Effect of Daily Life Reward Loop Functioning on the Course of Depression

Heininga, Vera E.; Ornee, Daan A.; Oldehinkel, Albertine J.; Bastiaansen, Jojanneke A.

Published in:
Behavior Therapy

DOI:
10.1016/j.beth.2023.01.007

Publication date:
2023

Available online at www.sciencedirect.com
ScienceDirect
Behavior Therapy 54 (2023) 734–746
Behavior Therapy
www.elsevier.com/locate/bt

Effect of Daily Life Reward Loop Functioning on the Course of Depression

Vera E. Heininga
Daan A. Ornee
Albertine J. Oldehinkel
University of Groningen

Jojanneke A. Bastiaansen
University of Groningen and Friesland Mental Health Care Services

Engagement in activities increases positive affect (Reward Path 1), which subsequently reinforces motivation (Reward Path 2), and hence future engagement in activities (Reward Path 3). Strong connections between these three reward loop components are considered adaptive, and might be disturbed in depression. Although some ecological momentary assessment (EMA) studies have investigated the cross-sectional association between separate reward paths and individuals' level of depression, no EMA study has looked into the association between individuals' reward loop strength and depressive symptom course. The present EMA study assessed reward loop functioning (5x/day, 28 days) of 46 outpatients starting depression treatment at secondary mental health services and monitored with the Inventory of Depressive Symptomatology—Self-Report (IDS-SR) during a 7-month period. Results of multilevel regression analyses showed significant within-person associations for Reward Path 1 ($b = 0.21$, $p < .001$), Reward Path 2 ($b = 0.43$, $p < .001$), and Reward Path 3 ($b = 0.20$, $p < .001$). Stronger average reward loops (i.e., within-person mean of all reward paths) did not relate to participants' improvement in depressive symptoms over time. Path-specific results revealed that Reward Paths 1 and 2 may have partly opposite effects on depressive symptom course. Together, our findings suggest that reward processes in daily life might be best studied separately and that further investigation is warranted to explore under what circumstances strong paths are adaptive or not.

Keywords: depression; motivation; positive affect; reward engagement; experience sampling method (ESM)

Funding: This work was supported by the charitable foundation Stichting tot Steun VCVGZ (239) in collaboration with the Dutch Depression Foundation. Smartphones were provided by the iLab of the department of Psychiatry of the UMCG (http://ilabpsychiatry.nl/en_US/).
The authors declare no conflicts of interest.
Address correspondence concerning to Vera E. Heininga, Ph.D., PO Box 30.001, 9700 RB Groningen, The Netherlands. e-mail: v.e.heininga@umcg.nl.

MAJOR DEPRESSIVE DISORDER (MDD) is one of the most common mental health conditions: almost one in five people experience a depressive episode at some point in their lives (Malhi & Mann, 2018). According to the *Diagnostic and Statistical Manual of Mental Disorders*, 5th Edition (DSM-5; American Psychiatric Association, 2013), individuals diagnosed with MDD experience five or more symptoms during at least 2 weeks, including at least one of two core symptoms: depressed mood and loss of pleasure. Loss of pleasure in previously rewarding activities, also known as anhedonia, has consistently been linked to reduced reward processing (Der-Avakian & Markou, 2012; Pizzagalli, 2014) and a poor MDD prognosis (Vrieze et al., 2013; Wardenaar et al., 2012).

Treatment for depression often starts with behavioral activation therapy. Behavioral activation is a structured, brief psychotherapeutic approach that aims to (a) increase engagement in rewarding activities, (b) decrease engagement in activities that maintain depression or increase risk for depression, and (c) solve problems that limit access to reward or that maintain or increase aversive control (Dimidjian et al., 2011). Interest in behavioral activation treatments for depression has increased over the past two decades, as it is less costly and complex than other psychotherapies (Ekers et al., 2011; Gortner et al., 1998), and at least as efficacious (see Ekers et al., 2014, for a meta-analysis).

The mechanisms of change that bring about depressive symptom improvement in behavioral activation treatments are not yet fully understood (Forbes, 2020; Janssen et al., 2021), but it is plausible that the treatment intervenes in the aberrant reward processing that is often found in MDD. Reward processing is complex, and is parsed into the components of wanting (i.e., motivation for rewards), liking (i.e., experiencing positive emotions, such as cheerfulness, relaxation, and enthusiasm), and learning (Berridge et al., 2009). Findings from neurobiology, primarily based on animal studies, strongly suggest that these components map onto partially different neurobiological pathways (Berridge & Robinson, 2003).

Based on neurobiological evidence and the principles of behavioral activation (illustrated in Figure 1), engaging in rewarding activities is expected to increase positive affect (Reward Path 1), which subsequently reinforces motivation (Reward Path 2) for engaging in such activities (Reward Path 3). Strong connections between reward loop components are believed to be adaptive because they steer an organism toward rewards (Berridge & Robinson, 2003; Rømer Thomsen et al., 2015). Hence, investigating dysregulation in the various components of reward processing in MDD holds promise for developing more targeted and efficacious treatment and intervention strategies (see Whitton et al., 2015, for a review).

Reward processing in MDD is typically studied in controlled environments, using laboratory tasks that involve stimuli and rewards that mimic real life. Unlike traditional assessment approaches, the ecological momentary assessment (EMA) approach enables researchers to observe reward processes in the flow of individuals' actual daily lives, and therefore offers a more ecologically valid approach to study reward functioning. An individual's engagement in rewarding activities, positive affect (PA), and motivation for engagement in rewarding activities can, for instance, be assessed by means of one or more short questionnaires per day over the course of several days or weeks. This repeated sampling allows researchers to study dynamic relationships on the individual level, for example, to what extent changes in an individual's engagement in activities are associated with changes in their subsequent PA. Below, we review studies that examined three components of reward processing, with a special focus on EMA research in MDD.

Engagement in Activities and Subsequent PA (Reward Path 1)

EMA studies consistently show that engagement in physical activity and social interaction are associated with higher levels of PA in healthy individuals (Aggio et al., 2017; Bos et al., 2018; Cushing et al., 2017; Glasgow et al., 2019; Pannicke et al., 2020; Schöndube et al., 2016), as well as in individuals with depressive symptoms (Flores et al., 2018; Hollands et al., 2020; Kesselring et al., 2021; Zawadzki et al., 2022; but see Bakker et al., 2017). An active lifestyle and social company have also been reported to diminish depressive symptoms (Kendall et al., 2014; Snippe et al., 2016), but the beneficial effects of physical activity may evaporate sooner in depressed than in nondepressed individuals (Wichers et al., 2012; but see Heininga et al., 2019). Taken together, EMA studies into "liking" processes suggest that changes in engagement in physical and social activities are associated with changes in the level of subsequent PA, and that this association might be weaker in individuals with depressive symptoms.

PA and Subsequent Motivation to Engage in Activities (Reward Path 2)

According to the broaden-and-build theory, high levels of PA boost psychological well-being because PA facilitates goal-directed action (Fredrickson, 2004; Fredrickson et al., 2000). In line with theory, experimental research shows that this path might be disturbed in individuals with MDD—for example, in an experimental study where depressed and nondepressed individuals were asked to rate how much they liked cartoons, the levels of liking predicted motivation to expend effort for rewards only in healthy participants but not in participants diagnosed with depression (Sherdell et al., 2012). However, motivation is a multifaceted construct and there is no consensus yet on how motivation is measured best in daily life. Using an EMA approach, Bakker and colleagues (2017) reported a positive association between the level of PA and the level of reward anticipation measured 90 minutes later in both healthy controls and individuals with at least moderate depressive symptoms. Bakker and colleagues asked participants to think about the most important situation they thought they would encounter in the next hour and to rate how much they were looking forward to this situation, a construct the

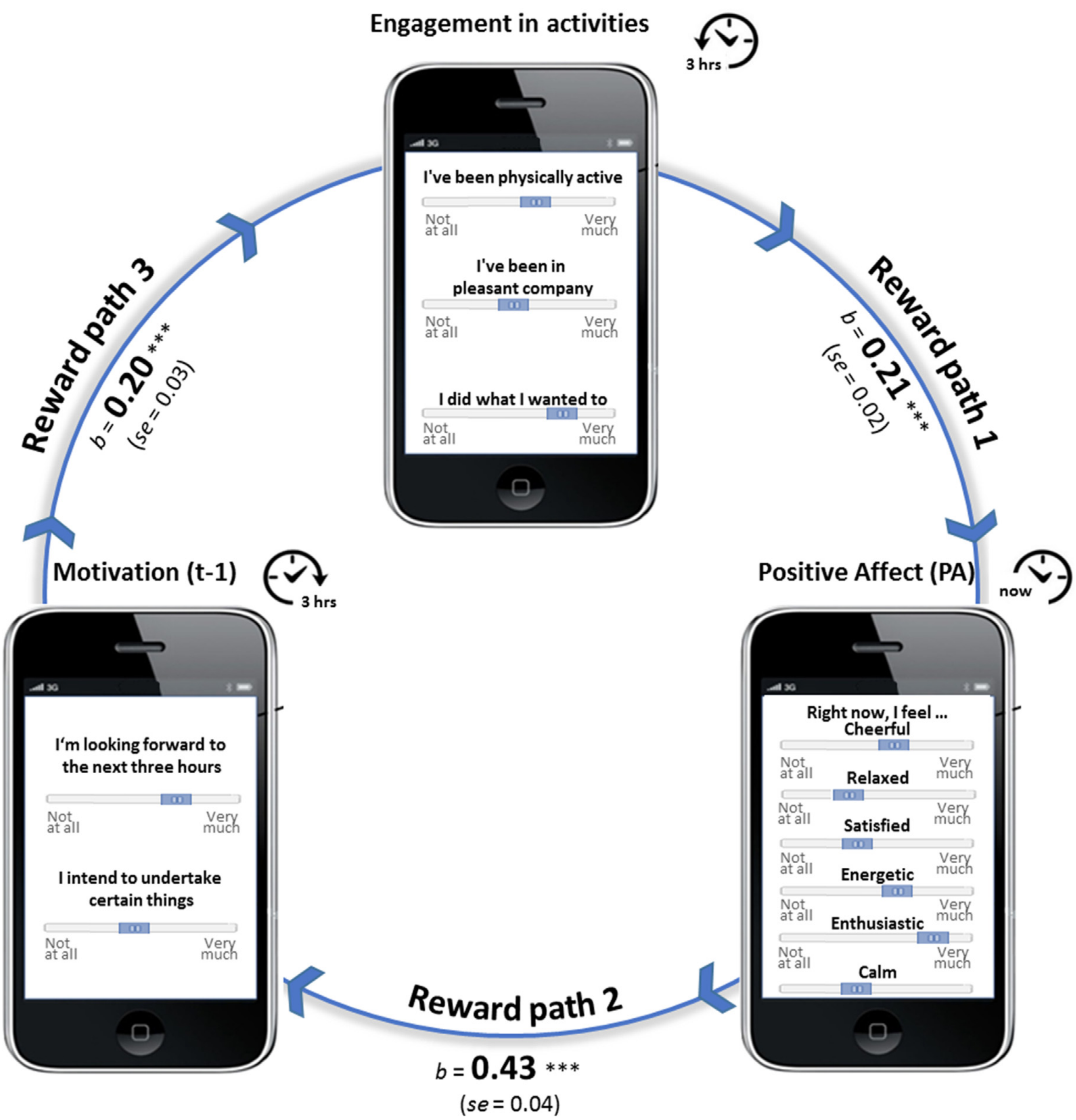

FIGURE 1 Overview of the three reward paths underlying the average reward loop strength, with the ecological momentary assessment (EMA) items used in this study listed below the three main concepts together with exemplary answers. According to the principles of behavioral activation, neurobiological evidence, and preliminary evidence from EMA studies, engaging in activities increases positive affect (Reward Path 1), which subsequently reinforces motivation (at *t*; Path 2) and hence engagement in future activities (using motivation *t*–1; Path 3). The *b* values reflect the person–mean-centered slope coefficients found in the present study. *SE* = standard error. ***$p < .001$.

authors labeled “reward anticipation.” Although anticipation of a reward is a concept similar to motivation, the motivation to engage in activities is a broader concept as it also includes an activation and effort-related aspect (Berridge et al., 2009; Engel et al., 2013; Sherdell et al., 2012). van Roekel et al. (2019), who operationalized motivation as the mean level of determination and the inverse of sluggishness, also reported a positive association between PA and motivation measured 6 hours later both in individuals with and without anhedonia. In contrast to the idea that strong connections between reward loop components are adaptive, individuals with anhedonia showed a stronger association between PA and subsequent motivation compared to healthy controls. In sum, EMA studies suggest that changes in PA are associated with changes in subsequent motivation, and that this association is either equal in depressed and nondepressed individuals or stronger in individuals with depressive symptoms.

Motivation and Subsequent Engagement in Activities (Reward Path 3)

Several EMA studies investigated the association between reward anticipation and subsequent engagement in activities—for example, using a large community sample, Bakker and colleagues (2017) reported no significant association between reward anticipation and subsequent engagement in activities. Engagement in activities was assessed with the item "I am actively engaged in something." Exploratory analyses by Bakker et al. in a subsample of 20 participants without any depressive symptoms showed that anticipation of reward positively predicted engagement in activities up to 3 hours later (on average 90 minutes). However, the authors report no association between anticipation of reward and subsequent active engagement in a subsample of 22 participants with at least moderate depressive symptoms. This (exploratory) finding contrasts with functional magnetic resonance imaging (fMRI) studies showing significant associations between reward anticipation and subsequent engagement in activities in individuals with depression, or individuals at risk for depression. In a study where reward anticipation was measured during an fMRI guessing task, adolescent youth at high familial risk for depression show reduced striatal response during the 12 seconds before a reward is presented (e.g., Olino et al., 2014), and such reduced reward anticipation correlated with lower positive affect as measured by EMA in adolescents with MDD (Forbes et al., 2009). In a similar vein, EMA studies that rely on self-reports of reward anticipation (i.e., participants reporting the extent to which they look forward to activities) report reduced reward anticipation in individuals with more severe depressive symptoms (Li et al., 2019). In conclusion, the path from motivation to engagement in activities is still understudied, and predominantly focused on reward anticipation—a related but distinct concept. So far, EMA findings indicate that changes in the anticipation of rewards are likely associated with changes in subsequent engagement in activities and that this association is weaker or absent in individuals with depressive symptoms.

The Present Study

It has been put forward that a strong reward loop is evolutionarily adaptive because it steers organisms toward rewards (Bakker et al., 2017; Berridge & Robinson, 2003; Rømer Thomsen et al., 2015). The EMA literature so far only partially supports this hypothesis, as EMA findings suggest that Reward Paths 1 and 3 might be weaker or absent in individuals with depressive symptoms, but Reward Path 2 is either similar or stronger in individuals with depressive symptoms.

The present study adds more clarity on whether a strong reward loop is evolutionarily adaptive, by testing the hypothesis more directly (preregistration of the hypothesis and analysis plan: https://osf.io/h5qta). Instead of the cross-sectional association between separate reward paths and individuals' level of depressive symptoms, the present study investigates the association between individuals' average reward loop strength (calculated as the mean coefficient across all three reward paths) and depressive symptom course over 7 months after the start of depression treatment. Given that activation is a key principle of behavioral activation (Dimidjian et al., 2011), we measured participants' intention to engage in activities (i.e., the activation and effort-related aspect of motivation) in addition to the extent to which participants look forward to activities (i.e., the reward anticipation aspect of motivation, as also measured by Bakker et al., 2017).

We expect that higher reward loop connection strength is associated with decreases in depressive symptoms over time. Given that previous EMA studies suggest that Reward Path 2 is either equal (Bakker et al., 2017) or stronger in individuals with depressive symptoms (van Roekel et al., 2016), we also investigate how the separate reward paths relate to depressive symptom course.

Material and Methods

PARTICIPANTS AND PROCEDURE

The sample consisted of 46 outpatients with a clinical diagnosis of depression starting depression treatment at secondary mental health services (mean age 32.80 years; $SD = 12.15$; 45.65% women). The sample is a subsample of the 161 participants from the ZELF-i study (Bastiaansen et al., 2018, 2020), of whom 55 were randomly assigned to an experimental condition involving weekly personalized feedback on their PA and activities (i.e., the "Do module").

The weekly feedback was mostly descriptive in nature—for example, during the first 3 weeks, participants got insight into what activities they did the most the past week and what their average level of PA was for that specific week (see https://osf.io/m9w8k for an example report after the first week). After 4 weeks, participants received personalized feedback based on vector autoregressive (VAR) models on their link between activities and PA (e.g., correlation between being outside and participants' mean level of PA), but this was after participants had completed the EMA part of the study.

Nine of these 55 participants were excluded from the analyses: four participants dropped out of the study due to practical reasons or time constraints, three for unknown reasons, one participant had possibly invalid data due to selecting the last questionnaire of the day for all measurements, and for one participant nearly all measurements were missing. Completers and dropouts did not differ significantly in baseline depression severity or psychosocial functioning (see Bastiaansen, 2020, supplementary appendix B).

At enrollment, participants were instructed on the EMA protocol and completed baseline questionnaires on depressive symptom severity, psychosocial functioning, and empowerment. Participants were sent five text messages per day containing a link to the online EMA survey following a fixed sampling scheme (i.e., 3 hours between assessments) for 28 consecutive days (via routine outcome monitoring software RoQua: www.roqua.nl). They received a reminder after 15 minutes and had 30 minutes to complete the EMA assessment, which consisted of in total 35 questions about the participant's current mood, physical state, and activities (see Bastiaansen et al., 2018, for the full item list). Each assessment comprised a momentary part, a retrospective part (past 3 hours), and a prospective (next 3 hours) part. In addition, the morning assessment included a question about sleep, and the evening assessment a few general questions on how participants experienced the past day and how they felt about the next day. In case 10 or more subsequent measurements had been missed, participants were called to ask whether they wanted to stop the EMA measurements. To account for a potential initial elevation bias (Shrout et al., 2018), the first five EMA measurements (i.e., the first day) were excluded from the analyses, leaving a maximum of 135 assessments for each of the 46 participants included in this study.

Participants received travel reimbursements and an optional €10 to compensate for the mobile phone data usage needed to complete the online surveys on their smartphone. The ZELF-i study complied with local ethical regulations and was approved by the Medical Ethical Committee of the University Medical Center Groningen (UMCG, 2015/530). All participants provided written informed consent.

MEASURES

Depression Severity

Depressive symptom severity was measured by the total score of the 30-item self-report Inventory of Depressive Symptomatology (IDS-SR; Rush et al., 1996), which was administered at six time points: baseline (*t*0); directly after the 28 days of EMA assessments (*t*1); and 1 month (*t*2), 2 months (*t*3), 3 months (*t*4), and 6 months (*t*5) after the EMA period. The IDS-SR includes all DSM-5 diagnostic criterion items for MDD (American Psychiatric Association, 2013), as well as commonly associated symptoms, such as irritability. Each item was scored on a scale from 0 to 3, with higher scores denoting greater symptom severity. The IDS-SR has good psychometric properties with high concurrent and internal validity (Cronbach's α at baseline = .84).

Engagement in Activities

Engagement in activities was operationalized as having been involved in physical, social, or planned activities. As shown in Figure 1, during each measurement, participants were asked to respond to the statements "I've been physically active," "I've been in pleasant company," and "I did what I wanted to"[1] with regard to the previous 3 hours, using a visual analogue scale ranging from 0 (*not at all*) to 100 (*very much*). Engagement in activities was calculated as the within-person average of the three items at each measurement.

Positive Affect

For each measurement, PA was calculated as the within-person mean score of six PA adjectives: cheerful, relaxed, satisfied, energetic, enthusiastic, and calm. As shown in Figure 1, participants rated how they felt at that moment on a visual analogue scale ranging from 0 (*not at all*) to 100 (*very much*). The adjectives were balanced regarding high and low arousal (Russell & Barrett, 1999; Watson & Clark, 1994). The nested alpha for multilevel data as proposed by Nezlek (2017) indicated high reliability of the scale (α = .82).

Motivation

Motivation was operationalized as the motivation to pursue rewards, and calculated as the within-person average of two items at each measurement. As shown in Figure 1, these items were "I intend to undertake certain things" and "I'm looking forward to the next three hours/day." Participants rated the items using a visual analogue scale ranging from 0 (*not at all*) to 100 (*very much*). The within-person correlation between the two items was .28 (N = 3,869; p < .001), and the between-person correlation was .62 (N = 46; p < .001).

[1] The "I did what I wanted to" item was linked to the prospective items on motivation for future engagement (i.e., "intend to undertake certain things" and "looking forward to the next three hours/day") for which participants were instructed to think of physical, social, and planned activities.

DATA ANALYTIC STRATEGY

Analyses were performed in a reproducible manuscript using R 4.1.2, Rmarkdown, papaja, lme4, and lmerTest. The hypothesis and data analytic strategy were preregistered via the Open Science Framework: https://osf.io/h5qta.

Descriptive Statistics

To describe how much variation in momentary mood states came from differences between versus within individuals, we calculated the intraclass correlation coefficient (ICC). The ICC is calculated by dividing between-person variance and the sum of between- and within-person variance. An ICC of 0.46 means that 46% of the variance in the variable is due to person-to-person variation (i.e., explainable by person-related characteristics). The remaining part, in this case 54% (i.e., 1–0.46), is due to within-person observation-to-observation variation (i.e., explainable by situational characteristics). There are no clear guidelines for interpreting an ICC, however; scores approaching 1.0 suggest that nearly all variation is occurring at the person level and that modeling individual reward loop strengths would thus not be the appropriate approach.

Determining Reward Path Strengths

The strength of the three reward paths was determined by separate random slopes multilevel linear regression analyses. To establish meaningful zero points on its scales and to prevent collinearity, all predictor variables were person–mean centered (i.e., values were subtracted from participants' own means). Furthermore, to investigate the increase in PA, motivation, or engagement in activities relative to the previous assessment, the lagged variant of each outcome variable was added as a covariate (i.e., EMA assessment *t*–1). All models were fitted using restricted maximum likelihood estimation, with random slopes and intercepts.

Within each participant, PA at assessment *t* was regressed on (retrospectively assessed) person–mean-centered engagement in activities at assessment *t* (Reward Path 1) and person–mean-centered PA at assessment *t*–1, and the person-specific regression coefficient for engagement in activities was saved for further analyses. Similarly, motivation at assessment *t* was regressed on person–mean-centered PA at assessment *t* (Reward Path 2) while controlling for person–mean-centered motivation at assessment *t*–1 (note that PA is momentarily assessed, and motivation is prospectively assessed, meaning that at assessment *t* both items are implicitly subsequent), and engagement in activities at assessment *t* was regressed on person–mean-centered motivation at assessment *t*–1 (Reward Path 3) while controlling for person–mean-centered engagement in activities at assessment *t*–1. The average person-specific regression coefficient of engagement in activities from Path 1, PA from Path 2, and motivation from Path 3 was calculated as a measure of average reward loop strength.

Average Reward Loop Strength and the Course of Depression

Next, we performed multilevel linear regression analyses with average reward loop strength predicting the course of depressive symptoms over time. The six time points at which depressive symptoms were measured (i.e., time variable) and average reward loop strength were entered as predictors of participants' depressive symptom severity. To prevent collinearity between time and time squared, the time variable was centered around its mean (i.e., 2,5) and squared thereafter. It should be noted that, due to mean centering the time variable, *t*0 refers to the midpoint of the six assessments (i.e., in between the 2- and 3-month follow-ups). All models were fitted using restricted maximum likelihood estimation, with random slopes and intercepts.

DEVIATIONS FROM PREREGISTRATION

1. In line with a previous publication (Bastiaansen et al., 2020), quadratic time trends were added to the average reward loop strength predicting the course of depressive symptoms over time because it slightly improved model fit for all models according to Akaike information criterion (see supplementary materials).

2. Because a more detailed review of the literature revealed the EMA literature only partially supports the hypothesis that a strong reward loop is evolutionary adaptive (i.e., Reward Path 2 might be similar or stronger in individuals with depressive symptoms), we also explored the associations between the separate reward path strengths and the course of depression.

Results

DESCRIPTIVE STATISTICS

Participants filled out 78.10% (SD = 16.40) of all assessments on average, with a minimum of 24.44% and a maximum of 97.04%. Table 1 shows a moderate average level of engagement in activities, PA, and motivation, and a moderate to strong correlation between the constructs on the group level. For the score distribution per variable, see the supplementary materials, Figure S1.

The ICC for engagement in activities, PA, and motivation were respectively 0.34, 0.53, and 0.32, meaning that respectively 47%, 66%, and 68% of the variance of these variables was due to within-person observation-to-observation variation.

REWARD PATH STRENGTHS

As depicted in Figure 1 and Table 2, for every unit participants exceeded their own average level of engagement in activities, their subsequent PA (Reward Path 1) increased by 0.21 units (p = <.001; range .10–.35). Similarly, for every unit participants exceeded their own average level of PA, their anticipatory pleasure and tendency to undertake things in the next 3 hours (Reward Path 2) increased by 0.43 units (p = <.001; range .07–.83), and for every unit participants exceeded their own average level of motivation, their engagement in activities in the next 3 hours (Reward Path 3) increased by 0.20 units (p = <.001; range –.04–.55)[2].

Participants' average reward loop connection strength across all three reward paths ranged from .10 to .42, with a group-level average beta of .28 (SE = 0.07).[3]

AVERAGE REWARD LOOP STRENGTH AND THE COURSE OF DEPRESSION

As expected, the course of depression decreased over time in a slightly convex shape (see Table S1 and Figure S2 in the supplementary materials). Contrary to our expectations, the association between participants' average reward loop strength and the course of their depressive symptoms was not significant (see Table 3).

Post Hoc Analysis: The Course of Anhedonia

To investigate whether the lack of an association between average reward loop strength and the course of depression could be explained by the heterogeneous nature of depressive symptoms, we also explored the association between average reward loop strength and the course of the most relevant depressive symptom for reward processing: anhedonia. Anhedonia was operationalized as the sum score of the four anhedonic items of the IDS-SR (i.e., 8: response of your mood to good or desired events; 21: general interest, 23; capacity for pleasure or enjoyment, excluding sex; and 24: interest in sex).

The course of anhedonia decreased marginally over time with the majority of symptom improvement between baseline and the post-EMA assessment (see Table S2 and Figure S3 in the supplementary materials). We found no interaction between participants' average reward loop strength and the amount of change in anhedonia over time (see Table 3). Thus, it is unlikely that the heterogeneity of the depression measure caused the lack of our association between average reward loop strength and the course of depression.

Table 1
Descriptive Statistics for the Three EMA Variables

Variable	M	SD	1	2
EA	42.09	12.70		
PA	40.69	13.94	.58** [0.34, 0.74]	
MOT	50.22	12.14	.70** [0.51, 0.82]	.75** [0.59, 0.86]

Note. EMA = ecological momentary assessment; M = mean; SD = standard deviation; EA = engagement in activities; PA = positive affect; MOT = motivation. Values in brackets indicate 95% confidence intervals. The correlations were calculated on the group level.
** p < .01.

Separate Reward Path Strengths and the Course of Depression

As shown in the left side of Table 4, analyses of the separate reward path strengths revealed a significant negative main effect of Reward Path 1 (from engagement in activities to PA) on depression at $t0$ (B = –4.41, p = .03); note that due to mean centering $t0$ refers to the midpoint of the six assessments (i.e., in between the 2- and 3-month follow-ups), and a significant interaction with the linear course of depression. The interaction between the strength of Path 1 and the quadratic course of depression was nonsignificant. Descriptive simple slopes estimated based on the quadratic model for Path 1 (see Figure S3, left graph) indicate that a stronger Reward Path 1 connection might be associated with more improvement in depressive symptoms over time.

The strength of Reward Path 2 (from PA to motivation) had a positive main effect on depression at t0. There was no interaction with the linear

[2] Given that a similar previous ESM study (Bakker et al., 2017) focused on reward anticipation, and our results show a low within-person correlation between the two motivation items, we reran our analyses while using only the "I am looking forward to" (i.e., reward anticipation) item. Although the coefficients for Reward Path 2 and Reward Path 3 were stronger on group level compared to the coefficients depicted in Table 2, there was still no significant association between participants' average reward loop strength and their course of depression. For more information, see the supplementary materials.

[3] Similar effects are found when adding a Level 2 predictor that represents the deviation of the person mean from the overall grand mean to the model. For details, see the supplementary materials.

Table 2
Reward Path Strengths

	Path 1 (from EA to PA)					Path 2 (from PA to MOT)					Path 3 (from MOT to EA)				
	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)
(Intercept)	40.95	2.08	45.12	19.64	0.00	50.35	1.85	45.06	27.19	0.00	41.97	1.91	45.23	21.97	0.00
Predictor	0.21	0.02	37.55	13.28	0.00	0.43	0.04	36.79	11.53	0.00	0.20	0.03	43.40	7.08	0.00
Control	0.42	0.02	44.47	16.94	0.00	0.14	0.03	41.28	5.39	0.00	0.23	0.02	46.81	9.29	0.00

Note. EA = engagement in activities; PA = positive affect; MOT = motivation; Est. = estimate; *SE* = standard error; *df* = degrees of freedom. Path 1: the effect of EA (predictor) on PA controlled for the level of PA at the previous assessment (control); Path 2: the effect of PA (predictor) on MOT controlled for the level of MOT at the previous assessment (control); Path 3: the effect of MOT at the previous assessment (predictor) on EA controlled for the level of EA at the previous assessment (control). All predictors and control variables are person–mean centered.

course of depression but a significant negative interaction with the curvilinear course of depression (see Table 4). The descriptive simple slope in the middle graph of Figure S3 shows that participants with a stronger Path 2 connection showed a rather linear decline in depressive symptoms over time. Participants with a relatively weak Path 2 connection strength improved more in the beginning of the follow-up period but regained depressive symptoms after 2 months post-EMA. Despite Path 2 strength-related differences in the estimated course of depression, all participant groups reported about similar levels of depressive symptoms at 6 months post-EMA.

The strength of participants' Reward Path 3 (from motivation to engagement in activities) had no significant main effect on depression at $t0$ and was not associated with the linear course of depression, but did show a significant association with the quadratic course of depression (see Table 4). As visualized in the descriptive simple slope graphs, participants with a relatively weak Reward Path 3 showed an estimated linear decline in depressive symptoms, whereas participants with a strong Reward Path 3 seemed to improve in depressive symptoms more strongly at first but partially regained depressive symptoms again after 2 months and seem to be worse off than those with a weak path at 6 months post-EMA (Figure S3).

Discussion

The present study was the first to examine the association between depressed individuals' real-life reward loop functioning and their depressive symptom improvement over time. Based on the premise that positive reward path strengths between the three major components of reward functioning (positive affect, motivation, and activities) are an indication of a good functioning reward system, we hypothesized that a stronger average reward loop strength would be associated with more depressive symptom improvement. Although all components of reward functioning were positively associated on the group level, and participants' depressive symptoms improved over time, there was no interaction between participants' average reward loop strength and their course of depression over a 7-month period. Path-specific results showed that this might be because Reward Paths 1 and 2 have partly opposite effects on depressive symptom improvement.

With regard to reward loop functioning, involvement in physical, social, or planned activities was significantly associated with participants' increase in positive affect approximately 3 hours later (Reward Path 1 of Figure 1). The increases

Table 3
Results of Multilevel Random Slopes Models Testing the Interaction Between Average Reward Loop Strength and Symptom Course for Depression and Anhedonia

	Depression					Anhedonia				
	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)
(Intercept)	26.59	2.09	43.94	12.72	0.00	3.32	0.43	43.47	7.76	0.00
Reward loop strength	2.24	2.13	46.54	1.05	0.30	0.43	0.44	46.86	0.98	0.33
t	-1.60	0.44	32.78	-3.63	0.00	-0.21	0.09	35.16	-2.39	0.02
t^2	0.59	0.26	34.74	2.26	0.03	0.12	0.06	33.19	2.04	0.05
Reward loop strength*t	-0.56	0.50	34.77	-1.12	0.27	0.00	0.10	37.10	-0.03	0.97
Reward loop strength*t^2	-0.17	0.28	41.98	-0.60	0.55	0.01	0.07	39.74	0.16	0.87

Note. Est. = estimate; *SE* = standard error; *df* = degrees of freedom. Depression severity was measured with the Inventory of Depressive Symptomatology (IDS-SR) across six time points. Anhedonia was measured with the four-item subscale of the ISD-SR. Reward loop strength was calculated as the average individuals' coefficient of the three reward loop pathways coefficients (see Figure 1) measured during the experience sampling method period. The variables t and t^2 refer to the linear and quadratic effect of time, respectively. Reward loop strength was standardized. Due to mean centering, $t0$ refers to the midpoint of the six assessments (i.e., in between the 2- and 3-month follow-ups).

in participants' level of positive affect, in turn, were associated with increases in their subsequent motivation to pursue rewards (Reward Path 2). Finally, participants' increases in motivation were significantly associated with increases in their engagement in physical, social, or planned activities in the next 3 hours (Reward Path 3). That we observed dynamic associations for all three reward paths in daily life provides further supportive evidence that the wanting and liking processes observed in laboratory settings can also be observed in the flow of daily life (i.e., ecological validity), and that there are individual differences in those paths—even within a sample of individuals diagnosed with depression.

Our findings with regard to the reward path strengths are largely consistent with the only previous EMA study that also examined all parts of the reward cycle, except for one path. In a community sample, Bakker and colleagues (2017) reported positive associations for Paths 1 and 2, but not for Path 3. Additional analyses showed a positive association for Path 3 in participants without depressive symptoms ($N = 20$) and no significant association in participants with at least moderate depressive symptoms ($N = 22$). That we found a significant Path 3 in our sample of depressed individuals and Bakker et al. did not may be due to differences in study design and analytical strategy—for instance, our larger time frame (3 hours vs. 90 minutes) might have provided more room for engagement in activities, or a better fit to model the effect of motivation on the engagement in activities. In addition, Bakker and colleagues used network analyses to study all bidirectional effect simultaneously in one model (i.e., results are controlled for all other effects in the model), whereas we studied the unidirectional effects separately. Moreover, we may have had more power to detect effects due to a larger sample size of individuals with depressive symptoms ($N = 46$ vs. $N = 22$).

A high average strength of the three reward paths, hence strong positive connections between behavioral, motivational, and emotional reward components, has been proposed to be a sign of a well-functioning reward system (Bakker et al., 2017) and evolutionary adaptiveness (Berridge & Robinson, 2003; Rømer Thomsen et al., 2015)—however, we find no support for the hypothesis that a high reward loop connection strength predicts more decreases in depressive symptom course over 7 months. Also when we zoomed in on anhedonia, a more proximal construct for reward functioning than the multifaceted construct of depression, we did not find support for the hypothesis (but note that variability in scores was rather low). Given that we tested the hypothesis more directly than previous EMA studies, our results cast doubts on whether a high average reward loop strength is always a sign of a well-functioning and adaptive reward system.

This is further supported by our path-specific analyses, which show that different positive reward path strengths work in partly opposite ways with regard to individuals' depression level and course—that is, for Reward Path 1 (from engagement in activities to PA), our results are in line with our expectations based on theory (i.e., the stronger the path, the better the depression course). However, for Reward Path 2 (from PA to motivation), our results show a negative effect of a strong connection: the stronger the path, the worse the depression, especially in the first couple of months after intake. Our finding for Path 2 is in line with findings by van Roekel and colleagues (2019), who found a stronger association between

Table 4
Associations Between the Strength of the Separate Reward Paths and Depressive Symptom Course

	Path 1					Path 2					Path 3				
	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)	Est.	*SE*	*df*	*t* value	Pr(>|*t*|)
(Intercept)	26.64	2.00	42.40	13.33	0.00	26.49	1.96	44.19	13.49	0.00	26.55	2.10	43.20	12.64	0.00
Path	−4.41	2.00	41.93	−2.21	0.03	5.42	1.98	45.22	2.74	0.01	−0.72	2.11	43.81	−0.34	0.74
t	−1.59	0.40	33.01	−4.01	0.00	−1.58	0.43	33.63	−3.65	0.00	−1.75	0.44	32.45	−3.97	0.00
t^2	0.58	0.26	32.22	0.69	0.04	0.62	0.24	37.73	2.54	0.02	0.52	0.22	32.83	2.34	0.03
Path*t	−1.08	0.39	32.21	−2.81	0.01	−0.60	0.46	33.92	−1.29	0.20	0.52	0.45	31.64	1.15	0.26
Path*t^2	−0.02	0.26	31.75	−0.09	0.93	−0.63	0.25	40.91	−2.49	0.02	0.61	0.22	31.68	2.71	0.01

Note. Est. = estimate; *SE* = standard error; *df* = degrees of freedom. Depression severity was measured with the Inventory of Depressive Symptomatology (IDS-SR) across six time points. The variables t and t^2 refer to the linear and quadratic effect of time, respectively. Due to mean centering, $t0$ refers to the midpoint of the six assessments (i.e., in between the 2- and 3-month follow-ups).

PA and subsequent motivation in people with anhedonia compared to healthy controls. The stronger association in individuals with anhedonia was mostly driven by lower levels of PA predicting a subsequent decrease in motivation. A strong connection between PA and motivation may thus be detrimental if individuals already experience low levels of PA to begin with. Another possible explanation comes from the literature on PA dampening—that is, mental strategies that downgrade the intensity and duration of PA by minimizing its significance or by directing attention away from it.

Previous research shows that dampening of PA predicts subsequent low motivation (Dunn et al., 2018)—hence, a strong Path 2 (from PA to motivation) might indicate a high degree of PA dampening. In turn, greater engagement in dampening following PA has been associated with a more negative course of depression (see Bean et al., 2022, for a meta-analysis). Taken together, our findings suggest that future researchers should be cautious about accumulating or averaging all three reward paths in daily life. One cannot simply assume that the pathways are affected in the same way for every individual, or that they interact in the same way with the course of depression. Although replication is warranted, for clinical practice, it may be useful to consider tracking patients' connections between engagement in activities and subsequent PA (Reward Path 1) and between PA and motivation (Reward Path 2) during treatments, as they could provide handles to further personalize behavioral activation therapy sessions. In the future, EMA researchers could assess patients' reward loop functioning for a longer duration of EMA, for example, across the whole span of patients' behavioral activation therapy sessions. That way, they could get insight into the extent to which Reward Paths 1 and 2 are dynamically changing over time, and to what extent these changes are associated with changes in participants' course of depressive symptoms. This approach is also interesting for clinicians because there are likely large individual differences between patients. While it may be especially important for one patient not to wait for motivation before engaging in pleasant activities, it may be more important for another patient to investigate why they cannot enjoy certain activities and how they can improve their level of PA. Purely speculatively, if clinicians are aware of (changes in) patients' personal connection strengths, they can take this into account in the treatment plan and therewith contribute to a faster depression recovery.

Limitations

The interpretation of the findings of the present study comes with a limitation. Participation of the Do module entailed weekly person-specific descriptive feedback, which could have changed participants' normal levels of positive affect and/ or physical activity—however, explicit feedback on the link between positive affect and engagement in activities was not provided until after the EMA period. In theory, participants could have drawn links between their descriptive graphs on the level of PA and physical activity over the past week—however, most participants reported that they did not notice any actual impact of the EMA intervention on their behavior (Folkersma et al., 2021). Moreover, there is no statistical evidence that the intervention of the Do module increased PA over time (Ornée et al., 2021) nor that it augmented the efficacy of regular depression treatment (Bastiaansen et al., 2020), suggesting that any distorting effects of the EMA module are limited.

Conclusions

That we were able to observe the three major components of reward processing in MDD across a 3-hour time frame and in the daily lives of individuals diagnosed with depression holds promise for developing more targeted and efficacious treatment and intervention strategies. Albeit strong reward loops are considered adaptive, the underlying components of reward processing may be differentially related to depressive symptom improvement.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.beth.2023.01.007.

References

Aggio, D., Wallace, K., Boreham, N., Shankar, A., Steptoe, A., & Hamer, M. (2017). Objectively measured daily physical activity and postural changes as related to positive and negative affect using ambulatory monitoring assessments. *Psychosomatic Medicine, 79*(7), 792–797. https://doi.org/10.1097/psy.0000000000000485.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Author. https://doi.org/10.1176/appi.books.9780890425596.

Bakker, J. M., Goossens, L., Lange, I., Michielse, S., Schruers, K., Lieverse, R., Marcelis, M., van Amelsvoort, T., van Os, J., Myin-Germeys, I., & Wichers, M. (2017). Real-life validation of reduced reward processing in emerging adults with depressive symptoms. *Journal of Abnormal Psychology, 126*(6), 713–725. https://doi.org/10.1037/abn0000294.

Bastiaansen, J. A., Meurs, M., Stelwagen, R., Wunderink, L., Schoevers, R. A., Wichers, M., & Oldehinkel, A. J. (2018). Self-monitoring and personalized feedback based on the experiencing sampling method as a tool to boost depression treatment: A protocol of a pragmatic randomized controlled trial (ZELF-i). *BMC Psychiatry, 18*(1), 1–11. https://doi.org/10.1186/s12888-018-1847-z.

Bastiaansen, J. A., Ornée, D. A., Meurs, M., & Oldehinkel, A. J. (2020). An evaluation of the efficacy of two add-on ecological momentary intervention modules for depression in a pragmatic randomized controlled trial (ZELF-i). *Psychological Medicine, 52*(13), 2731–2740. https://doi.org/10.1017/s0033291720004845.

Bean, C. A., Summers, C. B., & Ciesla, J. A. (2022). Dampening of positive affect and depression: A meta-analysis of cross-sectional and longitudinal relationships. *Behaviour Research and Therapy, 156*, 104153. https://doi.org/10.1016/j.brat.2022.104153.

Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends in Neurosciences, 26*(9), 507–513. https://doi.org/10.1016/S0166-2236(03)00233-9.

Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward: "Liking", "wanting", and learning. *Current Opinion in Pharmacology, 9*(1), 65–73. https://doi.org/10.1016/j.coph.2008.12.014.

Bos, F. M., Blaauw, F. J., Snippe, E., van der Krieke, L., de Jonge, P., & Wichers, M. (2018). Exploring the emotional dynamics of subclinically depressed individuals with and without anhedonia: An experience sampling study. *Journal of Affective Disorders, 228*, 186–193. https://doi.org/10.1016/j.jad.2017.12.017.

Cushing, C. C., Mitchell, T. B., Bejarano, C. M., Walters, R. W., Crick, C. J., & Noser, A. E. (2017). Bidirectional associations between psychological states and physical activity in adolescents: A mHealth pilot study. *Journal of Pediatric Psychology, 42*(5), 559–568. https://doi.org/10.1093/jpepsy/jsw099.

Der-Avakian, A., & Markou, A. (2012). The neurobiology of anhedonia and other reward-related deficits. *Trends in Neurosciences, 35*(1), 68–77. https://doi.org/10.1016/j.tins.2011.11.005.

Dimidjian, S., Barrera, M., Martell, C., Muñoz, R. F., & Lewinsohn, P. M. (2011). The origins and current status of behavioral activation treatments for depression. *Annual Review of Clinical Psychology, 7*(1), 1–38. https://doi.org/10.1146/annurev-clinpsy-032210-104535.

Dunn, B. D., Burr, L. A., Smith, H. B., Hunt, A., Dadgostar, D., Dalglish, L., Smith, S., Attree, E., Jell, G., Martyn, J., Bos, N., & Werner-Seidler, A. (2018). Turning gold into lead: Dampening appraisals reduce happiness and pleasantness and increase sadness during anticipation and recall of pleasant activities in the laboratory. *Behaviour Research and Therapy, 107*, 19–33. https://doi.org/10.1016/j.brat.2018.05.003.

Ekers, D., Godfrey, C., Gilbody, S., Parrott, S., Richards, D. A., Hammond, D., & Hayes, A. (2011). Cost utility of behavioural activation delivered by the non-specialist. *British Journal of Psychiatry, 199*(6), 510–511. https://doi.org/10.1192/bjp.bp.110.090266.

Ekers, D., Webster, L., Van Straten, A., Cuijpers, P., Richards, D., & Gilbody, S. (2014). Behavioural activation for depression: An update of meta-analysis of effectiveness and sub group analysis. *PLoS One, 9*(6), e100100. https://doi.org/10.1371/journal.pone.0100100.

Engel, M., Fritzsche, A., & Lincoln, T. M. (2013). Anticipatory pleasure and approach motivation in schizophrenia-like negative symptoms. *Psychiatry Research, 210*(2), 422–426. https://doi.org/10.1016/j.psychres.2013.07.025.

Flores, L. E., Eckstrand, K. L., Silk, J. S., Allen, N. B., Ambrosia, M., Healey, K. L., & Forbes, E. E. (2018).

Adolescents' neural response to social reward and real-world emotional closeness and positive affect. *Cognitive, Affective, and Behavioral Neuroscience, 18*(4), 705–717. https://doi.org/10.3758/s13415-018-0598-0.

Folkersma, W., Veerman, V., Ornée, D. A., Oldehinkel, A. J., Alma, M. A., & Bastiaansen, J. A. (2021). Patients' experience of an ecological momentary intervention involving self-monitoring and personalized feedback for depression. *Internet Interventions, 26*, 100436.

Forbes, C. N. (2020). New directions in behavioral activation: Using findings from basic science and translational neuroscience to inform the exploration of potential mechanisms of change. *Clinical Psychology Review, 79*, 101860. https://doi.org/10.1016/j.cpr.2020.101860.

Forbes, E. E., Hariri, A. R., Martin, S. L., Silk, J. S., Moyles, D. L., Fisher, P. M., Brown, S. M., Ryan, N. D., Birmaher, B., Axelson, D. A., & Dahl, R. E. (2009). Altered striatal activation predicting real-world positive affect in adolescent major depressive disorder. *American Journal of Psychiatry, 166*(1), 64–73. https://doi.org/10.1176/appi.ajp.2008.07081336.

Fredrickson, B. L. (2004). The broaden-and-build theory of positive emotions. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 359*(1449), 1367–1377. https://doi.org/10.1098/rstb.2004.1512.

Fredrickson, B. L., Mancuso, R. A., Branigan, C., & Tugade, M. M. (2000). The undoing effect of positive emotions. *Motivation and Emotion, 24*(4), 237–258. https://doi.org/10.1023/a:1010796329158.

Glasgow, T. E., Le, H. T. K., Scott Geller, E., Fan, Y., & Hankey, S. (2019). How transport modes, the built and natural environments, and activities influence mood: A GPS smartphone app study. *Journal of Environmental Psychology, 66*, 101345. https://doi.org/10.1016/j.jenvp.2019.101345.

Gortner, E. T., Gollan, J. K., Dobson, K. S., & Jacobson, N. S. (1998). Cognitive-behavioral treatment for depression: Relapse prevention. *Journal of Consulting and Clinical Psychology, 66*(2), 377–384. https://doi.org/10.1037/0022-006X.66.2.377.

Heininga, V. E., Dejonckheere, E., Houben, M., Obbels, J., Sienaert, P., Leroy, B., van Roy, J., & Kuppens, P. (2019). The dynamical signature of anhedonia in major depressive disorder: Positive emotion dynamics, reactivity, and recovery. *BMC Psychiatry, 19*(1), 59. https://doi.org/10.1186/s12888-018-1983-5.

Hollands, L., Lambert, J., Price, L., Powell, D., & Greaves, C. (2020). Ecological momentary assessment of mood and physical activity in people with depression. *Journal of Affective Disorders, 271*, 293–299.

Janssen, N. P., Hendriks, G. J., Baranelli, C. T., Lucassen, P., Voshaar, R. O., Spijker, J., & Huibers, M. J. (2021). How does behavioural activation work? A systematic review of the evidence on potential mediators. *Psychotherapy and Psychosomatics, 90*(2), 85–93. https://doi.org/10.1159/000509820.

Kendall, A. D., Wilt, J., Walls, C. E., Scherer, E. A., Beardslee, W. R., Revelle, W., & Shrier, L. A. (2014). The social context of positive and negative affective states in depressed youth. *Journal of Social and Clinical Psychology, 33*(9), 805–830. https://doi.org/10.1521/jscp.2014.33.9.805.

Kesselring, I., Yaremych, H. E., Pegg, S., Dickey, L., & Kujawa, A. (2021). Zoom or in-person: An ecological momentary assessment study of time with friends and depressive symptoms on affect in emerging adults. *Journal of Social and Clinical Psychology, 40*(2), 97–120. https://doi.org/10.1521/jscp.2021.40.2.97.

Li, X., Zhang, Y. T., Huang, Z. J., Chen, X. L., Yuan, F. H., & Sun, X. J. (2019). Diminished anticipatory and consummatory pleasure in dysphoria: Evidence from an experience sampling study. *Frontiers in Psychology, 10*, 2124. https://doi.org/10.3389/fpsyg.2019.02124.

Malhi, G. S., & Mann, J. J. (2018). Depression. *The Lancet, 392*(10161), 2299–2312. https://doi.org/10.1016/S0140-6736(18)31948-2.

Nezlek, J. B. (2017). A practical guide to understanding reliability in studies of within-person variability. *Journal of Research in Personality, 69*, 149–155.

Olino, T. M., McMakin, D. L., Morgan, J. K., Silk, J. S., Birmaher, B., Axelson, D. A., Williamson, D. E., Dahl, R. E., Ryan, N. D., & Forbes, E. E. (2014). Reduced reward anticipation in youth at high-risk for unipolar depression: A preliminary study. *Developmental Cognitive Neuroscience, 8*, 55–64. https://doi.org/10.1016/j.dcn.2013.11.005.

Ornée, D. A., Oldehinkel, A. J., & Bastiaansen, J. A. (2021). Comparison of two ecological momentary intervention modules for treatment of depression on momentary positive and negative affect. *Collabra Psychology, 7*(1), 18910. https://doi.org/10.1525/collabra.18910.

Pannicke, B., Reichenberger, J., Schultchen, D., Pollatos, O., & Blechert, J. (2020). Affect improvements and measurement concordance between a subjective and an accelerometric estimate of physical activity. *European Journal of Health Psychology, 27*(2), 66–75. https://doi.org/10.1027/2512-8442/a000050.

Pizzagalli, D. A. (2014). Depression, stress, and anhedonia: Toward a synthesis and integrated model. *Annual Review of Clinical Psychology, 10*(1), 393–423. https://doi.org/10.1146/annurev-clinpsy-050212-185606.

Rømer Thomsen, K., Whybrow, P. C., & Kringelbach, M. L. (2015). Reconceptualizing anhedonia: Novel perspectives on balancing the pleasure networks in the human brain. *Frontiers in Behavioral Neuroscience, 9*, 49.

Rush, A. J., Gullion, C. M., Basco, M. R., Jarrett, R. B., & Trivedi, M. H. (1996). The inventory of depressive symptomatology (IDS): Psychometric properties. *Psychological Medicine, 26*(3), 477–486.

Russell, J. A., & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *Journal of Personality and Social Psychology, 76*(5), 805–819.

Schöndube, A., Kanning, M., & Fuchs, R. (2016). The bidirectional effect between momentary affective states and exercise duration on a day level. *Frontiers in Psychology, 7*, 1414. https://doi.org/10.3389/fpsyg.2016.01414.

Sherdell, L., Waugh, C. E., & Gotlib, I. H. (2012). Anticipatory pleasure predicts motivation for reward in major depression. *Journal of Abnormal Psychology, 121*(1), 51–60. https://doi.org/10.1037/a0024945.

Shrout, P. E., Stadler, G., Lane, S. P., McClure, M. J., Jackson, G. L., Clavél, F. D., Iida, M., Gleason, M. E. J., Xu, J. H., & Bolger, N. (2018). Initial elevation bias in subjective reports. *Proceedings of the National Academy of Sciences, 115*(1), E15–E23.

Snippe, E., Simons, C. J. P., Hartmann, J. A., Menne-Lothmann, C., Kramer, I., Booij, S. H., Viechtbauer, W., Delespaul, P., Myin-Germeys, I., & Wichers, M. (2016). Change in daily life behaviors and depression: Within-person and between-person associations. *Health Psychology, 35*(5), 433–441. https://doi.org/10.1037/hea0000312.

van Roekel, E., Bennik, E. C., Bastiaansen, J. A., Verhagen, M., Ormel, J., Engels, R. C., & Oldehinkel, A. J. (2016). Depressive symptoms and the experience of pleasure in daily life: An exploration of associations in early and late adolescence. *Journal of abnormal child psychology, 44*, 999–1009.

van Roekel, E., Heininga, V. E., Vrijen, C., Snippe, E., & Oldehinkel, A. J. (2019). Reciprocal associations between positive emotions and motivation in daily life: Network analyses in anhedonic individuals and healthy controls. *Emotion, 19*(2), 292–300. https://doi.org/10.1037/emo0000424.

Vrieze, E., Pizzagalli, D. A., Demyttenaere, K., Hompes, T., Sienaert, P., de Boer, P., Schmidt, M., & Claes, S. (2013). Reduced reward learning predicts outcome in major depressive disorder. *Biological Psychiatry, 73*(7), 639–645. https://doi.org/10.1016/j.biopsych.2012.10.014.

Wardenaar, K. J., Giltay, E. J., van Veen, T., Zitman, F. G., & Penninx, B. W. J. H. (2012). Symptom dimensions as predictors of the two-year course of depressive and anxiety disorders. *Journal of Affective Disorders, 136*(3), 1198–1203. https://doi.org/10.1016/j.jad.2011.11.037.

Watson, D., & Clark, L. A. (1994). *The PANAS-X: Manual for the positive and negative affect schedule-expanded form*. University of Iowa. The University of Iowa. https://doi.org/10.17077/48vt-m4t2.

Wichers, M., Peeters, F., Rutten, B. P. F., Jacobs, N., Derom, C., Thiery, E., Delespaul, P., & van Os, J. (2012). A time-lagged momentary assessment study on daily life physical activity and affect. *Health Psychology, 31*(2), 135–144. https://doi.org/10.1037/a0025688.

Whitton, A. E., Treadway, M. T., & Pizzagalli, D. A. (2015). Reward processing dysfunction in major depression, bipolar disorder and schizophrenia. *Current opinion in psychiatry, 28*(1), 7.

Zawadzki, M. J., Small, A. K., & Mausbach, B. T. (2022). An upward cycle: Examining bidirectional relationships between everyday activities and momentary affective well-being in caregivers. *Journal of Positive Psychology, 17*(6), 847–857. https://doi.org/10.1080/17439760.2021.1952646.

Received: March 24, 2022
Revised: January 22, 2023
Accepted: January 26, 2023
Available online: 1 February 2023