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Published in:
Journal of Affective Disorders

DOI:
10.1016/j.jad.2021.04.036

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2021

Journal of Affective Disorders 291 (2021) 118–125

Contents lists available at ScienceDirect

Journal of Affective Disorders

journal homepage: www.elsevier.com/locate/jad

Research paper

Personalized lifestyle advice alters affective reactivity to negative events in anhedonic young adults

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ARTICLE INFO

Keywords:
Anhedonia
Affective reactivity
Personalized lifestyle advice
Experience sampling method

ABSTRACT

Background: Anhedonia is a common symptom of several disorders, but cost-effective treatments that focus on anhedonia specifically have been lacking. Therefore, personalized lifestyle advice has recently been investigated as a suitable means of enhancing pleasure and positive affect (PA) in young adults with anhedonia. This intervention provided individuals with a personalized lifestyle advice which was based on observed individual patterns of lifestyle behaviors and experienced pleasure in daily life. The present study extends this previous work by examining a potential mechanism of treatment success, affective reactivity.
Methods: We explored changes in affective reactivity to events in daily life from pre- to post-intervention in a subclinical sample of young adults with anhedonia (N = 69). Using the Experience Sampling Method (ESM), participants answered questions on their activities, their pleasure levels, PA and negative affect (NA) before and after the intervention.
Results: Multilevel analysis revealed that participants did not experience an altered affective reactivity to positive events after the intervention. The affective reactivity to negative events depended on the level of improvement in mean-PA after the lifestyle advice intervention.
Limitations: The present study used a subclinical sample with the majority of participants being female which limited the generalizability of the findings.
Conclusion: This study suggests that an altered affective reactivity to negative events is an underlying mechanism of the effectiveness of a personalized lifestyle advice.

1. Introduction

As a transdiagnostic symptom, anhedonia is present in psychiatric disorders such as depression, substance use disorder, eating disorders, schizophrenia spectrum disorders, and anxiety disorders. It is defined as an inability to enjoy experiences and activities that normally would be pleasurable (American Psychological Association [APA], 2013) and is associated with low pleasure derived from positive activities, low positive affect (PA; e.g., feeling happy or joyful) and increased negative affect (NA; e.g., feeling gloomy or nervous). Anhedonia is experienced in different domains such as social situations or physical experiences (Ho and Sommers, 2013) and linked to deficits in the appetitive system of the brain, which motivates action towards goals and rewards and elicits positive emotions (Michel-Chávez et al., 2015). People suffering from anhedonia are more likely to experience persistent mental health problems (Spijker et al., 2001), to benefit less from pharmacological treatment (McMakin et al., 2012) and to become suicidal (Hawes et al., 2018). Hence, treating anhedonia seems absolutely desirable.

Nonetheless, there is a lack of treatment approaches focusing on anhedonia as a transdiagnostic symptom specifically. To demonstrate, two interventions have been developed to reduce anhedonia in patients diagnosed with schizophrenia spectrum disorders: the Positive Emotions Program for Schizophrenia (PEPS; Favrod et al., 2015) and the Anticipatory Pleasure Skills Training (APST; Favrod et al., 2010). For individuals suffering from depression, behavioral activation (BA) training is often used to facilitate re-engagement in rewarding activities (Kanter

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https://doi.org/10.1016/j.jad.2021.04.036
Received 25 March 2020; Received in revised form 26 February 2021; Accepted 20 April 2021
Available online 27 April 2021

et al., 2010). Additionally, bilateral deep brain stimulation (DBS) to the nucleus accumbens, which is part of the reward center of the brain, is effective in reducing anhedonic symptoms in these patients (Schlaepfer et al., 2008). However, DBS is an irreversible and risky surgery and is only used when no other treatment is effective. As mentioned, these interventions were developed to treat anhedonia in depression and schizophrenia spectrum disorders (Schlaepfer et al., 2008; Favrod et al, 2010; Kanter et al., 2010; Favrod et al., 2015) and, thus, in specific clinical populations. More general approaches are based on cognitive behavior strategies, that require a trained therapist for skill-teaching in multiple sessions and are therefore not easily accessible. As a consequence, there is an lack of cost-effective, accessible treatments targeting anhedonia as a transdiagnostic symptom.

In response to this lack of interventions for anhedonia, Van Roekel et al. (2017) developed personalized lifestyle advice, to increase PA and pleasure in young adults suffering from anhedonia. Using the Experience Sampling Method (ESM), participants answered questions on their activities, their pleasure levels, PA and NA three times a day during an observation month. Based on these observations, participants received an empirically constructed, personalized lifestyle advice to engage more or less often in certain activities, to increase their pleasure levels. Three intervention groups were compared: a control group, a lifestyle advice only group and a lifestyle advice group with additional tandem skydive (Van Roekel et al., 2017). The tandem skydive was added to elicit an intense experience in the participants with the aim to kick-start the brain's reward center and thereby set the stage to implement the advised lifestyle changes. Regarding the effectiveness of the intervention, Van Roekel and colleagues (2017) found that both intervention groups equally increased in pleasure and PA after the intervention, suggesting a reduction of anhedonic symptoms in these groups, which was not found in the control group. Nevertheless, the skydive had no additional effect on anhedonia. No significant group differences were found in NA after receiving the interventions. From this study, it can be concluded that personalized lifestyle advice is an effective way to increase pleasure and PA in young adults suffering from anhedonia (Van Roekel et al., 2017).

The underlying mechanisms through which lifestyle advice improves pleasure and PA are not clear yet. Knowing how an intervention works is important for clinical implementation and can help to improve intervention techniques. The present study uses data from the original RCT (Van Roekel et al., 2017) to investigate possible mechanisms of change. One such potential mechanism of change can be an altered affective reactivity to daily events, as daily events trigger positive and negative affect. Moreover, anhedonia is by definition associated with a diminished response to positive events. As Van Roekel and colleagues (2017) showed that the lifestyle advice intervention increased mean levels of PA in the current sample, the first goal of the present study was to investigate whether the affective reactivity to positive events changed from pre- to post-intervention and, therefore, explains the increased PA mean levels after receiving the lifestyle advice.

Similarly, as a second goal, we investigated whether an altered affective reactivity to negative events is a possible working mechanism of personalized lifestyle advice. The lifestyle advice aims to increase enjoyable lifestyle activities such as physical activity, being outside or social interactions and increases well-being in individuals suffering from anhedonia (Van Roekel et al., 2017). According to the broaden-and-built theory (Fredrickson and Branigan, 2005), experiencing well-being (e.g., positive emotions) can extend an individual's momentary repertoire of thoughts and actions that determine the reaction to a situation or event, by broadening attention, cognition and action and therefore, building resources that can be adaptive in the coping process. Given that participants' well-being increased after receiving the advice, we expect them to react differently to negative events as well.

Furthermore, in the original RCT, Van Roekel and colleagues (2017) found individual differences in the extent to which individuals improved in PA levels after receiving the lifestyle advice. If an altered affective reactivity to events is the driving force of the success of lifestyle advice, it can be expected that only the participants who improved in PA levels after the lifestyle advice intervention, changed in affective reactivity. Hence, the third goal of this study was to investigate whether the amount of change in affective reactivity depended on the level of improvement in PA. In summary, the present study examined the following hypotheses:

1) The lifestyle advice intervention affects the relation between positive events and PA and NA, so that participants experience a larger increase in PA and a larger decline in NA in response to a positive event;
2) The lifestyle advice intervention affects the relation between negative events and PA and NA, so that participants experience a smaller decline in PA and a smaller increase in NA in response to a negative event; and
3) The level of change in affective reactivity depends on the level of improvement in mean PA.

2. Method

2.1. Participants

Participants were derived from the original intervention study (see Van Roekel et al., 2016). The intervention study was approved by the Medical Ethics Committee from the University Medical Center Groningen (no. 2014/508). In this larger study, young adults from the general population were asked to take part in a screening ($N = 2{,}937$). Inclusion criteria for the screening were age between 18 and 24 and fluency in Dutch. The sample suffering from anhedonia, which is used in the present study, was selected from this screened population ($N = 69$). The participant flow of the original intervention study (Van Roekel et al., 2017) is demonstrated in the supplementary material (Figure 3). To assess anhedonia, the Domains Of Pleasure Scale (DOPS) was used, consisting of 21 domain-specific items and one general item to assess anhedonia (Masselink et al., 2019). An unique feature of the DOPS is, that it not only assesses pleasure experiences in different domains, but also whether the experienced pleasure levels deviate from what is considered normal for that person, and, if applicable, the duration of loss of pleasure. Participants met the criteria for anhedonia if their general pleasure level was below the 25th percentile, this level was lower than normal for them, and this loss of pleasure persisted for more than two months. Anhedonia levels were assessed by a single-item measure of general pleasure, as it correlated higher with depressive symptoms and PA than the sum of the domain-specific items (Masselink et al., 2019). Each participant who fulfilled these criteria and was willing to engage in skydiving was included in the sample[1] with anhedonia. Participants were excluded if they were not able to keep an electronic diary, received psychological treatment or psychotropic medication, or suffered from a condition that made it impossible to engage in skydiving (e.g. height above 2m; the inability to raise one's legs 90°; cardiovascular problems). The mean age of the sample suffering from anhedonia was 21.46 years ($SD = 1.95$), 19% were male and 81% female. Besides the experience of anhedonia, the sample reported varying degrees of depressive symptoms ranging from minimal to severe (PHQ-9; Kroenke et al., 2001) (minimal symptoms: N = 6; mild symptoms: N = 28; moderate symptoms: N = 19; moderately severe symptoms: N = 11; severe symptoms: N = 5). Moreover, the sample was characterized by other mental health problems, with 7% falling into the clinical range for anxiety problems, 19% falling into the clinical range for avoidant personality, and 12% into the

[1] Notably, only 25 participants were unwilling to perform a tandem skydive. This group did not significantly differ from those who were willing to engage in skydiving on the severity of anhedonia (t = 1.30, p = .13), the level of consummatory pleasure (t = -0.84, p = .40) or depressive symptoms (t = 0.30, p = .77) (Van Roekel et al., 2017).

clinical range for attention deficit hyperactivity disorder (ADHD), based on Adult Self-Report (ASR; Achenbach and Rescorla, 2001). Substance use was limited in the sample. The majority had drunk occasionally in the past ($M = 4.54$, $SD = 3.94$). Ten participants (15%) smoked on a daily basis, with on average 8 cigarettes in the past two weeks ($M = 7.78$, $SD = 3.93$). The average use of soft drugs (i.e., weed, spacecake, hash) was three times ($M = 2.74$, $SD = 3.94$) and of hard drugs (e.g., XTC, speed or cocaine) only once ($M = 1.45$, $SD = 1.84$) in the past year.

2.2. Procedure

The data were collected in two stages at the University Medical Center Groningen in the Netherlands. First, as mentioned above, a general screening was conducted. The participants who filled in the screening survey received a voucher of 10 Euro and had a chance to win a prize in a lottery. Second, the effectiveness of the new lifestyle intervention was tested using experience-sampling methods in a randomized controlled trial (RCT) (Van Roekel et al., 2017). Participants who gave permission for being contacted for future research and who fulfilled the additional study criteria (see above) received an information letter about the intervention study and the informed consent form per email. Participation in the RCT-part was rewarded according to the amount of daily experience-sampling questionnaires the participants answered. In the sample with anhedonia, a participant could receive up to 500 Euro.

To assess the differences between the three intervention groups which was previously investigated by Van Roekel and colleagues (2017), participants filled out daily questionnaires for three consecutive months. Amongst other, participants reported their activities, pleasure, PA, NA and the pleasantness of daily events three times per day. An overview of all items can be found in the study protocol (Van Roekel et al., 2016). The daily questionnaires were sent with fixed 6-hour intervals (e.g., 9:00 A.M., 3:00 P.M., 9:00 P.M.) and prompted by a text message including a link to the questions. The sampling scheme was determined in consultation with the participant. Participants had 2 hours to answer the questions after the first notification. Reminders were sent after 60 and 90 minutes. Answering the questions took around 3 minutes. Participants knew that filling out the daily questionnaires was used to construct the lifestyle advice to increase their pleasure and PA levels and hence, filling out the assessments was of personal interest and also financially rewarded. Consequently, compliance was excellent, with an average percentage of only 8% missing values for the variables used to examine the research questions.

Participants were invited to a face-to-face instruction meeting, after which the experience sampling started for three consecutive months. After an observation month and before the start of the second month of experience-sampling, the RCT-participants were randomly assigned to one of the following three groups: lifestyle advice only group ($N = 22$), lifestyle advice group with additional tandem skydive ($N = 25$) or the control group receiving no intervention ($N = 22$). After the RCT study ended, all participants were free to choose an intervention (including the controls) for ethical reasons. All control participants chose the lifestyle advice with additional tandem skydive and therefore the whole anhedonic sample received the lifestyle advice intervention either after the first month or after the second month, as depicted in Fig. 1. Specifically, the observation month for participants originally from the control group was in the second month. As Van Roekel et al. (2017) already examined the effectiveness of lifestyle advice comparing different groups and finding no additional effect of the tandem skydive, the present study included the data of the whole sample (N = 69), to explore the working mechanisms of lifestyle advice, on the within-person level.

2.3. Personalized lifestyle advice

Based on the data of the observation month a personalized lifestyle advice was created for each participant. As part of the personalized lifestyle advice, participants received feedback on their reports, such as their average pleasure levels and lifestyle behaviors of the observation

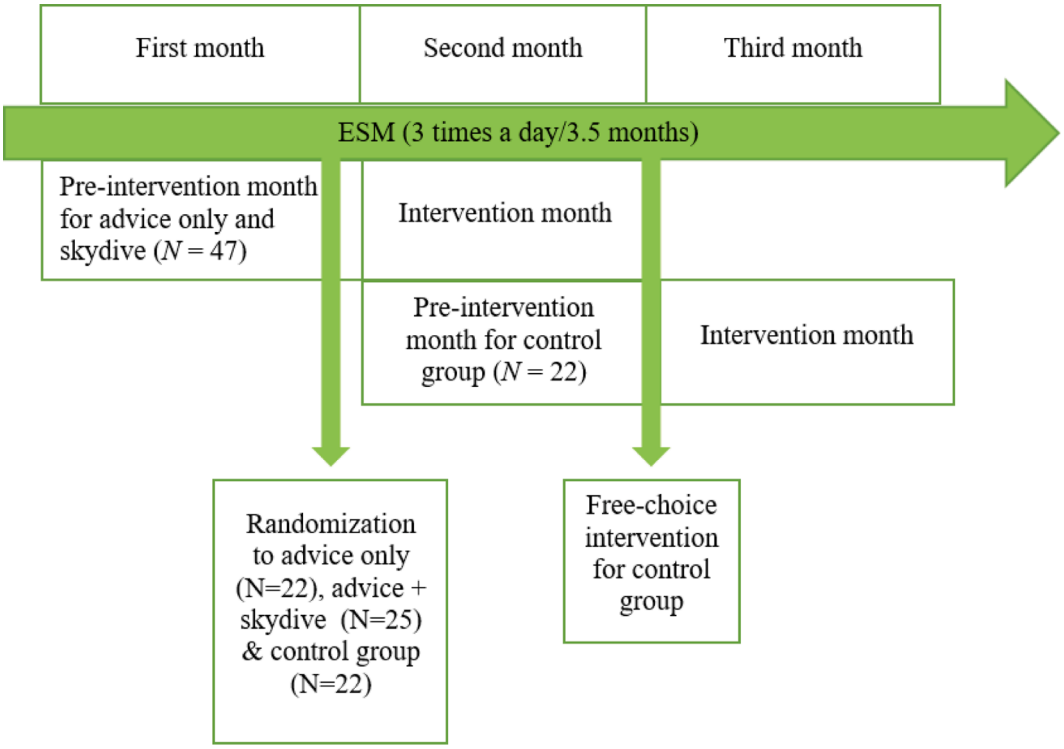

Fig. 1. Schematic design of the study. *Note.* All participants from the control group chose the lifestyle advice. For this group, the second month is the observation month to create the lifestyle advice. Therefore, all participants (N = 69) received the advice either after the first or after the second month. The advice was given in a single face-to face meeting and participants were advised to change certain behaviors in the next month. Colour on the web only.

month, as compared to those found in the general population. In addition, we constructed personal networks for every participant. A network is a graphical display of the associations between various lifestyle behaviors and pleasure. Those networks were identified by means of automated Vector Autoregressive modeling (VAR; Brandt and Williams, 2007; Autovar: Emerencia et al., 2015) and consisted of statistically significant associations between various lifestyle behaviors and pleasure. Based on these associations, we selected two or three lifestyle behaviors that were empirically related to pleasure in that participant and gave the advice to change these behaviors in order to increase their pleasure levels. Participants were asked to change lifestyle behaviors such as social activities, physical activities, being outside, reducing worrying (e.g. mindfulness exercises) and regarding their sleep rhythm. The advice was given during a face-to-face meeting and participants received a report to take home. Additional information on the intervention can be found in the paper of Van Roekel et al. (2017).

2.4. Measures

Positive Affect and pleasure. PA was measured with ten items as part of the ESM questionnaire. The participants were asked to rate to which degree they felt relaxed, interested, joyful, determined, calm, lively, enthusiastic, cheerful, satisfied, and energetic in the moment (when assessed in the morning) or during the last six hours (when assessed in the afternoon and evening). These items were rated on a Visual Analogue Scale (VAS) ranging from 0 to 100, anchored with the words 'Not at all' on the left and 'Very much' on the right. The participants were asked to move a slider along this continuum to report their level of affect. Similarly, pleasure was assessed. Participants were asked how much pleasure they experienced since the last assessment. For PA, Cronbach's alpha was .94, calculated over all observations, which indicates high internal consistency. Moreover, the within-person reliability was high (Cronbach's alpha = .93), as well.

Negative Affect. NA was examined in the ESM questionnaire with eight items (i.e., upset, gloomy, sluggish, anxious, bored, irritated, nervous, and listless) and reported in the same way as PA. Cronbach's alpha for all assessments was .86 and the within-person reliability was .96.

Positive and negative events. To measure positivity of positive events (PE), participants were asked: 'Think about the most pleasant event you experienced since the last assessment: how enjoyable was this event?'. To measure negativity of negative events (NE), they were asked 'Think about the most unpleasant event you experienced since the last assessment: how unpleasant was this event?'. Answers were indicated on a VAS scale, ranging from 0 to 100.

Improvement. To calculate improvement, we conducted Interrupted Time Series Analyses (ITSA) for PA, for each individual separately, by fitting Auto Regressive Moving Average (ARMA) models (see van Roekel et al, 2017 for details about these analyses). Improvement was defined as the level change in PA after the intervention, relative to a participant's score before the intervention (i.e., mean level difference between pre- and post-intervention scores). For each individual, these analyses resulted in a t-value, representing the standardized change in PA from pre-to post intervention. We included these continuous scores as an indicator of improvement.

2.5. Analytic approach

As the data consisted of momentary data (Level 1) nested within individuals (Level 2), multilevel linear regression analyses were conducted, using the Dynamic Structural Equation Modeling (DSEM) package in Mplus version 8 (Muthén and Muthén, 1998-2015). This package combines different techniques to account for correlations due to individual-specific effects, proximity of observations, the same stage of evolution and correlations between different variables (Asparouhov et al., 2018). Modeling these four types of correlations is used to achieve a better understanding of the dynamics in intensive longitudinal data, such as ESM data. Moreover, this approach accounts for missing data so that participants are not required to have data at every measurement occasion (Asparaouhov et al., 2018). DSEM is based on Bayesian statistics and Markov chain Monte Carlo methods are used to determine the convergence between two independent iterations estimating the specified model (Asparouhov et al., 2017). Convergence of the chains is determined by means of the potential scale reduction (PSR) factor with a suggested cut-off of PSR < 1.1.

Analyses were conducted separately for PE and NE, so that finally the relations between PA and PE, NA and PE, PA and NE and NA and NE were tested. Those relations were tested in a stepwise procedure. First, the main effects of Level 1 explanatory variables were tested, to examine whether PA and NA differed before and after the intervention, including the whole sample suffering from anhedonia from the previous intervention study (Van Roekel et al., 2017), instead of comparing different intervention groups. Hence, the outcome variables PA and NA were regressed on the explanatory variables: affect at previous assessment (i.e., PA_{t-1} or NA_{t-1}), PE or NE and intervention (i.e., 0 = pre-intervention, 1 = post-intervention). Affect at previous assessment was included to ensure that changes in affect were estimated rather than affect levels. All analyses are mathematically expressed on the basis of the PA and PE relation, as followed:

Level 1:

$$PA_{ti} = \beta_{0i} + \beta_{1i}(PA_{t-1})_{ti} + \beta_{2i}(PE)_{ti} + \beta_{3i}(intervention) + e_{ti}$$

Level 2:

$$\beta_{0i} = Y_{00} + u_{0i}$$
$$\beta_{1i} = Y_{10} + u_{1i}$$
$$\beta_{2i} = Y_{20} + u_{2i}$$
$$\beta_{3i} = Y_{30} + u_{3i}$$

PA_{ti} is the outcome variable for subject i at measurement occasion t which was predicted by the individual's specific intercept (i.e., β_{0i}), the individual's specific rate of change in the explanatory variables (i.e., β_{1i}, β_{2i} and β_{3i}) and an occasion specific error term (i.e., e_{ti}). The intercept was specified as random, as individual differences in mean levels of PA were expected. Further, the slopes of the Level 1 explanatory variables were modelled as random, as the relations between the outcome variables and the explanatory variables were expected to vary across individuals. To examine our first and second hypotheses, whether the affective reactivity to positive and negative events changed, the interaction between PE or NE and intervention were added to the first model. The slope of the interaction term was specified as random, to account for individual differences in changes in affective reactivity after the intervention. For the PA – PE relation, this was mathematically expressed as:

Level 1:

$$PA_{ti} = \beta_{0i} + \beta_{1i}(PA_{t-1})_{ti} + \beta_{2i}(PE)_{ti} + \beta_{3i}(intervention) + \beta_{4i}(intervention) * (PE)_{ti+}e_{ti}$$

Level 2:

$$\beta_{0i} = Y_{00} + u_{0i}$$

$$\beta_{1i} = Y_{10} + u_{1i}$$

$$\beta_{2i} = Y_{20} + u_{2i}$$

$$\beta_{3i} = Y_{30} + u_{3i}$$

$$\beta_{4i} = Y_{40} + u_{4i}$$

Finally, to examine our third hypothesis, whether the amount of change in affective reactivity depended on the level of improvement in PA after the intervention, the three-way interaction between events, improvement and intervention was added to the model, resulting in the following regression equation on the basis of PA – PE:

Level 1:

$$PA_{ti} = \beta_{0i} + \beta_{1i}(PA_{t-1})_{ti} + \beta_{2i}(PE)_{ti} + \beta_{3i}(intervention) + \beta_{4i}(intervention) * (PE)_{ti} + e_{ti}$$

Level 2:

$$\beta_{0i} = Y_{00} + Y_{01}(Improvement)_i + u_{0i}$$

$$\beta_{1i} = Y_{10} + u_{1i}$$

$$\beta_{2i} = Y_{20} + Y_{21}(Improvement)_i + u_{2i}$$

$$\beta_{3i} = Y_{30} + Y_{31}(Improvement)_i + u_{3i}$$

$$\beta_{4i} = Y_{40} + Y_{41}(Improvement)_i + u_{4i}$$

Improvement was added to Level 2, to assess whether the average level of an individual's affect was predicted by the level of improvement and whether the relation between PA or NA and PE depended on the level of improvement.

Finally, because improvement was operationalized as the increase in PA after the intervention, a sensitivity analysis was conducted, consisting of the same analyses as described above in which improvement was operationalized as the increase in pleasure after the intervention. Results are displayed in supplementary material (Table 4).

3. Results

Means and standard deviations of the variables of interest in this research can be seen in Table 1. Similarly, the results of paired sample *t*-tests, comparing the means of pre- and post-intervention scores, are displayed in Table 1. To ensure that the participants in the control arm of the study, who received the lifestyle advice one month later, were similar to the participants in the intervention arms, we compared mean levels of PA, NA, PE and NE during the observation month. Independent sample *t*-tests revealed no significant differences in PA $t(67) = -.14$, $p = .89$, NA $t(67) = -1.24$, $p = .22$, PE $t(67) = -1.64$, $p = .11$ or NE $t(67) = -1.49$, $p = .14$, supporting the approach to use the whole sample suffering from anhedonia, to examine within-person differences in affective reactivity as the lifestyle advice's underlying mechanism of success.

Table 1
Descriptive statistics.

		Pre-intervention		Post-intervention				
	N	M	SD	M	SD	df	t	
PA	69	53.91	10.52	57.73	10.96	68	-5.38	***
NA	69	22.75	10.96	19.07	9.35	68	6.96	***
PE	69	57.19	12.03	58.28	11.75	68	-1.16	
NE	69	38.44	12.03	36.27	13.63	68	2.45	**

Note. **p<.01; ***p<.001. PA stands for Positive Affect; NA stands for Negative Affect; PE stands for positivity of positive events; NE stands for negativity of negative events.

Tables 2 and 3 depict the coefficients for the three models (i.e., main effects, interaction and three-way interaction), including model fit criteria. The main effect model, which tested whether individuals overall experienced more or less affect after the intervention, revealed that participants experienced less NA and more PA after the intervention, as expected.

Hypothesis 1: Reactivity to positive events. No significant interactions between PE and intervention were found for neither PA, nor NA (Table 2, interaction models): the participants showed similar PA and NA responses to positive events before and after the intervention.

Hypothesis 2: Reactivity to negative events. The interaction effect between intervention and NE on PA was not significant, indicating that participants did not experience an altered PA reactivity to negative events after the intervention. We did find a significant interaction between intervention and NE on NA, suggesting that the NA response to negative events decreased after the intervention (Table 3, interaction models).

Hypothesis 3: Association with level of improvement. The three-way interaction between PE, intervention, and improvement was not significant, neither for PA, nor NA (see Table 2, cross-level interaction models), meaning that the affective reactivity (i.e., the level of increase in PA and the level of decrease in NA after experiencing a positive event) did not depend on the level of improvement in PA after the intervention. In sum, whether or not participants improved in mean PA did not affect the level of increase in PA to positive events, nor the level of decrease in NA, as displayed in Fig. 2.

The three-way interaction between NE, intervention and improvement was significant for both PA and NA, indicating that the affective reactivity to negative events depended on an individual's level of improvement (Table 3, cross-level interaction models). Improved participants experienced a smaller reduction in PA in response to negative events after the intervention than non-improvers did (Fig. 2). Similarly, improved participants experienced a smaller increase in NA in response to negative events after the intervention, compared to non-improvers (see Fig. 2).

4. Discussion

The goal of this study was to examine whether personalized lifestyle advice as an intervention for young adults with anhedonia altered individuals' affective reactivity to daily events from pre- to post-intervention. We hypothesized, first, that the lifestyle advice intervention affected the relation between PE and PA and NA, so that participants experienced a larger increase in PA and a larger decline in NA in response to a positive event after the intervention, as compared to before. Second, we hypothesized that the lifestyle advice intervention also affected the relation between NE and affect. Participants were expected to experience a smaller decline in PA and a smaller increase in NA in response to a negative event. Finally, we hypothesized that the level of change in affective reactivity depended on the level of improvement in mean PA after the intervention. These hypotheses were partly corroborated by the empirical findings.

4.1. PA and NA after positive events

Contrary to our expectations, the intervention did not alter the affective reactivity to positive events. Participants did not experience larger increases in PA, nor larger declines in NA in response to a positive event after the intervention, as compared to before. Further analyses showed that this effect was independent of the level of improvement in mean level PA. As anhedonia is defined as a deficit in the experience of pleasure and PA from normally pleasurable events, the result of no

Table 2
Affective reactivity to PE.

	PA			NA		
	Main effects	Interaction model	Cross-level interaction model	Main effects	Interaction model	Cross-level interaction model
Coefficients						
Intercept	54.22 (1.24)***	54.22 (1.29)***	54.79 (1.64)***	22.61 (1.17)***	22.58 (1.11)***	22.59 (1.43)***
Affect T-1	0.25 (.02)***	0.25 (.01)***	0.25 (.01)***	0.27 (.01)***	0.27 (.02)***	0.26 (.01)***
PE	0.28 (.01)***	0.27 (.01)***	0.24 (.02)***	-0.19 (.01)***	-0.20 (.01)***	-0.19 (.02) ***
Time	2.44 (.41)***	2.46 (.38)***	0.33 (.23)	-2.35 (.37)***	-2.39 (.36)***	-2.01 (.43)***
PE x time	0.00 (.01)	0.01 (.01)		-0.02 (.01)	-0.02 (.01)	
Time x Improvement		0.76 (.05)***			-0.14 (.09)	
PE x Improvement		0.00 (.00)***			-0.01 (.01)	
PE x Time x Improvement	-0.00 (.00)			-0.00 (.01)		
Model Summary						
Deviance	324191.480	436194.378	436258.697	324191.480	436194.378	436258.697
Parameters	3742.201	4940.519	4964.430	3742.201	4940.519	4964.430

Note. *p<.05; **p<.01; ***p<.001. The table displays the unstandardized estimates. PA stands for Positive Affect; NA stands for Negative Affect; PE stands for positivity of positive events.

Table 3
Affective reactivity to NE

	PA			NA		
	Main effects	Interaction model	Cross-level interaction model	Main effects	Interaction model	Cross-level interaction model
Coefficients						
Intercept	54.24 (1.24)***	54.25 (1.28)***	55.31 (1.67)***	22.51 (1.18)***	22.47(1.11)***	22.17 (1.46)***
Affect T-1	0.28 (.01)***	0.28 (.02)***	0.28 (.01)***	0.26 (.01)***	0.26 (.01)***	0.26 (.01)***
NE	-0.19 (.01)***	-0.19 (.01)***	-0.17 (.01)***	0.19 (.01)***	0.20 (.01)***	0.18 (.01) ***
Time	2.39 (.51)***	2.43 (.47)***	-0.36 (.23)***	-2.30 (.35)***	-2.34 (.33)***	-1.52 (.40)
NE x Time	0.01 (.01)	-0.01 (.01)		-0.03 (.01)***	-0.00 (.01)	
Time x Improvement		1.00 (.05)***			-0.31 (.08)***	
NE x Improvement		-0.01 (.00)*			0.01 (.00)*	
NE x Time x Improvement	0.01 (.00)***			-0.01 (.00)***		
Model Summary						
Deviance	329923.943	446620.548	446649.048	329923.943	446620.548	446649.048
Parameters	3742.349	4885.403	4904.257	3742.349	4885.403	4904.257

Note. *p<.05; **p<.01; ***p<.001. The table displays the unstandardized estimates. PA stands for Positive Affect; NA stands for Negative Affect; NE stands for negativity of negative events.

change in affective reactivity to positive events was unexpected. However, this finding is in line with previous research, as far as this study is comparable. Specifically, several studies compared healthy controls to participants suffering from anhedonia and did not find any differences in the experience of pleasure or PA derived from a positive event/stimuli (e.g. Gard et al., 2007; Germans and Kring, 2000; Heininga et al., 2017), which might indicate that the affective reactivity is not defective at all in individuals with anhedonia. The present study did not include a healthy control group, but did not find significant changes in affective reactivity using a within-person design either, despite increased PA-mean levels after the intervention. As Höflich et al., (2019) summarized in their review article, the reward experience in anhedonia is a multi-step process. This process starts with associating a behavior with pleasure or PA, followed by anticipating this affective experience and becoming motivated enough to engage in the behavior necessary to receive it. Once a person spends the effort to engage in the behavior, the consummatory phase begins, leading to the hedonic response (Höflich et al., 2019). The present study only examined one of these multiple steps, namely whether PA derived from a pleasurable moment differs from pre- to post-intervention. This means, that personalized lifestyle advice does not change this one step in the hedonic response and possibly, other steps in the reward process might contribute to the mean level changes in PA and pleasure from pre- to post intervention, found by Van Roekel et al. (2017). For instance, it is possible that participants were more motivated to engage in certain pleasurable behaviors such as social or physical activities, as they previously received the feedback that these behaviors are associated with their PA and pleasure levels. By increasing the motivation, participants might engaged more often in those pleasurable events which induces mean level increases in PA from pre- to post- intervention, but does not necessarily also change the amount of PA derived from such a pleasurable activity. Future research is needed to assess this premise.

4.2. PA and NA after negative events

Our findings indicate that the personalized lifestyle advice affected how participants responded to negative events, in that they experienced smaller reductions in PA and smaller increases in NA in response to a negative event after the intervention, as compared to before. The reason why participants experienced an altered reactivity to negative events can be either due to experiencing less negative events or because the interpretation of negative events changed, meaning that negative events are interpreted as less unpleasant than before which is in line with previous research. Specifically, advising individuals to engage more often in enjoyable activities such as physical or social activities, spending time outside or decreasing worrying might have resulted in an altered reactivity to daily negative events. For instance, physical activity has been shown to facilitate emotion regulation in response to a negative event (Edwards et al., 2017). Concretely, exercise prior to a negative event helped participants to react with less anxiety and anger (Edwards et al., 2017). Comparable results were found in a diary study, in which physical exercise and sleep buffered the effect of daily stress on PA and NA (Flueckiger et al., 2016). Moreover, Arch and Craske (2006) showed in laboratory task that mindfulness training can improve the affective

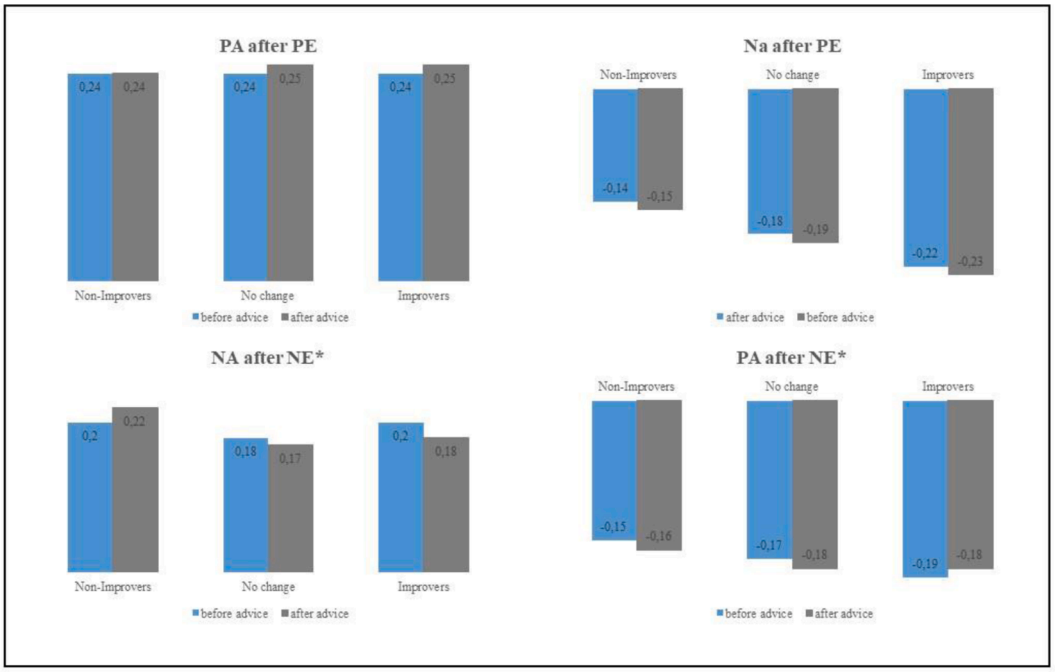

Fig. 2. *PA and NA after events. Note.* PA and NA after positive and negative events for improvers, non-improvers and participants who did not change in PA levels from pre- to post intervention. Groups were defined in terms of t-values which represent the standardized change in PA from pre-to post intervention. Positive t-values represented an increase in mean levels of PA from pre- to post intervention and thus indicated improvement (with t-values larger than 1.96 representing significant mean level change). Negative t-values represented a decrease in mean levels of PA from pre- to post intervention. We used a score of - 2 for non-improvers, 0 for no change and 2 for improvers. *p<.001. Colour on the web only.

reactivity to negative pictures. Given that this study used multiple measurements per day, participants who engaged in pleasurable activities at one occasion might react with less NA and a smaller decline in PA in response to a negative event at a later occasion. Therefore, the finding that participants reacted differently to negative events from pre- to post-intervention might explain the increased mean levels in PA that were previously found by Van Roekel et al., (2017) and be one of the underlying mechanisms of personalized lifestyle advice in decreasing anhedonic symptoms. Notably, participants also experienced an altered NA reaction to negative events, accentuating the potential value of a personalized lifestyle advice.

4.3. Strengths and limitations

Our study has notable strengths. First, it is the first to investigate why personalized lifestyle advice can enhance PA in young adults with anhedonia. Second, we used ESM data to answer the research questions. ESM is a tool to investigate variables in the individuals' natural environment that has high ecological validity (Trull and Ebner-Priemer, 2009). This is particularly valuable for the evaluation of mental health interventions, which generally aim to alleviate clinical problems in the daily lives of individuals (Trull and Ebner-Priemer, 2009). Furthermore, we related participants' affective responses to events after the intervention to their responses before the intervention, which enabled us to examine within-person effects and to account for individual differences.

Some limitations must be mentioned too. To start with, the data were only available up to one month after the intervention and, thus, no statements about the long-term effects of the lifestyle advice intervention on affective reactivity can be made. Further, the present data are derived from a highly engaged, subclinical population with the majority being female and willing to engage in skydiving. This limits the generalizability of the present results to other samples. Future research should investigate the effectiveness of the lifestyle advice intervention and its working mechanisms in clinical populations and examine whether the lifestyle advice works in the same way for males and females. Moreover, future research would benefit from objective measures to assess changes in affective reactivity to events, as previous research showed that objective measures in anhedonia often show intact performance as compared to subjective measures (Li et al., 2019).

5. Conclusions

The present study examined whether personalized lifestyle advice was a successful intervention for increasing PA and pleasure in young adults with anhedonia through alteration of their affective reactivity to daily events. Findings from the present study indicate that personalized lifestyle advice changed the affective reactivity to negative events of improved individuals but did not affect the reactivity to positive events. In conclusion, although more research is needed to examine the effectiveness of personalized lifestyle advice in increasing PA and pleasure levels, personalized lifestyle advice is a promising intervention against anhedonia, mainly increasing changes in affective reactions to negative events.

Author statement

All authors have seen and approved the final version of the manuscript being submitted. We warrant that the article is our original work, hasn't received prior publication and isn't under consideration for publication elsewhere.

Authors' contribution

E.vR., V.E.H. and A.J.O.: were involved in the conception of the larger clinical trial and the data acquisition. M.S. and E.vR analyzed and interpreted the patient data regarding the working mechanism of personalized lifestyle advice. M.S. drafted the manuscript and revised it after feedback from E.vR., V.E.H. and A.J.O. All authors read and approved the final manuscript.

Funding

This work was supported by the Dutch Research Council (NWO) [NWO 016.001/002].

Declarations of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jad.2021.04.036.

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