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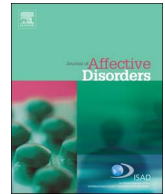
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Research paper

Positive affective functioning in anhedonic individuals' daily life Anything but flat and blunted



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ABSTRACT

Background: Anhedonia, the decreased interest and pleasure, is often described as ‘flat’ or ‘blunted’ positive affect (PA). Yet, little is known about PA functioning in anhedonic individuals’ daily lives. The current study investigates PA reactivity to pleasurable experiences in anhedonia together with its relevant temporal dynamics (i.e., variability, instability, and inertia), and expands current knowledge by exploring the role of arousal therein.

Methods: Using the Experience Sampling Method (ESM), we collected 90 assessments of real-life PA experiences across 30 days in 18–24 year old individuals with anhedonia (N = 69) and without anhedonia (N = 69).

Results: Multilevel analyses showed that anhedonia was associated with less intense pleasure experience, and lower levels of PA. Contrary to predictions from laboratory research and depression theory, individuals with anhedonia showed more variability and less stability in PA, and no signs of blunted PA reactivity. In fact, when exploring high and low arousal PA, individuals with anhedonia showed a slightly stronger reactivity to pleasurable experiences in high-arousal PA but not low-arousal PA.

Limitations: We did not control for previous pleasure experiences and, instead of the last positive event, accumulation of positive events may have determined the change in high-arousal PA.

Conclusions: Individuals with anhedonia are likely less ‘flat’ or ‘blunted’ than generally thought. Although replication is warranted, impairments in high-arousal positive emotions may be of particular interest in the clinical treatment of anhedonia.

1. Introduction

In psychology and psychiatry, positive moods such as feeling enthusiastic, cheerful, or relaxed are collectively referred to as Positive Affect (PA). In addition to its natural ebbs and flows (Peeters et al., 2006), PA is transiently elicited by appetitive cues. The uplift in PA in response to these cues has the power to establish, maintain, or disrupt an individuals’ ongoing relations to the environment and facilitates action tendencies to approach or to avoid (Eid and Diener, 1999; Frijda, 1988; Lang and Bradley, 2010). Whereas high levels of PA foster a wide array of positive outcomes in one’s daily life (Fredrickson and Joiner, 2002; Fredrickson, 2013; Lyubomirsky et al., 2005; Tice et al., 2007), dysregulation of PA plays an incremental and crucial role in mood disorders – and in anhedonia in particular.

Anhedonia is clinically defined as the “markedly diminished interest or pleasure in all, or almost all, activities most of the day, nearly every

day” (American Psychiatric Association, 2013). The symptom is common in eating disorders, substance use disorders, and schizophrenia, and is most known for its prominence in the depression diagnosis. That is, anhedonia is one of the two core symptoms of depression, has a prominent role in both adult depression (e.g., see Pizzagalli, 2014, for a review) and youth depression (e.g., see Forbes and Dahl, 2012, for a review), and is present in about 72% of emerging adults’ first major depressive episode (Lewinsohn et al., 2003). Despite the transdiagnostic nature of anhedonia and its prominence in depression diagnosis, PA functioning in anhedonia is not yet fully understood.

2. PA reactivity in anhedonia: hypo or hyper?

Based on conceptual models of depression, there are two relevant views on how anhedonia impacts individuals’ PA functioning. The first relevant view is called the Positive Attenuation hypothesis, which

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predicts a reduced responsiveness to appetitive stimuli in depression, manifested by reduced reactivity to positive emotional stimuli or contexts (Rottenberg et al., 2005). The second view is the Emotion Context Insensitivity (ECI) theory which predicts constricted affective reactions to both positive and negative contexts, because depression would flatten the emotional landscape as a whole and would cause insensitivity to any given emotional context (ECI; Rottenberg, 2005). Irrespective of the inclusion of negative affect (NA), both views postulate that depressive symptoms go along with flat and blunted PA that is hypo reactive to positive contexts or stimuli.

In line with these conceptual models, laboratory research consistently shows blunted reward responses to stimuli in individuals with depression or depressive symptoms (see for a meta-analysis: Bylsma et al., 2008), and in individuals with social and physical anhedonia (Kerns et al., 2008). Contrary to predictions by conceptual models of depression and findings from laboratory research, however, studies designed to capture momentary ratings of experiences using the Experience Sampling Method (ESM; Csikszentmihalyi and Larson, 1987) or Ecological Momentary Assessment (EMA; Stone and Shiffman, 1994) show quite a different picture. That is, the few ESM studies investigating PA reactivity to pleasurable experiences show either no evidence of blunted reactivity in relation to depression or depressive symptoms (Bylsma et al., 2011; Oorschot et al., 2013; Thompson et al., 2012; van Roekel et al., 2015), or evidence for the opposite: a stronger PA response to positive events in depressed versus non-depressed (Peeters et al., 2003).

In addition to the surprising stronger PA response, Peeters et al. (2003) found a stronger decrease in NA in response to positive events in individuals with MDD. This improvement of mood that was counter-intuitively greater in depressed than non-depressed individuals was coined the “mood-brightening effect”. Since then, other studies of emotion reactivity to positive events in daily life observed the same effects: a greater reactivity in the sense that depressed individuals showed a stronger decrease in NA in response to positive events than their non-depressed counterparts (Bylsma et al., 2011; Thompson et al., 2012).

3. PA dynamics in anhedonia

To gain more insight into how the dynamics of positive affective experiences unfold in daily life, one can study PA in terms of its variability, inertia, and instability (Houben et al., 2015; Trull et al., 2015; Wichers et al., 2015). Whereas emotional variability refers to the spread or dispersion in scores (e.g., standard deviation or variance), emotional inertia refers to the resistance to change as captured by the autocorrelation (i.e., the correlation between PA on T and PA on T-1 within the individual that can vary randomly across individuals). High inertia means high moment-to-moment transfer of emotions, and strongly consistent continuation in feeling as one has felt previously may indicate low context sensitivity. Emotional instability is generally measured by the Mean Squared Successive Difference (MSSD; Jahng et al., 2008), which captures the magnitude of consecutive emotional change after a frequency of shifts correction.

Although anhedonia is often operationalized as lack of PA (e.g., Bedwell et al., 2014), ‘flat’ PA (e.g., Myin-Germeys et al., 2000), or ‘blunted’ PA (e.g., Shankman et al., 2014), only one ESM-study investigated the temporal dynamics of PA in anhedonia. van Roekel et al. (2015) were the first and only to zoom in on the anhedonia symptom. Contrary to what the authors expected, however, those adolescents who endorsed the anhedonia symptom did not differ from those who did not endorse the symptom in terms of their variability, stability, and inertia in PA. According to the authors, this lack of associations might stem from the fact that anhedonia was assessed with a single item on loss of interest, which is why the authors call for a

replication with a more extensive measure of anhedonia. Furthermore, the few ESM-studies that investigated the temporal dynamics of PA among depressed individuals or individuals with depressive symptoms have shown inconsistent findings. Whereas some find more depressive symptoms related to higher levels of PA variability and PA instability (van Roekel et al., 2015), others find no differences in temporal dynamics in PA related to depression (Peeters et al., 2003; Thompson et al., 2012).

4. The possible role of arousal in PA functioning

In addition to the valence dimension of affective experiences, affect most likely also holds an arousal dimension that conveys information on an individuals’ general action readiness or behavioral activation (Bradley and Lang, 2007; Harmon-Jones et al., 2013; Lowe and Ziemke, 2011). Individuals with anhedonia have consistently been found to exhibit reduced motivation and impaired effortful decision-making in depression and schizophrenia (Franzen and Brinkmann, 2016; Gold et al., 2013; McCarthy et al., 2015; Shankman et al., 2014; Yang et al., 2014). Notwithstanding the large variation in how the valence and arousal dimension of affective experiences are related to each other (Barrett, 1995; Kuppens, 2008), the valence-arousal relation may covary by other psychological characteristics (Kuppens et al., 2016). So far, there is support for the role of an arousal-related deficit in anhedonia (Germans and Kring, 2000), yet only one laboratory study by Kerns et al. (2008) explored whether impairments in PA functioning in anhedonia particularly resided in high-arousal PA. Although the authors found social and physical anhedonia both associated with decreased PA reactivity to lab stimuli, this decrease was not specifically pronounced in high-arousal PA. However, the difference in PA functioning for low and high arousal PA has never been investigated in daily life, and by means of ESM.

5. The present study

Given the prominence of anhedonia in the depression diagnosis and its transdiagnostic nature, the present study describes PA functioning in individuals with anhedonia with the aim to contribute to the existing literature in two important ways. First, we investigated PA reactivity to pleasurable experiences in anhedonia together with its relevant temporal dynamics (i.e., variability, instability, and inertia), providing a complete picture of PA functioning in the daily life of emerging adults with anhedonia. Second, we distinguished between high and low arousal PA functioning, and are the first ESM study to explore the role of arousal in the PA functioning of anhedonic individuals.

We compared PA functioning in daily life between individuals with and without anhedonia, and expected individuals with anhedonia to show: 1) less intense pleasure experiences; and 2) lower levels of PA. Furthermore, given that predictions from laboratory and ESM studies on PA reactivity are contradictive, we expected those with anhedonia to show 3) deviations in PA reactivity to pleasure experiences, and 4) deviations in temporal dynamics of PA (i.e., variability, instability, and inertia). Finally, we explored the potential role of arousal by re-examining the second to fourth hypotheses on PA functioning while distinguishing low from high arousal PA.

6. Method

6.1. Sample

Data come from the experience-sampling part of the ‘No Fun No Glory’ (NFNG) study. The NFNG randomized controlled study is

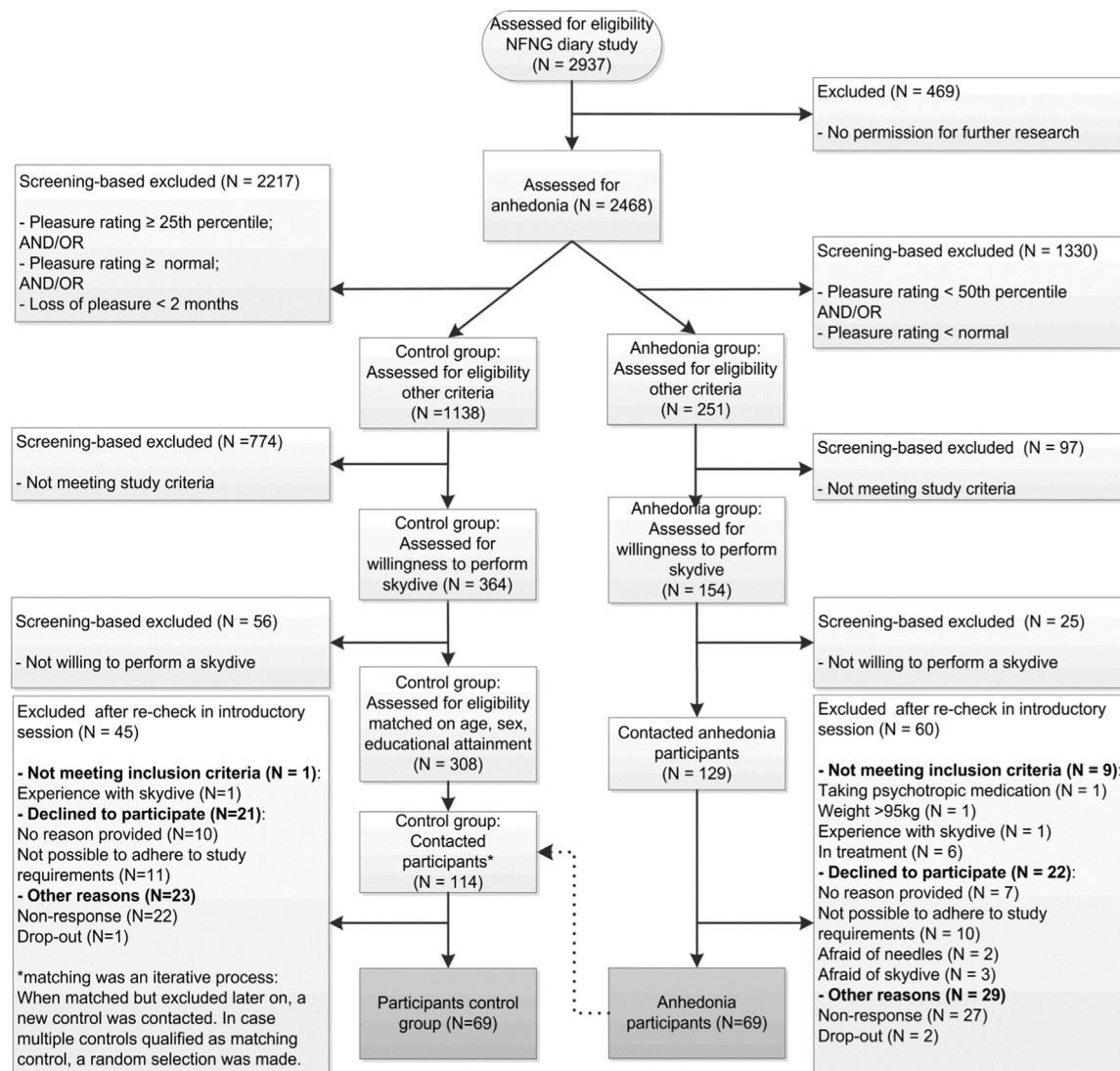


Fig. 1. Flowchart of participant enrollment (dotted line indicates matching procedure).

registered in the Dutch Clinical Trial Register (NTR5498), was approved by the Dutch Central Medical Ethics Committee from the University Medical Center Groningen (no. 2014/508), and is described in more detail by van Roekel et al. (2016). In short, the NFNG study included an online screening-tool among 2937 emerging adults living in the Northern part of the Netherlands (78% women; $M_{age} = 21.4$ years, age range: 18–24 years), of which 138 participants were enrolled in the experience-sampling part of the study: 69 anhedonic young adults, and 69 matched controls. Anhedonic young adults filled out momentary assessments of pleasure and lifestyle behaviors for three months, whereas their non-anhedonic counterparts filled out these momentary assessments only during the first month. For the current study, we used experience-sampling data from the first 30 observational days, during which no interventions were applied. For a flowchart of participation rates and participation loss due to study criteria, see Fig. 1.

Participants were eligible for the anhedonia group if they met the following three criteria from the Domains of Pleasure Scale (Masselink, van Roekel, Heininga, Vrijen, Nederhof, & Oldehinkel: Domains Of Pleasure Scale (DOPS): a novel questionnaire to assess anhedonia, submitted): 1) their pleasure rating was below the 25th percentile of pleasure scores; 2) which they considered *less*, or *much less than normal*; and 3) this loss of pleasure lasted longer than two months. These participants were invited to participate in further research by email

which included a cover letter; information about the study; the reason why they were selected; and a consent form. Immediately after receiving a signed consent form from an anhedonia participant, a control participant was matched based on age, gender, and educational attainment. Control participants could be matched if their pleasure rating was above the 50th percentile, which the participant considered *just as much*, *more than normal* or *much more than normal*.

Participants were excluded on the following criteria: the inability to keep an electronic diary three times a day; current professional treatment for psychiatric problems; and current use of psychoactive drugs. In addition, since the intervention of the NFNG study included a tandem skydive¹, other exclusion criteria were: unwillingness to perform a tandem skydive¹; epilepsy; pregnancy; conditions that make it impossible to be attached to the tandem master (e.g., loose prostheses); height of more than 2 m; weight of more than 95 kg; inability to raise one's legs 90°; significant visual or hearing impairments; prior experi-

¹ Of the total sample that was screened, it should be noted that only 12.8% were unwilling to perform a tandem skydive (N=376) and that these participants did not significantly (i.e., $p > .05$) differ from those who were willing (N=1759; 59.9%), or from those who 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).

ence with skydiving, bungee jumping, or base jumping; or cardiovascular complaints/problems.

6.2. Measures

6.2.1. Positive affect (PA)

To assess momentary PA, participants were asked to rate the extent to which they experienced a certain emotion by moving a slider along the continuum of a Visual Analogue Scale (VAS), that was anchored with *not at all* (left) and *very much* (right). The location of the slider was converted into a score between 0 and 100. Whereas in the morning affect was measured in the moment (i.e., “I feel [insert emotion]”), in the afternoon and evening assessments, affect was measured in retrospect (i.e., “Since the last assessment, I have felt [insert emotion]”). Positive affect (PA) was calculated by averaging the VAS-scores of the following 10 emotions: feeling interested, joyful, determined, calm, lively, enthusiastic, relaxed, cheerful, satisfied, and energetic. Cronbach's alpha was 0.94 (calculated over all assessments).

6.2.2. High/low arousal PA

High-arousal PA was calculated as the average of the PA items ‘enthusiastic’ and ‘energetic’, whereas low-arousal PA was the average of the PA items ‘calm’ and ‘relaxed’ (c.f., Longo, 2015). The inter-item correlation between the two high-arousal and low-arousal items, based on the average scores over 90 measurements, was high: $r=0.90$ and $r=0.91$, respectively.

6.2.3. Variability in (high/low arousal) PA

Variability in PA, or high/low arousal PA, was defined as the within-person variance of PA across time, calculated at each assessment as the squared deviation of participants’ own mean. Given that Mplus allows for the analysis of nested variables within a multi-wave design we considered this the best approach to test variability in PA and high/low arousal PA, although it slightly differs from previous studies who averaged the standard deviation over all momentary assessments within one individual (e.g., van Roekel et al., 2015).

6.2.4. Pleasure experience (PE)

PE was defined as the amount of pleasure experienced during the most positive event since the last assessment. Participants rated the pleasure experience by moving a slider along a continuum anchored with the words: *not at all* and *very much*. During an introductory session, participants were instructed that the most positive events did not necessarily have to be major events, and that relatively small events such as a coffee break or having a good conversation could be considered as most positive event too. We converted the location of the slider into a score between 0 and 100.

6.3. Data analytic plan

Hypotheses were tested by means of multilevel modeling in Mplus version 7.4 (Muthén and Muthén, 1998–2015). Multilevel modeling is pre-eminently suitable to examine the relation between anhedonia and daily life PA, as it allows the researcher to simultaneously examine the relations between the measurements specified at beep-level (Level 1; e.g., PE and PA) and the dependency of this relationship on individual characteristics (Level 2; e.g., anhedonia). To separate within-person effects from between-person effects (Curran and Bauer, 2012), all predictors were person-mean centered.

To decide whether we should include age, sex and time (1–90 assessments) as control variables, we regressed these variables on PA_{ij} . Results showed that PA did not vary by age or sex, but that there was a small but gradual increase of PA over time ($B=0.05$, $SE=0.01$,

$p < 0.001$). Since the increase of the composite measure of PA over time did not differ between anhedonic and non-anhedonic young adults, the time variable was not included as control variable.

To test the first and second hypothesis that anhedonia is associated with lower levels of PE and lower levels of PA, we regressed PE and the composite measure of PA on ‘Anhedonia status’ (i.e., 0 = non-anhedonic; 1 = anhedonic; Eq. (1b)), mathematically modelled as:

Level 1:

$$PE_{ij} \text{ or } PA_{ij} = \beta_{0j} + r_{ij} \quad (1a)$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{anhedonic status}) + u_{0j} \quad (1b)$$

To test the third hypothesis, that anhedonia would be associated with deviations in PA reactivity, we modelled the cross-level interaction mathematically as:

Level 1:

$$PA_{ij} = \beta_{0j} + \beta_{1j}(PA^{T-1}) + \beta_{2j}(PE) + r_{ij} \quad (2a)$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{anhedonic status}) + u_{0j} \quad (2b)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{anhedonic status}) + u_{1j} \quad (2c)$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}(\text{anhedonic status}) + u_{2j} \quad (2d)$$

Simultaneously, the inertia-part of the fourth hypothesis was tested by means of the autocorrelation of PA (i.e., PA^{T-1} on PA^T ; Eq. 2c). To test for deviations in variability, the second part of the fourth hypothesis, within-person variance was modelled as:

Level 1:

$$\text{Within-person variance of } PA_j = \beta_{0j} + r_{ij} \quad (3a)$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{anhedonic status}) + u_{0j} \quad (3b)$$

The last part of the fourth hypothesis, whether anhedonia was prospectively associated with deviations in stability in PA, we performed a between groups *t*-test in SPSS 23.0.0.0 (IBM Corp, 2015) on

the Root Mean Squared Successive Difference (RMSSD; $\sqrt{\frac{(PA^t PA^{t-1})^2}{89}}$; see also van Roekel et al. (2015)).

Finally, in order to explore the role of arousal in the second to fourth hypotheses, the composite measure of PA_{ij} was substituted by its high arousal and low arousal variant.

7. Results

The results section is organized in accordance with the hypotheses. After a short overview of sample characteristics and compliance rate, the differences between anhedonic and non-anhedonic individuals in PE and PA functioning are described in the chronological order of hypotheses. Thereafter, and in a similar fashion, the results for high arousal PA functioning and low arousal PA functioning are described.

7.1. Sample characteristics and compliance rate

Participants ranged in age from 18 to 25. Of the total 138 participants, 20% was male, and the majority was enrolled in higher vocational education or university (see Table 1). Participants filled out 73–100% of all assessments with an average compliance rate of 93%.

Table 1
Demographics of the matched anhedonic and non-anhedonic sample.

	No anhedonia (controls)		Anhedonia	
Men (%)	14	(20)	14	(20)
Mean age in years (SD)	21.51	(1.90)	21.45	(1.96)
Current education (%)				
University	41	(59)	40	(58)
Higher vocational	26	(38)	25	(36)
Secondary education	2	(3)	3	(4)
Lower secondary education	0		1	(2)
Compliance rate (%)	83.52	(92.8)	84.33	(93.7)

Notes. Age reflects the age in years on the day before the introductory session. Due to differences in educational systems, current education is grouped based on Fig. 1 in Veldman et al. (2014). N=69 in both groups. Highest level of completed education of the three participants without current education were: lower and higher secondary education, and higher vocational education. Three participants reported no current education, and were categorized on the basis of their highest level of education attained (namely lower secondary education; higher secondary; higher vocational). Compliance rate was the average number of assessments filled out of 90, averaged over all participants within that group.

The compliance rate did not differ in anhedonic and non-anhedonic participants.

7.2. PE in anhedonia

Compared to participants without anhedonia, the participants with anhedonia reported the most positive events as less pleasurable ($B = -5.89$, $SE = 1.81$, $p < .001$).

7.3. PA functioning in anhedonia

7.3.1. PA

As shown in Table 2, participants with anhedonia reported on average a lower level of PA than participants without anhedonia.

7.3.2. PA reactivity

For each point that a PE exceeded one's own average, participants increased 0.22 points in PA in response to pleasurable experiences ($SE = 0.02$; see Table 2). The increase did not differ by anhedonia status.

7.4. Temporal dynamics in PA

7.4.1. Variability

As shown in Table 2, anhedonic participants varied roughly one and a half times more in their PA experience.

7.4.2. Stability

The between groups *t*-test showed a larger RMSSD for those participants in the anhedonia group ($M_{diff} = 2.37$, $t_{136} = 3.59$, $p < .001$), indicating that participants with anhedonia showed less stability or greater instability in PA than those participants without anhedonia.

7.4.3. Inertia

The autocorrelation between PA^{T-1} and PA^T was moderately strong ($r = 0.29$; $SE = 0.02$; see Table 2) and similar across anhedonia status, meaning that there was no difference in inertia between anhedonic and non-anhedonic participants.

7.5. PA functioning in anhedonia: the role of arousal

7.5.1. High/low arousal PA

Anhedonia status was negatively associated with both low arousal PA and high arousal PA (see Table 2), with a respective *B*-value of -6.25 ($SE = 1.79$) and -11.47 ($SE = 1.79$).

7.5.2. High/low arousal PA reactivity

Results showed no difference in low arousal PA reactivity by anhedonia status, but a stronger reactivity to pleasurable experiences in high arousal PA in participants with anhedonia. That is, for each point that a PE exceeded one's own average, participants without anhedonia showed a significant increase in high arousal PA of 0.26 point ($SE = 0.03$), whereas participants with anhedonia showed an increase of 0.32 in high arousal PA ($SE = 0.03$). Visual representation of the small difference in slopes is depicted in Fig. 2.

7.6. Temporal dynamics in high/low arousal PA

7.6.1. Variability

Although anhedonia status was unrelated to the variance in low arousal PA, participants with anhedonia showed higher variance than non-anhedonic participants in their high arousal PA (see Table 2).

7.6.2. Stability

With regard to stability, the between groups *t*-tests of the RMMSD between groups showed that participants with anhedonia had less stable low arousal PA ($M_{diff} = 2.54$, $t_{136} = 3.16$, $p < .01$), and less stable high arousal PA ($M_{diff} = 2.76$, $t_{136} = 3.42$, $p < .01$).

7.6.3. Inertia

With regard to inertia, the PA autocorrelation showed no difference in estimate by anhedonia status, not for low arousal PA nor for high arousal PA.

Table 2

Estimates of PA reactivity in individuals without anhedonia and differences of those estimates in individuals with anhedonia (full model).

	Anhedonia status					
	No anhedonia (controls)			Anhedonia		
	Est.	95% CI	<i>p</i>	Est. diff.	95% CI	Diff. <i>p</i>
Composite measure of PA						
PA	63.71	[61.53, 65.88]	***	-10.00	[-13.13, -6.86]	***
PA variability ^a	91.17	[76.31, 106.01]	***	43.49	[14.82, 72.16]	**
PA reactivity:						
PA	63.76	[61.58, 65.95]	***	-10.12	[-13.27, -6.97]	***
PA ^{T-1} on PA ^{Tb}	0.29	[0.24, 0.33]	***	-0.05	[-0.11, 0.01]	
PE on PA	0.22	[0.19, 0.26]	***	0.04	[-0.00, 0.09]	~
Low arousal PA						
PA	65.67	[63.33, 68.01]	***	-6.25	[-9.76, -2.74]	***
PA variability ^a	159.36	[139.33, 179.39]	***	36.33	[-0.24, 72.89]	~
PA reactivity:						
PA	65.67	[63.33, 68.01]	***	-6.37	[-9.89, -2.85]	***
PA ^{T-1} on PA ^{Tb}	0.25	[0.22, 0.29]	***	-0.02	[-0.07, 0.03]	
PE on PA	0.20	[0.16, 0.24]	***	-0.01	[-0.07, 0.04]	
High arousal PA						
PA	61.72	[59.22, 64.22]	***	-11.47	[-14.98, -7.96]	***
PA variability ^a	164.55	[143.68, 185.41]	***	51.78	[15.10, 88.46]	**
PA reactivity:						
PA	61.79	[59.29, 64.30]	***	-11.59	[-15.11, -8.07]	***
PA ^{T-1} on PA ^{Tb}	0.22	[0.18, 0.26]	***	-0.03	[-0.09, 0.03]	
PE on PA	0.26	[0.22, 0.30]	***	0.06	[0.00, 0.11]	*

Notes. Est. = Estimate. CI = Confidence Interval. PE = Pleasure Experience. PA = Positive Affect. Estimates for PA reactivity were calculated based on the initial full model. N = 69 in both groups.

^a Variability in variance.

^b Autocorrelation, or inertia.

~ $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

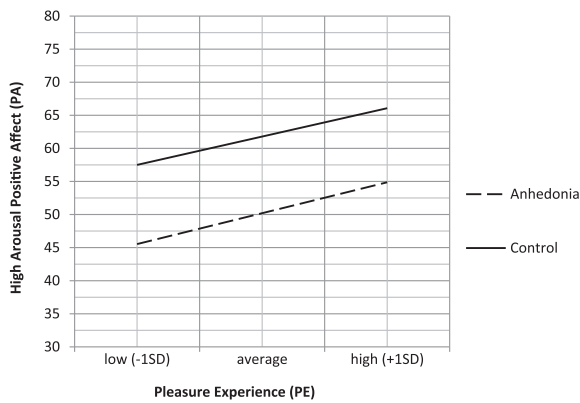


Fig. 2. High Arousal PA (i.e., feeling enthusiastic and energetic since the last assessment) reactivity to intensity of PE since the last assessment by group for low PE, average PE, and high PE.

8. Post hoc analyses

8.1. Trimmed versus full model

Contrary to our expectations, the autocorrelation (i.e., inertia) did not differ significantly between groups. Given its non-significance, we trimmed the initial full model (Eq. 2a) by omitting the cross-level interaction between anhedonia status and high arousal PA^{T-1} on level 2, mathematically modelled as:

Level 1:

$$\text{High Arousal PA}_{ij} = \beta_{0j} + \beta_{1j}(\text{PA}^{T-1}) + \beta_{2j}(\text{PE}) + r_{ij} \quad (4a)$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{anhedonic status}) + u_{0j} \quad (4b)$$

$$\beta_{1j} = \gamma_{10} + u_{1j} \quad (4c)$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}(\text{anhedonic status}) + u_{2j} \quad (4d)$$

The trimmed model outcomes showed no notable differences, except that the significance of the high arousal PA reactivity effect now disappeared (see Table 2b in Supplementary material). To examine which model was most reliable, the initial ‘full’ model or the latter ‘trimmed’ model, we did a Multiple Group Analysis in Mplus in which the autocorrelation parameter was stipulated to be equal across anhedonia status. The chi square difference test (Sattora-Bentler) showed $\Delta\chi^2(1) = 5.69$, $p < .017$, indicating that the effect of PE on high arousal PA differed significantly by anhedonia status, and providing further evidence for the existence of a small but significantly stronger high arousal PA reactivity to PE in participants with anhedonia.

8.2. NA reactivity

To explore whether individuals showed a mood brightening effect in both PA and NA, we reran the analyses on NA using the full model (Eq. 2a). After the autocorrelation of NA was found not to differ between groups, we reran the analyses on NA using the trimmed model (Eq. 4a). NA was comprised of “I feel / felt”: upset; gloomy; sluggish; anxious; bored; irritated; nervous; listless. For the exact procedures and order of assessment, please see: van Roekel et al. (2016). Using Eq. 4a with NA instead of PA we found that, compared to individuals without anhedonia, those with anhedonia showed a small but significant ($p < .001$) larger reduction in NA in reaction to their PE ($B = -0.07$). That is, for each point that a PE exceeded an individuals' own average, individuals without anhedonia reacted with a decrease in NA of 0.11 points ($SE = 0.01$), whereas individuals with anhedonia reacted with a de-

crease in NA of 0.18 points ($SE = 0.02$).

9. Discussion

With the aim to provide a more complete picture of PA reactivity to pleasurable experiences in anhedonia and to explore the role of arousal therein, we investigated PA functioning in the daily lives of individuals with anhedonia. Multilevel analyses showed that, on average, individuals with anhedonia showed less intense PE and lower levels of PA than those without anhedonia. In reaction to pleasurable experiences, anhedonic versus non-anhedonic individuals showed no differences in overall PA or low arousal PA (i.e., feeling calm; relaxed), but showed an increased reactivity in high arousal PA (i.e., feeling enthusiastic; energetic). Furthermore, the anhedonic individuals showed equal moment-to-moment transfer of PA (i.e., inertia), but more variability (i.e., variance) and instability (i.e., higher magnitude of consecutive changes in PA as measured by the MSSD) in their daily patterns of PA. Finally, our post hoc analyses showed that individuals with anhedonia also decrease slightly more in overall NA in reaction to pleasurable experiences, compared to individuals without anhedonia.

That we found anhedonia associated with less intense PE on a daily basis is in line with the DSM definition of anhedonia as markedly diminished interest or pleasure in almost all daily activities (American Psychiatric Association, 2013), and aligns with previous research on PE in depression (e.g., social interaction; Larson et al., 1990; Nezlak et al., 2000; Peeters et al., 2003; van Roekel et al., 2015). Furthermore, the lower mean level of PA in individuals with anhedonia, and the magnitude of its difference with healthy controls, was comparable to that found in depressed individuals (Bylsma et al., 2011; Peeters et al., 2003; van Roekel et al., 2015).

With regard to PA reactivity, our finding of no difference in PA reactivity to pleasurable experiences in daily life of individuals with and without anhedonia is in line with previous ESM-findings in individuals with or without depression or depressive symptoms (Bylsma et al., 2011; Oorschot et al., 2013; Thompson et al., 2012; van Roekel et al., 2015), and previous ESM-findings among individuals with or without negative symptoms in schizophrenia (Oorschot et al., 2013). Nonetheless, we also found a stronger increase in high arousal PA and a greater reduction in overall NA in response to positive contexts, which is in line with the curious “mood brightening effect” as reported previously (Bylsma et al., 2011; Thompson et al., 2012; Peeters et al., 2003). Although most researchers find only a significant decrease in NA reactivity and no difference in PA reactivity (Bylsma et al., 2011; Thompson et al., 2012; Peeters et al., 2003), or a borderline significant increase in PA in response to pleasurable experiences (van Roekel et al., 2015), the present study is the second ESM-study that found evidence of greater emotional reactivity to pleasurable experiences in both PA and NA. Why depressed individuals or individuals with anhedonia show a greater “mood brightening effect” to pleasurable experiences than their healthy counterparts is, however, not yet fully understood. Perhaps, this hyper responsivity reflects a higher threshold for pleasurable experiences to be quantified as such. If the threshold to experience pleasure is higher in individuals with anhedonia, positive experiences reported as equally pleasurable in anhedonic and non-anhedonic individuals may lead to a stronger PA reaction in those individuals with anhedonia compared to those without anhedonia. However, this reasoning does not explain why we found a stronger PA reaction in high arousal PA, but not in low arousal and overall PA.

In addition to individuals' reactivity in PA, we also investigated anhedonic versus non-anhedonic individuals' temporal dynamics in PA. That we found higher peaks and deeper lows in PA, together with equal overall PA reactivity, suggests that PA abnormalities in the daily life of anhedonic individuals involves dysregulation rather than hypo or hyper PA reactivity to pleasurable experiences. That we found initial responsiveness to reward attainment in individuals with anhedonia to be intact, but dysregulations of their longer-term responsiveness to reward

fits with recent findings on unbalanced pleasure networks in the brains (see for a review: Rømer Thomsen et al., 2015). Indeed, recent neuroscientific findings suggest that non-depressed individuals have a natural hedonic equilibrium to return to, whereas individuals with depressive symptoms have a less clear hedonic equilibrium: core initial reactions of liking seem to be intact but are then followed by a steep decline (see, for example, Fig. 2 in Rømer Thomsen et al., 2015). Interestingly, two previous ESM studies also found evidence in support of this notion, albeit in a shorter time frame than used in the present study. One ESM study measured PA reactivity in depressed individuals continuously for 7 min, during which PA appeared to be generated in individuals with depression but not sustained at equivalent levels as in non-depressed individuals (Horner et al., 2014). The other ESM study found that the positive effect of physical activity on PA was lost more rapidly in those with a history of depression (Wichers et al., 2012). It may thus be fruitful for future ESM studies of anhedonia to focus on longer-term reward responsiveness instead of the initial PA reactions and closely investigate the dysregulations in temporal dynamics of PA such as variability, stability, and inertia.

With regard to variability and stability of PA, we found that individuals with anhedonia showed greater variance and a higher magnitude of consecutive changes or instability in PA. These findings coincide with those found in adolescents (van Roekel et al., 2015), but not with findings from studies that investigated depressed adults (Peeters et al., 2003; Thompson et al., 2012), suggesting that there may be developmental issues at play. Interestingly, a recent study that assessed five-day diaries throughout adolescence (from ages 13–18 years) found that variability of PA measured as “happy”, “glad”, and “cheerful” declined across adolescence (Maciejewski et al., 2015). Perhaps, variability and instability in PA typically decline when individuals transition from childhood into adulthood, but this decline is delayed in adolescents with anhedonia or other depressive symptoms. Future researcher on temporal dynamics in PA may thus be extra cautious in comparing dynamics across different age ranges, or investigating these parameters in a sample of large age difference.

Contrary to variability and stability, we found no difference in inertia by anhedonia status, and thus equal moment-to-moment transfer of positive emotions in individuals with and without anhedonia. No difference in inertia is consistent with findings from studies among individuals with depression (Peeters et al., 2003; Thompson et al., 2012) and depressive symptoms (van Roekel et al., 2015). Given that our assessments were every six hours and the previous studies that also reported lack of similar associations had semi random time intervals of approximately 90 min apart, together, these findings suggests that equal emotion regulation self-efficacy skills, if any, take place well within 90 min and may therefore not be detected by studies with larger timescales. Future ESM research on possible deficits in PA functioning of individuals with anhedonia may focus best on variability and stability in PA, or explore at which timescale emotional inertia can be captured and/or at which timescale a short-term retrospective nature would be unduly influenced by retrospective biases.

It seems counterintuitive that we and other ESM-studies show equal or hyper responsivity to reward while hypo responsivity is predicted based on theory (Rottenberg et al., 2005; Rottenberg, 2005) and laboratory research (Bylsma et al., 2008; Kerns et al., 2008). Several interpretations of this apparently paradoxical discrepancy have been proposed (Bylsma and Rottenberg, 2011; Bylsma et al., 2011). First, it has been argued that ESM-studies finding different results than laboratory studies signifies that other environmental and interpersonal factors are at play that are not recreated in the laboratory but typify daily living and influence PA reactivity. Second, if a higher threshold in individuals with depression or anhedonia to quantify something as pleasurable explains the hyper responsivity to pleasurable experiences, the heightened threshold could reflect the hypo responsivity as found in laboratory research. Third, emotions are dynamic phenomena of multi-dimensional nature (Kuppens, 2015; Larsen et al., 2009), and ESM

provides an elegant way to study into group-level differences in PA reactivity while simultaneously investigating its dynamics and dimensions. In sum, findings from laboratory research and ESM-studies may be complementary rather than contradictory, and highlight the need for new depression theories that are aimed at the idiographic level of emotion and properly accommodate its dynamic as well as its multi-dimensional nature.

Our discrepancy in findings when using the full model versus the trimmed model further illustrates how minor differences in methodological strategy can have a large impact on the conclusions of an ESM-study. That is, statistical significance of the increased high-arousal PA reactivity to pleasurable experiences in individuals with anhedonia depended on the in- or exclusion of the non-significant Level 2 interaction between inertia and anhedonia status in the model. Interestingly, the study that used our initial, full model, found no evidence for PA reactivity (Thompson et al., 2012), whereas those who used a trimmed model (i.e., controlling for PA^{T-1} but not for its interaction with anhedonia) found indications for greater PA reactivity in depression (Peeters et al., 2003). Together, the differences in findings between our initial (full) and final (trimmed) model (see Table 2b in Supplementary material) suggests that future research on PA reactivity would benefit from more elaborate reporting on the statistical models used, and specifically from denoting whether the control variables in testing PA reactivity included only the lagged PA variable, or also its interaction with the grouping variable. Given that we found no evidence for PA inertia in anhedonia compared to controls, and thus no indication for a difference in autocorrelation in emerging adults with anhedonia, future research using similar samples, timescales, and statistical techniques may consider to report both models, or only the trimmed model.

9.1. Strengths and limitations

This study had several notable strengths. An important asset is a design that highlights participants' interaction with their natural environment, providing great ecological validity. Furthermore, we used a specific and elaborate measure of persistent anhedonia for the selection of participants. A final strength is the high average compliance rate of 92% in our study, which provides high confidence in both the validity and reliability of our findings. There are also limitations. First, we studied differences in PA reactivity, but conceptualized reactivity as the rise in PA to pleasurable experiences within the same time slot. Although we controlled for PA levels at preceding assessment, and thus examined to what extent the more intense pleasurable nature of positive events was related to a *change* in momentary PA, we did not control for the intensity of pleasurable experiences at the preceding assessment. Therefore, we cannot fully exclude the possibility that the intensity of the last positive event determined the change in high-arousal PA, or rather the accumulation of events. Second, we used a non-standard sampling strategy in which we assessed affect momentary in the mornings and short-term retrospectively in the afternoon and evenings, and our non-standard sampling strategy may have resulted in different findings than would be obtained with a regular assessment strategy in which every assessment is momentary. Although short-term retrospective impressions might present the information that people use to make subsequent decisions more accurately than momentary assessments, we cannot exclude that our short-term retrospective assessments are unduly influenced by factors such as salience or recency of affective experiences. Third, our sample consisted mostly of women, which possibly limits the generalizability of our findings to the population of young adults as a whole.

10. Conclusion

Depression is one of the most prevalent, chronic and recurrent mental illnesses, yet its core symptom anhedonia remains poorly

understood. Although replication is warranted, individuals with anhedonia are likely less ‘flat’ and ‘blunted’ than commonly assumed, as our results demonstrate dysregulation of context- and time-dynamic patterns in PA and high arousal PA in particular.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.jad.2017.04.029>.

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