning rate. In some cases, early-life stress might result in an extremely low learning rate, implying that parameters remain largely unmodified when the environment changes. We propose that it is such excessively low learning rate, resulting from early-life stress (combined with a specific genetic profile), which predisposes individuals to develop depression later in life. When do early stressful events produce an excessively small learning rate? A possibility is that this depends on the temporal pattern of stressful events. Experiencing stressful events all close in time might lead to the interpretation that the reference point μ can change abruptly, leading to a large learning rate. Conversely, experiencing the same stressful events but now sparse in time might lead to the interpretation that the reference point μ is rather fixed, leading to a small learning rate.

Table 2. Difference in subjective value V_R for pairs of adjacent outcomes (reported in rows) and different parameter sets (reported in columns) relative to a context characterised by raw values 10, 20, 30, 40, 50, 60, and 70 (each with equal probability).

	μ = 40, σ = 20	μ = 100, σ = 20
20-10	0.0865	0.0070
30-20	0.1086	0.0113
40-30	0.1225	0.0181
50-40	0.1225	0.0285
60-50	0.1086	0.0433
70-60	0.0865	0.0632

Let us now examine the role of late-life stress, proposed to be responsible for the onset of depression. Within the RDMD, what happens when severe negative events (e.g. the death of a family member or contraction of a serious illness) are experienced later in life? Such negative events imply that the environment has changed (e.g. the family member is now dead, or the illness is now unavoidable), namely, that the environment is now characterised by lower average outcome. This requires lowering the reference point μ accordingly. Considering an individual with an appropriate learning rate, negative events will be initially experienced as highly punishing. However, with some time, the reference point μ will be lowered up to a point where it becomes appropriate for the new environment. As a consequence, now negative events will not be perceived as dramatic as before. Consider now an individual characterised by an excessively low learning rate (as outlined above, this is proposed to arise from early-life stress and genetic predisposition). This person will only minimally adjust the reference point, implying that the reference point will remain excessively high for the new environment. This explains why, for predisposed people (predisposed because of genetic factors and early-life stress), late-life stress produces an excessive reference point μ, which is proposed to be at the core of depression by the RDMD. In essence, while people with an appropriate learning rate would react to late-life stress by adjusting the reference point μ (experiencing the signs of depression only immediately following the negative events, after which these signs disappear; note that a prolonged experience of symptoms is necessary for a diagnosis of depression), people with excessively low learning rate would be uncapable to do so (hence manifesting the symptoms in a stable manner).

Various empirical observations fit with the proposal that a decreased learning rate characterises depression. In general, evidence indicates that lower cognitive flexibility is typical of depressed patients (Paulus et al., 2016; Stange et al., 2017); our proposal interprets this as arising from a diminished learning rate. More specifically, recent investigations have examined performance in reversal learning tasks, where reward and punishment contingencies change over trials and thus require participants to keep track of these changes. These paradigms are particularly suitable to assess the learning rate, that is, to assess how fast one realises that changes occur. In line with the RDMD, a recent study adopting a reversal learning task has revealed that depressed patients manifest a decreased learning rate compared to controls (Mukherjee et al., 2020). Moreover, a recent investigation has examined performance in a reversal learning task comparing healthy participants who had experienced early life stress against controls (Wilkinson et al., 2021). A decreased learning rate emerged for the first group of participants, supporting the RDMD's proposal that, in some circumstances, early life stress leads to a diminished learning rate.

In short, the RDMD argues that early-life stress (in conjunction with specific genetic traits) can lead to an excessively low learning rate, predisposing individuals to depression. When stress is experienced later in life, an excessively low learning rate impairs the ability to adjust the reference point μ to the new environment, resulting in an excessive reference point μ and thus in depression.

Discussion

By introducing the RDMD, this paper explores implications of contemporary models of referent dependent evaluation for understanding depression. These models inspire the proposal that early negative events (combined with certain genetic traits) might lead to developing an extremely low learning rate that governs the change of a reference point parameter. When experiencing stress later in life, such low learning rate would fail to adjust the reference point to a new environment, leading to an excessive reference point. The latter is sufficient to explain affective aberrations observed in depression, including low mood, poor self-esteem, reduced controllability, and blunted emotional reactivity.

Our model is inspired by previous accounts of depression emphasising the critical role of affective aspects such as poor controllability and learned helplessness (Maier & Seligman, 1976; Seligman, 1974), self-esteem (Sowislo & Orth, 2013), and emotional impairments (Rottenberg, 2005; 2017; Rottenberg et al., 2005; Rottenberg & Johnson, 2007; Yoon & Rottenberg, 2020). By proposing a single factor (i.e. an excessive reference point) as underlying all these aspects, our model offers a framework for integrating different perspectives within a unifying framework.

Moreover, in line with recent approaches to depression (Chen et al., 2015; Huys et al., 2015),

our model adopts a computational perspective. A key advantage of this approach is that, by adopting mathematical formalism, it offers precise descriptions of key concepts and of their relationship, facilitating theoretical debate and the identification of specific empirical predictions—for a detailed discussion of this approach see (Frank et al., 2016; Montague et al., 2012). More specifically, our model builds upon recent computational proposals examining aspects of evaluation in the context of depression (Huys et al., 2015). However, previous work has neglected reference dependency, which is at the core of influential theories of evaluation (Kőszegi & Rabin, 2006; Louie et al., 2013; 2015; Rigoli, 2019; Rigoli et al., 2016a; Stewart, 2009; Stewart et al., 2006; Woodford, 2012). This paper suggests that referent dependent evaluation might explain core affective processes characterising the disorder.

The RDMD has strong similarities with control theory as applied to depression (Carver & Scheier, 1990; Hyland, 1987; 2020). Control theory posits that goal-directed behaviour is steered by perceiving a mismatch between a goal and the current state. The theory distinguishes between goal mismatch (i.e. a state of discrepancy between the goal and the current state) and error sensitivity, the latter reflecting the level of motivation to pursue the goal. When applied to depression, this framework interprets the disorder as arising when, for an individual characterised by strong error sensitivity, a highly desired goal remains unfulfilled for a long period of time (Hyland, 1987). This persistent unfulfillment would be the consequence of entertaining goals that are unobtainable and of failing to disengage from such goals despite repeated unsuccess (Carver & Scheier, 1990; Hyland, 1987; Pyszczynski et al., 1987). In turn, the persistent state of unfulfillment would elicit hallmarks of depression such as poor self-esteem, poor controllability, and negative affect. The notion of unobtainable goal proposed by control theory has similarities with the idea of excessive standard postulated by the RDMD. However, the concept of *goal* is not exactly equivalent to the concept of *standard* as applied by to RDMD: a depressed person might entertain excessive standards and yet pursue realistic goals. For example, after a dear friend has passed away, a depressed patient might now find life unbearable because the current situation is compared against a better past when the friend was alive (this corresponds to an excessive standard as described by the RDMR). Yet, the patient might be totally aware that returning to the past is impossible, thus not pursuing any goal concerning a return to the past.

Another parallelism can be drawn between the idea of an inability to disengage from unattainable goals and the idea of diminished learning rate, the former proposed by control theory (Carver & Scheier, 1990; Hyland, 1987; Pyszczynski et al.,, 1987) and the latter by the RDMD. Yet again, despite the similarity, the two concepts are not equivalent. To understand why, let us apply the RDMD to describe a person who suddenly loses a job. If not affected by depression, the person will abandon the goal of going back to the old job and will seek a less ambitious new job (reflecting an ability to disengage from unobtainable goals). Concomitantly, the person will manage to adjust the standards about subjective value: readjusted standards imply that the subjective value of new jobs, despite being negative at the beginning, will now appear quite good—intuitively, the person thinks: "After all, jobs available on the market are not as bad". If the same person is prone to depression, she might still be able to abandon the goal of going back to the old job and seek a less ambitious new job (thus manifesting a normal ability to disengage from unattainable goals); but (because of a low learning rate), according to the RDMD, the depressed person will fail to adjust the standards, implying that the subjective value of new jobs will continue to appear as quite grime. As this example illustrates, the RDMD suggests that depressed patients might entertain excessive standards despite pursuing obtainable goals. This picture is compatible with empirical literature reporting that depressed patients are as good as controls in disengaging from unattainable goals (Dickson et al., 2016; Koppe & Rothermund, 2017; but see Dunne et al., 2011; Wrosch et al., 2003).

So far, we have assumed that early-life stress alone shapes the learning rate. However, this view is likely to be simplistic: at least to some degree, the learning rate is arguably affected also by stress experienced later in life. A possibility is that, for people predisposed to depression, every new stress experience decreases further the learning rate. This implies that every new experience of stress will enhance the sensitivity to subsequent stress, thus rendering depression more likely to arise in response to new stress (this is because, as examined above, the smaller the learning rate, and the lower the ability to adjust the standards in

response to stress). This possibility fits with the "kindling" hypothesis of depression, positing that previous episodes of the illness render new episodes more likely—an hypothesis supported by empirical literature (Kendler et al., 2000; Monroe & Harkness, 2005).

Dual-process theories (Kahneman, 2011) raise the question of whether subjective value, which is a key concept in the RDMD, is represented in an explicit or implicit form in the mind. Although sometimes people might be aware about their subjective values, the latter are likely to be primarily under the control of implicit processes. This picture fits with a recent proposal that abnormal implicit processes, more than explicit ones, are central to depression (Hyland, 2020).

Our framework can inspire process theories examining how treatments of depression work, thus contributing to developing better treatments. Let us first consider the psychological domain. Here, mindfulness has emerged as an effective intervention for the disorder (Hofmann et al., 2010). Within our model, by promoting acceptance and mental flexibility, mindfulness practices can be interpreted as strategies aimed at adapting the reference point to the ongoing environment. Considering the pharmacological domain, drugs targeting the neurotransmitter serotonin are standard treatments for depression (Hieronymus et al., 2018; but see). Within our model, their effect can be interpreted as increasing the learning rate so that, after new learning occurs, the reference point can adjust to a new environment. This view is consistent with the observation that the benefits of serotoninergic drugs on depression are delayed (Michely et al., 2020). Note however that, although serotoninergic drugs are standard treatments for the disorder, recent evidence indicates that, to a substantial degree, placebo processes mediate the effectiveness of these drugs (Jakobsen et al., 2020; Kirsch, 2019). In light of this evidence, a possibility raised by our model is that, somehow, placebo-related processes might also increase the learning rate, thereby benefitting patients.

In summary, this paper introduces a theory of depression grounded on the notion of reference dependent evaluation. The model interprets multiple facets of the disorder as all arising from a unique factor, that is, from an excessive reference point which is rigidly maintained despite changes in the environment. This framework contributes to building a computational understanding of depression, which can inspire research (both empirical and theoretical) as well as the development of better interventions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data are not available because this is a theoretical paper and no data were analysed.

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