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# How Personalized Behavioral Activation Interventions Improve the Behaviors of Individuals with Anhedonia

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## Abstract

**Background.** Interventions for anhedonia often focus on re-engagement in pleasurable activities. We aimed to examine how anhedonic individuals changed their lifestyle behavior (i.e., physical activity, time outside, worrying, and social activity) after a personalized lifestyle advice session, and how these changes in behavior where associated with improvement. **Methods.** Participants were 69 young adults with persistent anhedonia, who filled out 3 assessments per day about lifestyle behaviors and affect for 3 months. After an observation month, participants received personalized lifestyle advice. **Results.** Results showed that only changes in social interaction, physical activity, and worrying were associated with improvement in positive affect (PA) and pleasure. Further exploration of the reciprocal associations between behaviors and PA and pleasure showed that physical activity and worrying were reciprocally associated with PA or pleasure, indicating a positive feedback loop. **Conclusions.** Results indicate that momentary assessments are an effective tool to detect mechanisms of change in interventions.

**Keywords.** anhedonia; behavioral activation; personalized lifestyle advice; experience sampling method; activity scheduling

Anhedonia is a transdiagnostic symptom, characterized by a lack of pleasure and lack of motivation to participate in positive activities (Treadway & Zald, 2011). Interventions to reduce anhedonia often focus on re-engagement in positive activities (e.g., behavioral activation) (Cuijpers et al., 2007; Kanter et al., 2010). Previous research exploring the effectiveness of behavioral activation treatments has shown that homework compliance (e.g., planning and participating in positive activities) is an important predictor of improvement (Addis & Jacobson, 2000; Hopko et al., 2011). However, it has rarely been explored which type of activities are most effective in these treatments and what the pathway to improvement is, that is, whether changes in specific behaviors are most likely to result in improvement, relative to other behaviors. This is mainly due to the fact that appropriate measures of behavioral change have been lacking, as behavioral activation is often personalized and focuses on a range of behaviors. Therefore, measurement of behavior change is difficult (Manos et al., 2010). This is an important gap in our knowledge, as insight in these processes of behavior change may result in better treatment.

A promising way to explore these processes of change is to use the Experience Sampling Method to explore real-time changes in behavior in daily life. In a recently conducted study (van Roekel et al., 2016), we developed and evaluated an intervention to regain pleasure in individuals with persistent anhedonia, which involved personalized lifestyle advice (provided in a single session) based on observed patterns between daily life behaviors and pleasure (van Roekel et al., 2017). Results were promising and showed that individuals who had received the advice significantly improved in positive affect (PA) and pleasure, compared to the control group who received no intervention. Because the advice was personalized and could relate to different behaviors, these overall findings did not reveal through which mechanisms the improvement was brought about. However, in contrast to standard behavioral activation treatments, we did

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obtain detailed reports (3 times per day) on behaviors in the month before and the month after the intervention, and were therefore able to examine changes in behavior in the present study, taking into account the type of advice participants received.

The intervention in the above-mentioned study involved personalized advice that was provided in a single session to each individual participant, based on associations between pleasure and lifestyle behaviors found in their own data. The four main types of lifestyle advice provided to the participants, i.e., physical activity, time spent outside, worrying, and social activity (split into social interaction and social contact), also emerge from the literature as being imperative for mental health (Sarris et al., 2014; Serrano Ripoll et al., 2015). With regard to physical activity, we know that in healthy populations, increased physical activity is related to increases in positive affect (PA) (Mata et al., 2012; Wichers et al., 2012). For time spent outside, the associations with PA are not as clear. Previous research has indicated that spending more time outside is associated with better mood (Keller et al., 2005), possibly due to a higher exposure to natural light (Wirz-Justice et al., 1996). On the other hand, high levels of sunlight have been associated with decreases in negative affect (NA) but not with increases in PA (Denissen et al., 2008), hence it is questionable whether spending more time outside will be effective to reduce anhedonia as such. Worrying has been related to decreases in PA (McLaughlin et al., 2007), whereas social activity (i.e., social company and social interaction) has often been associated with higher levels of PA (Brown et al., 2011; Silk et al., 2011). More specifically, in adolescence, spending time alone was found to be associated with lowest levels of PA, spending time with family with medium levels of PA, and spending time with peers with the highest levels of PA (Silk et al., 2011). Together, these findings highlight the potential importance of lifestyle factors for the experience of PA in daily life, and suggest that all four main types of lifestyle advice may have contributed to improvement in pleasure that was found.

In the study reporting on the primary outcomes, we examined whether the group who received the advice differed from a control group receiving no intervention in PA, pleasure, NA, and monthly measures of anhedonia and depression (van Roekel et al., 2017). We have not yet explored whether specific types of advice had different effects, and whether lifestyle behaviors change due to the intervention. Therefore, we aimed to explore in the present study whether (1) the most frequent types of advice (i.e., increase physical activity, increase time outside, decrease worrying or increase social company and social interaction) were effective in increasing PA and pleasure at the group-level, (2) individuals actually changed their behavior based on the advice they received, and (3) changes in behavior were associated with improvement in PA and pleasure.

## Methods

### Participants

The full procedure and primary results from the present intervention study can be found elsewhere (van Roekel et al., 2016; Van Roekel et al., 2017). In short, a screening survey was administered among 2,937 young adults (aged between 18 and 24), from which 69 young adults with anhedonia were selected for an intervention study testing the effects of personalized lifestyle advices with or without a consecutive tandem skydive. Inclusion criteria were low levels of experienced pleasure (i.e., below the 25$^{th}$ percentile), reported to be less or much less than normal, with a duration of at least two months, as reported on the Domains of Pleasure Scale (Masselink et al., 2019), and willingness to perform a skydive. Additional analyses showed that this inclusion criterion did not lead to a biased sample[1]. Exclusion criteria were inability to keep an electronic diary three times a day; professional treatment for psychiatric problems; use of psychotropic medication; epilepsy; pregnancy; conditions that obstruct participating in a tandem skydive (i.e., loose prostheses; height of more than 2 meters; weight of more than 95 kg; inability to raise one's legs 90 degrees; cardiovascular complaints or problems; and significant visual or hearing impairments); and experience with skydiving, bungee jumping, or base jumping. The study was approved by the Medical Ethical Committee from the University Medical Center Groningen (no. 2014/508).

As we did not have pilot data with effect sizes to base a power analyses on, we relied on general sample size recommendations for Dynamic Structural Equation Modeling (Schultzberg & Muthén, 2018). For the first questions examining cross-level interactions

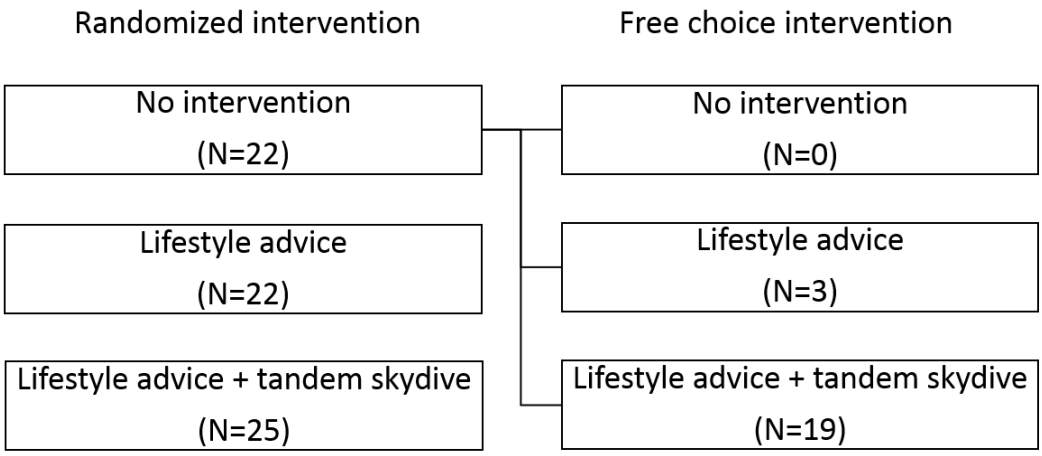
[1] Of the total sample that was screened, only 12.8% were unwilling to perform a tandem skydive (N = 376). These participants did not differ significantly from those who were willing to perform a skydive (N = 1759; 59.9%), or indicated 'maybe' (N = 802; 27.3%) on sex, age, trait PA, depressive symptoms (PHQ-9; Kroenke et al., 2001), and reward responsiveness (RR; Van den Berg et al., 2010). Within the anhedonic subsample, no significant differences were found in severity of anhedonia, level of consummatory pleasure, or depressive symptoms between the group who was not willing to perform a skydive (N = 25) and the group who was willing to perform a skydive (answer yes or maybe).

between the type of advice and mean level changes in affect and behavior, Schultzberg and Muthén have shown that, for a cross-level interaction with T = 100, a total number of assessments (N * T) of > 3000 would suffice for a power of .80. The cross-lagged analyses in our study are based on N = 69 individuals and T = 180 assessments (three times a day for two months, see below), which leads to a total number of 12,240 assessments (69 * 180). Therefore, we assumed our study is sufficiently powered. For the within-person cross-lagged associations, Schulzberg and Muthen (2018) state that the relative bias for a model with one dependent variable and one autoregressive predictor is close to 1 - indicating good performance - for the means of random coefficients for samples with T ≥ 10 and N > 15. We had T = 90 assessments per individual, and a varying N (depending on the type of advice received) between 32 and 59. Although our models are a bit more complex than those included in the simulation studies, we trust that the relative bias in our study is low based on these numbers.

**Procedure**

Participants for the screening survey were recruited in the northern part of the Netherlands through flyers, electronic learning environments, advertisements on social media, and invitations during lectures and classes. When individuals wanted to participate, they had to subscribe on the study website (www.nofunnoglory.nl), after which they received an email with the link to the online questionnaire. Participants received a gift card of 10 euro after completion of the questionnaire. Eligible participants for the intervention study were sent an email containing an information letter and informed consent form. Upon receipt of the signed consent form, participants were invited by telephone for an introductory meeting. During this meeting, study criteria were checked again, study procedures were explained, and the momentary questionnaires were practiced with participants. The momentary questionnaires started within a few days after the introductory meeting. We used a web-based application (www.roqua.nl) through which text messages were sent to participants with a link to the questions, which they could fill out online, on their own smartphone. Participants received three questionnaires per day with six hour intervals. Three questionnaires per day was considered sufficient for this purpose, since the effects of various lifestyle behaviors have been reported to last at least several hours (Kamarsu et al., 2020; Liao et al., 2016; Snippe et al., 2014, 2015; Stavrakakis et al., 2015). The timing of the first questionnaire of the day was determined together with participants, but the time between assessments was fixed (e.g., participants could receive assessments at 8:00, 14:00, 20:00, or at 10:00, 16:00, 22:00). The momentary questionnaires included questions about affect, lifestyle behaviors, and events (for details, see van Roekel et al., 2016). The momentary questionnaires continued for around 3.5 months. Each month, participants filled out an additional online survey. After one month, participants were randomly assigned to one of three intervention groups: no intervention (N = 22), lifestyle advice only (N = 22), and lifestyle advice in combination with a tandem skydive (N = 25) (for details on tandem skydive, see Appendix A). After the second month, participants were free to choose which intervention they wanted to receive. As can be seen in Figure 1, all participants who were assigned to the control group after the first month chose an intervention after the second month, mostly consisting of lifestyle advice plus tandem skydive. Given that we did not find differences in improvement between the lifestyle advice only group and the group who had also received a tandem skydive (van Roekel et al., 2017), these groups were both included in the

**Figure 1.** Intervention Distribution



analyses. Further, because we were no longer interested in comparing the intervention group with a control group, we included all individuals from the control group who had received the advice after the second month, which resulted in a total sample of 69 individuals, of whom 44 had received the lifestyle advice after the first month and 25 after the second. Figure 2 shows the timing of the different interventions, and which data was used in the present study for the interventions groups versus the control group.

**Personalized lifestyle intervention**

For each individual, we created a personal report, presenting the associations between various lifestyle behaviors and pleasure. The lifestyle report consisted of three components: (1) descriptive statistics of pleasure and lifestyle behaviors, (2) comparison of frequency of lifestyle behaviors with norm groups, and (3) personal networks representing cross-sectional and lagged associations between lifestyle behaviors and pleasure. The personal networks were created by using Autoregressive Moving Average (ARMA) analyses and automated Vector Autoregressive modeling (VAR). Based on these associations, we identified potential targets for the lifestyle advice, which were discussed with participants in a 1.5-hour individual face-to-face session with one of the four team members. Each participant received two or three concrete suggestions on which lifestyle behaviors to change in order to experience more pleasure. For physical activity, time outside, and social activity, these suggestions involved direct ways to increase these behaviors. For worrying, we provided mindfulness exercises as a therapeutic tool (e.g., participants were instructed to complete mindfulness exercises 4-5 times per week, for 15 minutes). The participants were instructed to implement these suggestions in the following month. A detailed description of the lifestyle advice can be found in (van Roekel et al., 2017) and example figures are depicted in Appendix B (supplementary material).

**Measures**

Detailed information about all materials used in the present study can be found in van Roekel and colleagues (2016) and in the codebook published on the Open Science Framework (https://osf.io/gp5x8/).

***PA and pleasure***

PA and pleasure were measured at each assessment. PA consisted of the following items: feeling interested, joyful, determined, calm, lively, enthusiastic, relaxed, cheerful, satisfied, and energetic. For pleasure, participants were asked to report how much pleasure they experienced since the last assessment. Participants rated the extent to which these statements were applicable by moving a slider along a continuum (i.e., Visual Analogue Scale; VAS) anchored with the words *not at all* on the left and *very much* on the right. The location of the slider was converted into a score between 0 and 100. Cronbach's alpha was .94 for PA (calculated over all assessments).

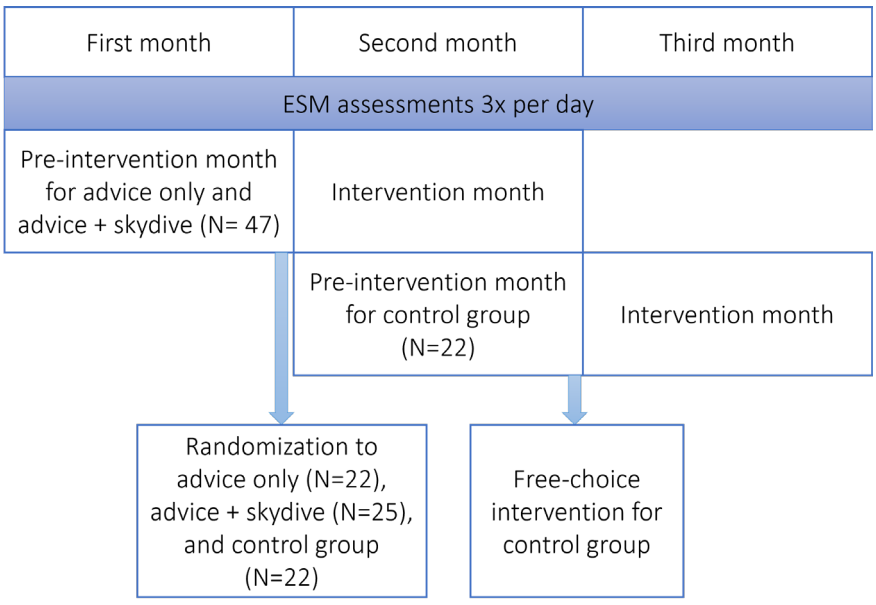
***Physical activity***

At each assessment, participants reported the extent to which they were physically active on a VAS scale ranging from 0 (*not at all*) to 100 (*very much*).

***Time outside***

For time outside, participants rated how much time they had been outside since the last assessment, on a

**Figure 2.** Intervention Timing for the Different Intervention Groups



VAS scale ranging from 0 (*not at all*) to 100 (*very much*).

***Worrying***

Participants were asked to report the extent to which they had been worrying since the last assessment on a VAS scale ranging from 0 (*not at all*) to 100 (*very much*).

***Social activity***

For social activity, we measured the time participants had spent alone and the time they had been in social interaction since the last assessment. For time spent alone, participants were asked whether they had been alone since the last assessment, and if yes, how much time they had spent alone, to be indicated on a VAS ranging from 0 (*very little)* to 100 (*very much)*. For social interaction, participants reported how much they had been talking to other people, ranging from 0 (*not at all)* to 100 (*very much)*. Social activity and social interaction represent different aspects of social activity, which is reflected in the fact that these items are only moderately correlated ($r$ = -.45).

**Strategy of Analyses**

Given the nested structure of our data (assessments within individuals), we used Dynamic Structural Equation Modeling (DSEM) in Mplus 8 (Muthén & Muthén, 1998) to answer our research questions. DSEM incorporates Bayesian estimation with uninformative priors (Asparouhov & Muthén, 2010; Muthén & Asparouhov, 2012), which uses two Markov Chain Monte Carlo chains. Convergence of the chains is assessed with the potential scale reduction (PSR) factor. The default cut-off for convergence in Mplus is PSR < 1.1, yet smaller cut-offs have been recommended in previous research (e.g., Brown et al., 2011; Hoofs, van de Schoot, Jansen, & Kant, 2017)). We set the BCONVERGENCE option in Mplus to .005 to overrule the default and set the PSR to < 1.01, with a minimum number of iterations of 2,000. When the chains converged (i.e., PSR < 1.01) and no stable low sequence of PSR's was established at 2,000 iterations, we doubled the number of iterations to ensure a stable low sequence of PSR's. First, we explored whether the type of advice was associated with improvement in PA and pleasure after the intervention. Improvement was operationalized as the mean level difference in PA and pleasure between the pre-intervention month and the post-intervention month. We examined this association by adding a variable for time, which represented whether the assessment took place before (score = 0) or after (score = 1) the intervention, to the multilevel model as a predictor for PA and pleasure. To explore the effects of advice on this level difference, we tested cross-level interactions between the variable for time (pre/post intervention) and dummy variables for the type of advice. Please note that we did not include a control group receiving no intervention in these analyses. Hence, the reference group in each of these models were participants who received other types of advice than the one in the model.

Second, we investigated whether individuals changed the behavior that was targeted in their advice. This was done by adding the variable for time (pre/post intervention) as a predictor for the four types of behavior (i.e., physical activity, time outside, social activity and worrying). We tested whether the change in a particular behavior differed between those who had received advice on that type of behavior compared to those who had not by a cross-level interaction of time (pre/post intervention) with advice (yes/no).

Third, we investigated whether a change in behavior was associated with improvement in PA and pleasure, by regressing the level effect for PA and pleasure on the level effect for behavior. This association was only examined in the group who received the advice, because we were mainly interested in the mechanism of change if participants received the specific advice. These analyses indicated whether changes in behavior were associated with improvement in PA, but could not provide insight in the possible causal direction of these associations. We therefore additionally used a cross-lagged multilevel multivariate model to explore whether and how behavior and PA were reciprocally associated over time in the post-intervention month within individuals who received the advice, controlling for the stability paths. In these models, PA, pleasure and behavior at the current time point (t) were predicted by PA, pleasure, and behavior at the previous time point (t-1). These associations were allowed to differ between individuals (i.e., random slopes).

For the first and second research question, we reported unstandardized coefficients, as the predictor in these analyses is dichotomous (pre/post intervention) and we were interested in the absolute mean level changes from pre- to post-intervention. For the reciprocal associations between PA, pleasure and behavior, we reported within-person standardized coefficients. The syntaxes, output, and data used in the present study are openly available via https://osf.io/gp5x8/.

## Results

Out of the total sample (N = 69), 85.5% of participants (N = 59) received the advice to increase social activity, 73.9% of participants to increase physical activity (N = 51), 42.0% of participants received advice to increase time spent outside, and 46.4% (N = 32) to decrease worrying. Please note that participants

**Table 2.** Unstandardized Associations Between Type of Advice and Changes in PA, Pleasure and Behavior After the Intervention.

| | PA | | Pleasure | | Behavior | |
|---|---|---|---|---|---|---|
| | No advice | Δ Advice | No advice | Δ Advice | No advice | Δ Advice |
| **Physical activity** | | | | | | |
| Level change | 4.14 (1.41)** | -0.33 (1.65) | 3.36 (1.62)** | 0.13 (1.89) | -0.88 (1.68) | 1.37 (1.97) |
| **Time outside** | | | | | | |
| Level change | 3.64 (0.94)*** | 0.71 (1.47) | 2.108 (1.04)* | 3.21 (1.64) | 0.57 (1.23) | 3.49 (1.90) |
| **Worrying** | | | | | | |
| Level change | 4.03 (0.98)*** | -0.24 (1.43) | 4.29 (1.10)*** | -1.85 (1.65) | -3.80 (1.18)** | -5.14 (1.77)** |
| **Social activity** | | | | | | |
| *Social interaction* | | | | | | |
| Level change | 4.01 (1.88)* | -0.13 (2.04) | 4.07 (2.13)* | -0.78 (2.32) | 2.41 (2.19) | -4.31 (2.37) |
| *Social company* | | | | | | |
| Level change | 4.01 (1.88)* | -0.13 (2.04) | 4.07 (2.13)* | -0.78 (2.32) | 3.46 (2.32) | -2.02 (2.45) |

*Note.* * $p < .05$, ** $p < .01$, *** $p < .001$. Advice is dummy-coded into 0 = no advice and 1= advice, indicating that the coefficient for level change in the "No advice" column represents the change in the group who did not receive the advice, and the coefficient for level change in the "Advice" column represents whether and how this change is significantly different in the group who did receive the advice. The coefficients are unstandardized.

received multiple types of advice, which means that they could receive a combination of 2 or 3 types of advice.

We did not find that specific types of advice were significantly stronger associated with improvement in PA and pleasure than others (see Table 1). Further, changes in physical activity, time outside, and social activity did not differ between the individuals who received these types of advice compared to the individuals who received different ones. For worrying, both groups decreased in worrying after the intervention, but this decrease was stronger in the group who received the advice.

Next, we explored whether changes in behavior were associated with improvement in PA and pleasure (see Table 2). No relation was found between a change in behavior and changes in PA or pleasure for time outside and social company. We found that the level change in physical activity was significantly associated with the level change in PA and pleasure, indicating that an increase in physical activity after the intervention was related to an increase in PA and pleasure. The change in worrying was not significantly associated with a change in PA, but did show a significant association with a change in pleasure, indicating that a decrease in worrying after the intervention was associated with an increase in pleasure. Increases in social interaction were associated with increases in both PA and pleasure.

**Table 1.** Unstandardized Associations Between Level Changes in Behavior and Level Changes in PA and Pleasure.

| | Level change PA | Level change Pleasure |
|---|---|---|
| Level change physical activity | 0.40 (0.15)** | 0.37 (0.18)* |
| Level change outside | 0.11 (0.17) | 0.13 (0.19) |
| Level change worrying | -0.16 (0.14) | -0.43 (0.15)** |
| Level change social company | -0.11 (0.18) | 0.06 (0.21) |
| Level change social interaction | 0.30 (0.13)* | 0.48 (0.15)*** |

*Note.* * $p < .05$, ** $p < .01$, *** $p < .001$.

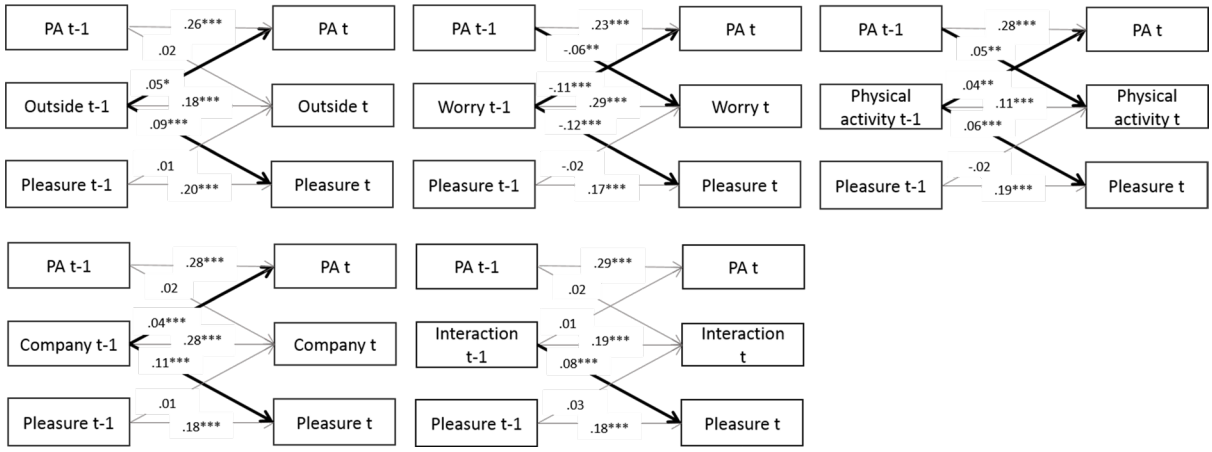
The results of the cross-lagged models are presented in Figure 3 and Table 3. Please note that these analyses represent momentary associations between behavior and affect in the post-intervention month, whereas the previous analyses focused on the changes in average levels between the pre-intervention and post-intervention month. For all four behaviors, we found paths from the behavior to either PA or pleasure, indicating that a within-person deviation from one's own mean of behavior was associated with a within-person change in PA or pleasure at the next assessment. For physical activity and worrying, we also found paths from PA at the current assessment to behavior at the next assessment. For physical activity, these findings indicate that individuals who received this advice were not only more likely to experience more PA after they had been more physically active, they were also more likely to increase physical activity after they had experienced more PA. For worrying, the association was negative, in that decreases in worrying were associated with more PA at the next assessment, and increases in PA were associated with decreases in worrying at the next assessment.

**Table 3.** Reciprocal Within-Person Standardized Momentary Associations Between PA, Pleasure, and Behavior

| | Physical activity | Outside | Worrying | Social company | Social interaction |
|---|---|---|---|---|---|
| PA t on PA t-1 | .28 (.02)*** | .26 (.02)*** | .23 (.02)*** | .28 (.01)*** | .29 (.01)*** |
| PA t on Behavior t-1 | .04 (.02)** | .05 (.02)* | -.11 (.02)*** | .04 (.01)*** | .01 (.01) |
| Pleasure t on Pleasure t-1 | .19 (.02)*** | .20 (.02)*** | .17 (.02)*** | .18 (.02)*** | .18 (.02)*** |
| Pleasure t on Behavior t-1 | .06 (.02)*** | .09 (.02)*** | -.12 (.02)*** | .11 (.02)*** | .08 (.02)*** |
| Behavior t on PA t-1 | .05 (.02)** | .02 (.02) | -.06 (.02)** | .02 (.02) | .02 (.02) |
| Behavior t on Pleasure t-1 | -.02 (.02) | .01 (.02) | -.02 (.02) | .01 (.02) | .03 (.02) |
| Behavior t on Behavior t-1 | .11 (.02)*** | .18 (.02)*** | .29 (.02)*** | .28 (.01)*** | .19 (.02)*** |

*Note.* * $p < .05$, ** $p < .01$, *** $p < .001$.

**Figure 3.** Reciprocal Associations Between PA, Pleasure, and Different Types of Lifestyle Behaviors.




*Note.* The numbers represent unstandardized coefficients. Bold arrows represent significant cross-paths from PA or pleasure to behavior or vice versa. * $p < .05$, ** $p < .01$, *** $p < .001$

## Discussion

Research on potential mechanisms of change in the effectiveness of treatments such as behavioral activation is currently lacking. In the present study, we aimed to examine how anhedonic individuals regained pleasure after receiving personalized lifestyle advice, by investigating how changes in behavior were associated with improvement in PA and pleasure.

On a group level, we did not find one specific advice being more effective than other types of advice. This may be due to individual variation in the extent to which participants followed up on our advice. Our analyses further showed that advice for worrying led to the greatest behavioral change, as compared to no such advice, and this was the only change that was statistically significant. Other types of advice seemed to be less able to produce a behavioral change in many individuals. Given that not all individuals changed their behavior after receiving an advice, it is particularly important to further explore whether individuals who did change their behavior also improved in PA and pleasure.

Within-person increases in physical activity and social interaction after the intervention were associated with within-person increases in PA and pleasure, and within-person decreases in worrying were associated with within-person increases in pleasure. For time outside and social company, no associations were found between changes in behavior and changes in PA or pleasure. This could mean that physical activity, social interaction, and worrying were particularly important for the intervention effect found. Caution is warranted, however, because the above-mentioned results only indicate that behavior change and pleasure change were correlated and did not provide any clues regarding to the direction of these effects. Changes in behavior may have preceded changes in PA and pleasure, but increases in PA and pleasure could also induce individuals to exercise more or worry less. Therefore, we explored the direction of effects by investigating the reciprocal associations between the different types of behavior and PA and pleasure in the month following the intervention. These momentary reciprocal associations between the behaviors and PA and pleasure yielded important insights in the direction of effects. For time outside, social interaction, and social company, only paths were found from the behavior to PA or pleasure, showing that when participants engage in this behavior, they experience

more PA or pleasure at the next assessment. This association is not surprising, because the participants only received a specific type of advice if we found associations between the behavior and pleasure in the pre-intervention month. For physical activity and worrying, we also found reciprocal paths, indicating that increases in PA were associated with increases in physical activity or decreases in worrying at the next assessment. These bidirectional associations could be indicative of a positive feedback loop or vicious circle, in which, for example, decreases in worrying are associated with increased PA, and these increases in PA are in turn associated with further decreases in worrying. These findings may explain why changes in physical activity and worrying were associated with improvement, and why interventions such as running therapy and mindfulness interventions have been reported particularly effective in increasing PA and decreasing depressive symptoms (Garland et al., 2015; Knapen et al., 2015; Snippe et al., 2015). Increases in social interaction were also associated with improvement, but we did not find reciprocal associations between PA/pleasure and social interaction. This lack of reciprocity might be due to the large variation in the extent to which individuals who received a social advice actually changed their behavior; on a group-level, social interaction even tended to decrease in individuals who received the advice. Perhaps the association between changes in behavior and changes in PA and pleasure was mostly driven by the few individuals who did increase in social interaction. Since most individuals did not follow-up on the advice to increase the quantity of social interactions, it is debatable whether this is an effective intervention to decrease anhedonia. Possibly, improving the quality of social interaction may be more effective in reducing anhedonia, but we did not measure this in the present study and thus could not explore this.

The feedback loop between worrying and PA may be mediated by mindfulness, as we advised participants to try mindfulness exercises to reduce their worrying. Important to note, however, is that previous studies on the bidirectional relationship between daily mindfulness and affect or depressive symptoms in individuals receiving a mindfulness intervention found that changes in mindfulness preceded changes in depressive symptoms (Snippe et al., 2014) and affect (Snippe et al., 2015), but not the other way around. These diverging findings could be caused by differences in the time frame, as we measured worrying and affect more often (i.e., three times a day). Further research is needed to explore the reciprocal associations between mindfulness, worrying and affect within days.

Our results showed slightly diverging findings for the PA and pleasure measures. Both measures likely capture different aspects of pleasure or anhedonia, as the PA measure includes multiple items for both high and low arousal PA, and is thus a more comprehensive measure. Pleasure was only measured with one item, which likely captured the pleasure participants experienced in response to different activities. These different measures may have led to slightly diverging results for PA and pleasure. It would be interesting to further explore differences in these operationalizations of anhedonia in daily life and how these measures change in response to interventions in future research.

**Strengths and limitations**

The main strengths of the present study are that we provided participants with a personalized lifestyle advice, based on individual associations between lifestyle behaviors and pleasure. Further, because of the large number of momentary assessments before and after the intervention, we were able to explore detailed mechanisms of change within individuals. However, some limitations need to be acknowledged as well. First, we included a non-referred anhedonic sample. Although we selected participants with persistent anhedonia, our results may not be generalizable to clinically depressed samples. Second, as a tandem skydive was part of the intervention, we only included participants who were willing to participate in a tandem skydive. Importantly though, we showed in a previous study (van Roekel et al., 2017) that the individuals who reported to be definitely or maybe willing to perform a skydive in the screening survey, did not significantly differ from the ones who were not willing to perform a skydive on demographics and other relevant variables (e.g., depression, reward responsiveness). Third, we used self-reports for all lifestyle behaviors, whereas for example physical activity could be more accurately measured by using an accelerometer (Prince et al., 2008). Fourth, despite the large number of momentary assessments, we had a relatively small sample size at the between-person level (N=69). Although our sample size was in line with general recommendations (Schultzberg & Muthén, 2018), we may have been underpowered to find differences between groups, particularly for the models in which the subgroups were unequally distributed (e.g., only 10 participants did not receive a social activity advice). Fifth, participants could receive different combinations of advice. Given our small sample size, we were not able to test whether certain combinations were more effective in increasing PA and pleasure than others. Further research in larger samples is needed to examine possible differences in effectiveness between types of advice in more detail.

## Conclusions

In sum, we can conclude that physical activity and worrying play an important role in the path to improvement in individuals with anhedonia. For these two behaviors, positive feedback loops existed between PA and the behavior, which could explain why changes in these behaviors were particularly relevant for improvement. Results from the present study indicate that momentary assessments are an effective tool to detect important mechanisms of change in interventions.

## Supplementary Materials

The supplementary materials can be found here: https://osf.io/yckr3/

## Additional Information

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### Conflict of Interest

The authors declare that they have no competing interests.

### Ethical approval

The current study was carried out in accordance with the Declaration of Helsinki and was approved by the Medical Ethical Committee from the University Medical Center Groningen (no. 2014/508).

### Data Availability

All data and input files are shared on the Open Science Framework: https://osf.io/gp5x8/

### Author CRediT Statement

van Roekel: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization
Oldehinkel: Conceptualization, Methodology, Data Curation, Writing – Editing, Supervision, Funding acquisition



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