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Aberrant positive affect dynamics in individuals with subthreshold depression: Evidence from laboratory and real-world assessments

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ABSTRACT

Background/Objective: Reduced positive affect (PA) is a core feature of major depressive disorder (MDD). However, the precursor of MDD, subthreshold depression (StD), has received less attention in this regard. Therefore, we examined PA dynamics in StD, integrating laboratory-based and ecological momentary assessment (EMA) approaches.
Method: Participants were college students recruited from Chinese universities (31 with StD, and 39 healthy controls (HC)). Positive mood was induced in the laboratory by an eight-minute comedy clip used to assess PA reactivity and maintenance. To extend findings to the real world and explore mechanisms of PA maintenance, 53 participants with StD and 64 HC reported their emotional states 14 times daily for one week via EMA. Multilevel models were used to test for predictors of PA inertia.
Results: In the laboratory, participants with StD achieved the same PA reactivity as HC when facing positive stimuli, yet the curve-fitting revealed difficulties for the StD group in maintaining PA over time. Such reduced capacity was further observed in real-world settings, manifesting in significantly greater PA inertia.
Conclusions: High PA inertia in daily life may reflect resistance to mood change in StD, explaining anhedonia and difficulties with emotional maintenance, and highlighting the need for early identification.

Introduction

Positive affect (PA) is important for preventing mental illness. Studies have shown that PA appears to be consistently associated with a range of benefits, including better mind-body connections, greater life satisfaction, and improved emotional functioning (Akhtar, 2012; Lyubomirsky, King & Diener, 2005; Santos et al., 2013). Apart from intense feelings of negative affect (NA), reduced PA (i.e., anhedonia) is also generally considered as one of the hallmarks of major depressive disorder (MDD), a debilitating mental disorder with high prevalence (Heller et al., 2009). Early studies provided evidence of the links between PA and MDD in physiological and behavioral domains. For instance, compared with typical controls, individuals diagnosed with depression reported significantly lower PA in response to positive images (Fiorito & Simons, 1994). Additionally, patients with endogenous and nonendogenous depression showed fewer facial electromyography (EMG) responses in corrugator ‘happy’ trials, suggesting a lack of distinct reactivity to positive imagery (Greden, Genero, Price, Feinberg & Levine, 1986).

Research on affect in MDD frequently yields a static view of emotional experience. Although such views provide important insights, in recent years growing attention has been directed to the concept of affective dynamics that takes into account the moment-to-moment ebb and flow of affect (Trull, Lane, Koval & Ebner-Priemer, 2015). Two specific features of affective dynamics have gained popularity in characterizing the temporal fluctuation of emotions in response to emotional

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stimuli or events: affective reactivity and affective maintenance (Booij, Snippe, Jeronimus, Wichers & Wigman, 2018). Affective reactivity is typically defined as the difference in emotional intensity from before to after an emotion-inducing procedure (Guhn, Sterzer, Haack & Köhler, 2018). Affective maintenance is the process by which an individual's emotional response recovers to the baseline level after experiencing an emotional event, often expressed by the duration of the emotional response (De Calheiros Velozo et al., 2023). Emotional inertia is another feature of affective dynamics that refers to resistance to change in emotional states, formalized as the autocorrelation between an individual's current and previous emotional states (Kuppens, Allen & Sheeber, 2010; Suls, Green, & Hillis, 1998). Emotional inertia should be viewed as conceptually distinct from emotional variability (Jahng, Wood & Trull, 2008). High emotional inertia implies that a person's emotional state is likely to persist over time, indicating it may be relatively more impervious to external events or regulation efforts. Notably, an important function of affect is to change in response to fluctuating environmental demands. Hence, high emotional inertia indicates poor flexibility to adapt to changing circumstances, and deficits in effective emotion regulation (Koval, Sütterlin & Kuppens, 2015). Visual representations of these indices are shown in Fig. 1A and 1B. Such indicators of affective dynamics sensitively reflect individual differences in the processing of emotional information, and are, therefore, considered important markers of psychological functioning and key factors for identifying mood disorders in psychopathology (Fearey, Evans & Schwartz-Mette, 2021; Trull et al., 2015).

To date, most studies of affective dynamics in MDD have focused on NA, demonstrating higher levels of NA inertia and higher instability relative to healthy individuals (Koval, Pe, Meers & Kuppens, 2013; Thompson et al., 2012). In many cases of depression, deficits in inhibitory control lead to continuous rumination and an uncontrollable focus on negative events, which may also affect PA (Song, Long, Wang, Zhang & Lee, 2022). Low levels of PA, despite being a core feature of MDD, have received relatively less attention than NA in affective dynamics research. Nevertheless, a six-month follow-up study found that PA dynamics are as significant as NA dynamics in predicting the course of depression (Panaite, Rottenberg & Bylsma, 2020). A recent study used humorous cartoons to induce PA in remitted individuals with a history of recurrent MDD, measuring PA several times after the viewing. Remitted MDD group showed significantly lower overall PA ratings and shorter PA duration compared with a healthy group (Admon & Pizzagalli, 2015). These studies provide strong evidence for aberrant PA dynamics in people with depressive symptoms who are not currently diagnosed with MDD.

Recent studies point out that the alterations in PA dynamics vary between symptomatic and diagnosed samples, which provides an opportunity for further study of subthreshold depression (StD). Individuals with StD experience relevant depressive symptoms, but do not meet the diagnostic criteria for MDD (Berhe et al., 2022; Houben, Van Den Noortgate & Kuppens, 2015). StD has a high prevalence of approximately 11 % (Zhang et al., 2022), and people with StD face an increased risk of developing MDD compared with the asymptomatic population. Therefore, StD is an important risk indicator or a prodromal phase of MDD (Eaton, Badawi & Melton, 1995; Lee et al., 2019). Identifying the

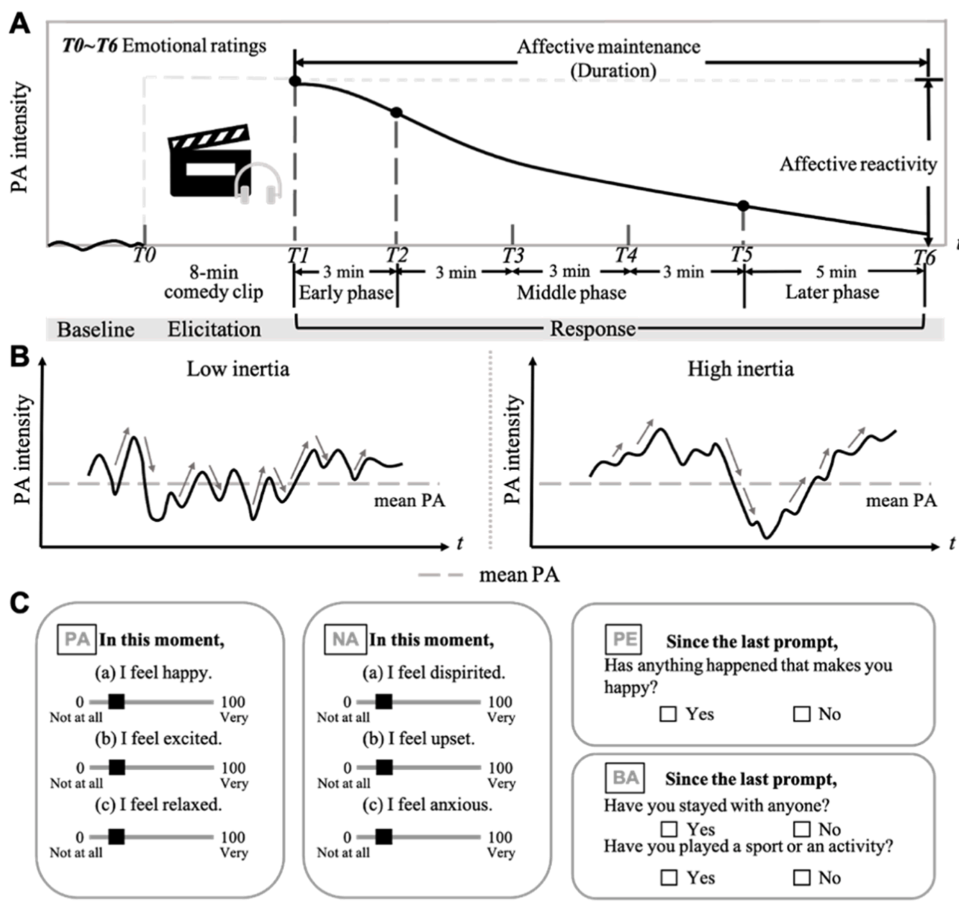

Fig. 1. Structure of positive affective dynamics and task description. (A) Description of the laboratory task and parameters that construct positive affective dynamics. T0-T6 indicated emotion assessments at different time points. (B) Framework of daily PA dynamics. The solid black line represented emotional change curve, reflecting fluctuations in mood at all times. Low emotional inertia referred to that the emotional level at one time point (e.g., t-1) could not well predict the emotional level at the later time point (e.g., t). Otherwise, the inertia was high. (C) Illustration of the smartphone-based ecological momentary assessment. PA, Positive affect; NA, Negative affect; PE, Positive events; BA, Behavioral activation.

PA dynamics of StD may elucidate the characteristics of StD and facilitate early identification, providing an effective way to prevent StD from developing further into MDD. However, few studies have fully investigated the PA dynamics of StD to determine whether StD has a unique pattern that differs from that of healthy individuals and those with MDD. In other words, it remains to be explored whether individuals with StD can experience intense PA in response to positive stimuli. Whether they have the same difficulty maintaining PA as depressed people, and whether they also have resistance to mood change still remain unclear.

The overarching aim of the current study was to comprehensively describe the PA dynamics of people with StD, integrating laboratory and ecological approaches. Ecological momentary assessment (EMA) techniques are particularly useful in this context and are frequently used in daily affective dynamics research for MDD (Bos, de Jonge & Cox, 2019) because they allow individuals to continuously report real-time situations, capturing the subtle hour-to-hour fluctuations in PA and NA in daily life (Aminikhanghahi, Schmitter-Edgecombe & Cook, 2020). Therefore, we recruited two samples to complete laboratory-based and real-world assessments. The first sample experienced laboratory positive mood induction by watching an eight-minute comedy clip, which was used to assess positive emotional intensity and duration of emotional response. Following previous findings in individuals with a history of depression (Admon & Pizzagalli, 2015), we hypothesized that the emotional experience of individuals with StD may be as intensely positive as that of healthy controls (HCs) when facing positive stimuli, but that they will fail to sustain PA over time. To further extend the findings of laboratory-based study in the real world and explore possible mechanisms of emotional maintenance, the first sample of participants and an additional sample completed 7 days of EMA, reporting their emotional states 14 times a day. We hypothesized that StD individuals would exhibit greater PA inertia than HCs. Combining these approaches, we expected to yield novel insights into the nature and range of altered affective dynamics in individuals with StD.

Methods

Participants

Sample 1: Laboratory-based PA elicitation and maintenance. Seventy-three students (including those with StD and HC) were recruited from universities in Guangzhou, China and screened using a two-stage method (Li et al., 2015; Takagaki et al., 2014). Specifically, the Beck Depression Inventory (BDI-II) and Center for Epidemiological Studies Depression Scale (CES-D) were administered for initial screening. In accordance with previous studies (Gotlib, Mclachlan, & Katz, 1988; Li et al., 2015), a BDI-II score of 6 and below indicated that an individual was not depressed, while a score of 14 and above indicated a minor depression. For CES-D, a score of 16 or more was the critical cut-off for depression (Radloff, 1977). Therefore, in the second step, participants who scored 14 or above on the BDI-II and 16 or above on the CES-D were invited to have a MINI-International Neuropsychiatric Interview (M.I.N.I.) conducted by two trained postgraduate students in the Department of Psychology. Based on the interview results, participants were excluded if they: (a) fulfilled the DSM-IV diagnostic criteria for MDD; (b) had a self-reported history of neurological or psychiatric disorders; and (c) had a history of taking any psychotropic drugs (see the supplementary material for further details). All participants had normal or corrected hearing and vision. Two participants dropped out and one participant was subsequently excluded because of poor performance. Therefore, Sample 1 included 31 participants in the StD group ($M_{age} = 21.32$, $SD = 2.17$, 18–27 years; 80.6 % female) and 39 participants in the HC group ($M_{age} = 19.95$, $SD = 1.64$, 18–25 years; 69.2 % female). The two groups scored significantly differently on the BDI-II ($M_{HC} = 2.44$, $M_{StD} = 20.71$, $t = -16.70$, $p < 0.001$) and CES-D ($M_{HC} = 6.92$, $M_{StD} = 27.61$, $t = -15.02$, $p < 0.001$).

Sample 2: Ecological momentary assessment (EMA). We expected EMA would be a practical extension of the laboratory experiments. Participants from Sample 1 were included in the EMA to maintain consistency of results. Furthermore, robust ecological validity and statistical power require support from a larger sample size (Singh et al., 2023), and therefore, we increased the original sample size. Fifty-five additional participants were recruited using the same method. Eight participants dropped out during the 7-day EMA. Thus, Sample 2 consisted of 117 young adults, including 53 in the StD group ($M_{age} = 21.38$, $SD = 2.07$, 18–27 years; 58.5 % female) and 64 in the HC group ($M_{age} = 20.59$, $SD = 2.30$, 18–29 years; 53.1 % female). Scores of the two groups were significantly different for the BDI-II ($M_{HC} = 2.31$, $M_{StD} = 20.34$, $t = -22.87$, $p < 0.001$) and CES-D ($M_{HC} = 6.00$, $M_{StD} = 28.55$, $t = -20.80$, $p < 0.001$). All participants read and filled out the informed consent form before each formal experiment.

Procedure

The studies involving human participants were reviewed and approved by the Institutional Review Board (IRB) of Southern Medical University. The laboratory-based task consisted of emotion elicitation and assessment (Fig. 1A). An eight-minute film clip entitled “Hands up!” was used as emotion-inducing material. Details of the selection process of the video clip can be found in the supplementary materials. Scales used for T0–T6 emotion assessment were adapted from the Positive and Negative Affect Schedule (PANAS) (Watson, Clark & Tellegen, 1988). Positive emotion that is briefly induced by a specific procedure passes quickly (Behnke et al., 2023). Thus, it was of great importance to ensure the questionnaire included the main dimensions of PA measurement, and that participants could complete it quickly. A lengthy questionnaire would have meant a longer response time, which would be distracting and affect the continuation of positive emotional experiences. The selection of a subset of items from the PANAS scale helped streamline the assessment process without compromising the validity of our measurement (Hennemann, Wenzel, Van den Bergh, Wessels & Witthöft, 2023). Therefore, PA assessment included three items, and participants were asked to rate “how happy/excited/relaxed you feel right now” on a 9-point Likert scale from 1 (not at all) to 9 (very). NA assessment also consisted of three items regarding “how dispirited/upset/anxious you feel right now.” Before watching the film clip, baseline PA and NA levels were rated. Within 17 min of watching it, emotion ratings at different time intervals were recorded (Fig. 1A).

The EMA procedure used Psychorus (version 1.0.34, Beijing Huixin Technology Co., Ltd). A questionnaire was sent to participants with each prompt divided into four parts: (a) PA – consisting of three items: “In this moment, I feel happy/excited/relaxed; (b) NA – consisting of three items: “In this moment, I feel dispirited/upset/anxious; (c) positive events (PE) – “Since the last prompt, has anything happened that makes you happy?; and (d) behavioral activation (BA) – consisting of two items: “Since the last prompt, have you stayed with anyone?/have you played a sport or done an activity?” The PA and NA assessments each contained the same three items as the laboratory experiment, with the bipolar choices “not at all” to “very” presented at the two edges of visual analogue scales with sliding locators (score range from 0 to 100). PE and BA measured the participants’ daily experiences of positive events and engagement in sports or activities. The inclusion of PE and BA was based on two considerations although the aim of the study was to capture PA dynamics. On the one hand, we wanted to examine whether participants were in an abnormal situation (such as having no PE in the week or no engagement in activities). On the other hand, we aimed to further validate whether the reduced activities found in previous research for the population with depression (Paluska & Schwenk, 2000) had also occurred for individuals with StD in our study. More detailed information is provided in Fig. 1C.

For the EMA, participants in Sample 2 were prompted between 8:30 a.m. and 9:30 p.m. with a fixed interval of one hour, resulting in 14 prompts per day over seven consecutive days. Participants were required to respond as soon as possible after receiving the questionnaire. If the response time (the interval between start time for completing the questionnaire and the questionnaire delivery time) exceeded 10 min, it was considered an invalid data point and was excluded from analysis (Liu & Lou, 2019). Responses where participants spent less than an average of 1 s per item were also considered invalid (Jaso, Kraus & Heller, 2021). Further, if participants completed less than 50 % of their scheduled assessments (i.e., less than 7 in this study) on a given day, all their responses on that day were excluded from the statistical analysis (Litt, Cooney, & Morse, 1998). Ten participants responded to fewer than 7 prompts on at least one day during the EMA sampling, with 7 of those participants from the StD group.

Data analysis

Laboratory-based PA elicitation and maintenance (Sample 1). Emotion ratings were collected for each participant from T0–T6. For emotional intensity, we first conducted repeated measures analysis of variance (ANOVA) with group (HC versus StD) as a between-subject factor and seven time points as repeated measures to compare the differences in emotion ratings between the two groups from T0 to T6. To further clarify the differences in emotional dynamics between individuals in the HC and StD groups, our analysis focused on two aspects: affective reactivity and maintenance. A 2 (group: StD versus HC) $\times$ 2 (time: T0 versus T1) repeated measures ANOVA was conducted to identify whether the film clip validly induced PA and whether the participants with StD had the same affective reactivity as HC. For PA maintenance, the data of participants whose T0 scores were equal to or exceeded that of T1 were regarded as outliers and not included in the following analysis ($n = 6$). Two methods were used to examine PA maintenance. First, we estimated individuals' specific emotion duration after emotion elicitation using curve fitting with the least square method using MATLAB R2017b. PA intensity was obtained from the average of the three items (i.e., happy, excited and relaxed), and the average PA of each participant at each time (i.e., T1 to T6) could be described as a specific coordinate. For example, if an individual's average PA at T2 was 6, the coordinate could be represented as (3,6). Six coordinates determine an individual's emotional response curve (third-order polynomial curve fitting), and the abscissa of the intersection of the response curve and the line represented by the baseline emotion indicated the estimated duration of the emotion. Independent sample t-tests were used to examine whether there were differences between the HC and StD groups. Second, in addition to estimating the duration, we analyzed the emotional response stage in segments. Previous studies have revealed that PA induced by video clips typically lasts for over 10 min, even up to 20 min Larcom and Isaacowitz (2009). However, Li et al. (2009) suggested that 3 min may be a crucial turning point after which the changes in positive emotions tend to level off. To capture any potential phase-related changes in PA and ensure that no significant transitions were missed, we delineated an additional late stage. Specifically, the period from T1 to T2 after watching the positive film clip was defined as the early stage of emotion maintenance. The period from T2 to T5 was defined as the medium stage, and the period from T5 to T6 as the later stage. In each stage, the coordinates of the start and endpoints were used for line fitting to determine the unique line of each participant's response, and the slope was obtained. The slope reflected an individual's intuitive change in PA at this stage. Using the calculated slopes, independent sample t-tests were conducted to explore the differences in emotion maintenance between the two groups at each stage.

Ecological momentary assessment (EMA) (Sample 2). We calculated the overall compliance rate and the EMA measure. Items in the PE and BA assessments were coded (0 = no, 1 = yes). The relationship between the predictors and the response was measured at different hierarchical levels given the nature of the EMA approach. We estimated the effect of participant group (categorical variable: 1 = HC, 2 = StD) on PA by conducting random-intercept multilevel model analysis in R (version 4.1.2, R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/), nesting e-diary assessments (level 1) within participants (level 2). Multilevel modeling made use of all available data obtained from the study, accounting for the hierarchical structure and potential dependencies in the data. We averaged the scores of the three items (happy/excited/relaxed) for using as dependent variables in our multilevel analyses. Besides our main predictor group, we added the level-1 predictors 'time of day' and 'time of day squared' to the model to control for time of day effects on PA. Age and gender were also included as level-2 covariates. Additionally, to test emotional inertia, the lagged variables (PA at $t-1$, $t-2$ and $t-3$) were calculated with the first observation of each day being set to missing. The constructed multilevel model still controlled for the 'time of day' and 'time of day squared' variables. All equations of the full models are shown in the supplementary materials.

Results

Positive affect dynamics in laboratory settings

First, we checked individuals' PA intensity at each time point. The repeated measures ANOVA revealed a main effect of group ($F = 38.39$, $p < 0.001$), indicating that the StD group consistently showed lower PA intensity than the HC group across all time points, and a main effect of time ($F = 16.57$, $p < 0.001$) (Fig. 2). There was also a significant group by time interaction ($F = 2.80$, $p = 0.02$). No significant effects emerged in NA dynamics between the HC and StD groups. Table S3 shows the complete data for the two groups, including PA and NA.

The effectiveness of PA elicitation and differences in affective reactivity were tested by conducting a 2 (group: StD versus HC) $\times$ 2 (time: T0 versus T1) repeated measures ANOVA. PA intensity at T0 and T1 was calculated by averaging the scores of the three items. A main effect of time ($F = 26.88$, $p < 0.001$) manifested in the PA intensity of each group significantly increasing from baseline after watching the videos, indicating that participants' positive emotions were effectively induced by the video material. There was no significant group by time interaction ($F = 0.02$, $p = 0.89$), indicating that the two groups showed the same magnitude of PA change from T0 to T1. That is, given the difference in baseline, individuals with StD had the same emotional experience as those in the HC group when faced with positive stimuli.

Third, we tested whether individuals with StD showed aberrant PA maintenance. Curve fitting using the least square method found that the mean PA duration of individuals in the HC group was 10.68 min, which was significantly higher than the 7.00 min of the StD group ($t = 2.28$, $p = 0.03$). After segmenting the entire emotional response phase (early stage: from T1 to T2; middle stage: from T2 to T5; later stage: from T5 to T6), we further calculated the slope of the simulated line of emotional response of each participant in each stage, namely the slope of emotional change. In the first three minutes after watching the video, the StD group experienced the largest decline in PA, and at a significantly faster rate than the HC group ($t = 2.50$, $p = 0.02$, Table 1). However, there was no significant difference in the rate of decline in PA between the two groups in the middle and late stages. This suggests that individuals with StD were more likely to return to their original state immediately even though they could experience PA after being exposed to PE.

Positive affect dynamics in real-world settings

Laboratory results showed that participants with StD had a shorter duration of PA and a faster rate of early PA decline. To further explore these phenomena in the real world, we conducted a series of analyses using EMA reports. We first examined compliance with the EMA protocol. The sample's total response rate was 87.17 % of all scheduled prompts ($n = 11{,}466$) between 8:30 a.m. and 9:30 p.m. for 7 consecutive days. Response rates were 88.25 % in the HC group and 85.79 % in the StD group, which was not significantly different between the groups ($t =$

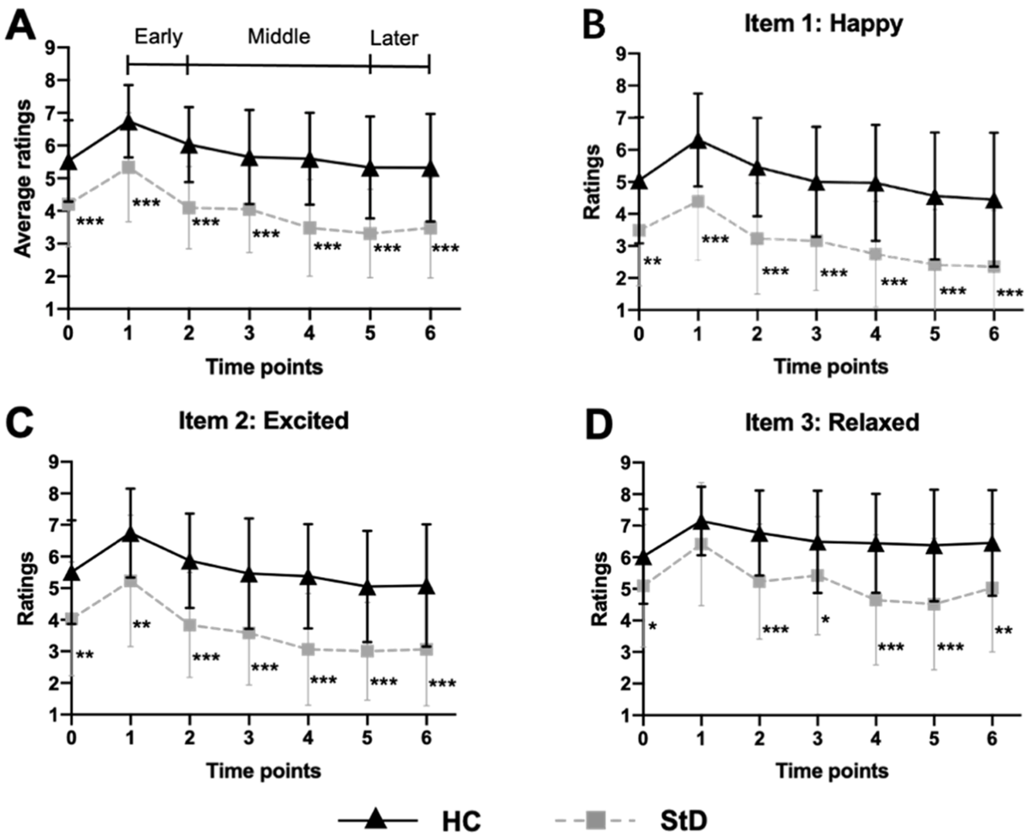

Fig. 2. Comparison of positive affect between HC and StD group at different time points. (A) Plot showed significant differences between HC and StD group on average ratings of three items. (B)Plot showed significant differences between HC and StD group on item1 (i.e., how happy you feel right now). (C) Plot showed significant differences between HC and StD group on item2 (i.e., how excited you feel right now). (D) Plot showed significant differences between HC and StD group on item3 (i.e., how relaxed you feel right now) at each time point except T1. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 1
Comparison of positive affect decline between two groups at different stage.

	HC (n = 39)		StD (n = 31)			
	Mean	*SD*	Mean	*SD*	*t*	*p*
Early phase (K1)	**−0.23**	**0.21**	**−0.42**	**0.36**	**2.50**	**0.02**
Middle phase (K2)	−0.07	0.12	−0.10	0.14	0.82	0.41
Later phase (K3)	−0.00	0.19	0.03	0.15	−0.86	0.39

Note: Positive affect was calculated by averaging 3 items measuring happy, excited and relaxed. K1, the slope of the line fitted in the early phase from T1 to T2; K2, the slope of the line fitted in the middle phase from T2 to T5; K3, the slope of the line fitted in the later phase from T5 to T6.

1.16, $p = 0.25$). We examined the average scores of each item on the PA and NA assessments for the two groups over the 7-day sampling period. The two groups differed significantly in PA ($ps < 0.001$; Table 2). There were also significant differences between the HC and StD groups on three NA items ($ps < 0.001$; Table 2). PE and BA items were dummy coded (0 = no, 1 = yes). Overall, the HC group experienced an average of 3.59 ($SD = 2.16$) PE per day, while the figure for the StD group was 2.65 ($SD = 2.15$). There was a significant difference in the number of PE experienced per day between individuals in the HC group and those in the StD group over the days ($t_{115}= 2.34, p = 0.021$). In addition, the StD group had significantly more times of solitude per day than the HC group ($t_{115}= 3.38, p = 0.001$), while the number of hobbies and activities in the groups did not differ significantly ($t_{115}= 1.89$, $p = 0.061$; Table 2).

Third, we examined whether the groups predicted a distinct level of PA through a multilevel model. Daily-life PA in individuals with StD was significantly lower than that of the HC group after controlling various covariates like age and gender ($p < 0.001$, Table 3). In other words, the

Table 2
Average EMA ratings of 7 days.

	HC (n = 64)		StD (n = 53)			
Items	Mean	*SD*	Mean	*SD*	*t*	*p*
PA assessment						
In this moment, I feel happy.	52.26	20.42	31.42	16.88	5.94	<0.001
In this moment, I feel excited.	57.02	17.41	39.19	14.99	5.87	<0.001
In this moment, I feel relaxed.	61.43	15.70	47.56	16.92	4.59	<0.001
NA assessment						
In this moment, I feel dispirited.	10.51	12.20	22.57	15.52	−4.71	<0.001
In this moment, I feel upset.	10.94	12.08	23.50	16.12	−4.81	<0.001
In this moment, I feel anxious.	16.43	14.50	29.77	15.97	−4.73	<0.001
PE assessment [a]						
Since the last prompt, has anything happened that makes you happy?	3.59	2.16	2.65	2.15	2.34	.02
BA assessment [b]						
Since the last prompt, have you stayed with anyone?	7.25	3.55	5.10	3.25	3.38	<0.001
Since the last prompt, have you played a sport or an activity?	2.32	2.01	1.66	1.72	1.89	.06

Note: Independent *t*-tests were used to compare means. [a,b] Items in PE assessment and BA assessment were coded (0 = no, 1 = yes). PA, positive affect; NA, negative affect; PE, positive events; BA, behavioral activation.

Table 3
Multilevel model results of group predicting positive affect.

Dependent variable		Group	Beta coefficient	Standard error	*t* value	*p* value
Mean PA (0–100)	**Fixed effects**					
	Intercept		58.34	13.95	4.18	<0.001
	Age		0.06	0.65	0.09	0.932
	Gender		7.95	3.24	2.45	0.014
	Time		0.48	0.17	2.83	0.005
	Time-squared		0.00	0.01	0.34	0.738
	Group	StD	−16.81	2.91	−5.78	**<0.001**
		HC	Reference category	Reference category	Reference category	Reference category
	Random effects					
	Intercept		232.22	15.24		
	Residual		240.48	15.51		

Note: Mean PA was calculated by averaging the three items measuring positive affect.

average PA intensity of the StD group was 16.81 units less than that of the HC group.

Finally, we calculated the lagged variables of PA in the past one (*t*-1), two (*t*-2) and three (*t*-3) hours in the EMA data. We examined whether the lagged variables of PA predicted current PA and tested the connection between the groups and the lagged variables using three models. Consistent with the previous analysis, age and gender were still included in the equation as covariables. Results showed that PA at *t*-1 was a significant predictor of current PA, but there was no significant difference in this autocorrelation of PA between the two groups ($b = -0.01$, $SE = 0.02$, $p = 0.570$). However, the autocorrelations of PA within two ($b = 0.05$, $SE = 0.02$, $p = 0.012$) and three ($b = 0.06$, $SE = 0.02$, $p = 0.002$) hours were stronger in the StD group than in the HC group (Table 4). This suggests that in a relatively long-term process, the PA autocorrelation of individuals with StD was stronger, that is, the PA inertia was greater than for the control group. In contrast, similar results for NA were not found. The autocorrelation of NA within one ($b = -0.00$, $SE = 0.02$, $p = 0.806$), two ($b = -0.02$, $SE = 0.02$, $p = 0.309$) and three ($b = -0.03$, $SE = 0.02$, $p = 0.115$) hours did not significantly differentiate the two groups.

Table 4
Multilevel model results of lagging positive affect (*t-n*) predicting subsequent affect (*t*) ($n = 1, 2, 3$).

Dependent variable	Fixed effects	Beta coefficient	Standard Error	*t* value	*p* value
Model 1: Mean PA at *t*	Intercept	34.92	9.27	3.77	<0.001
	Age	−0.00	0.43	−0.00	1.000
	Gender	5.13	2.13	2.40	0.016
	Time	0.82	0.17	4.91	<0.001
	Time-squared	−0.03	0.01	−2.44	0.015
	Group	−10.19	2.11	−4.84	<0.001
	Mean PA at t-1	0.38	0.03	13.44	<0.001
	Group* (Mean PA at t-1)	−0.01	0.02	−0.57	0.570
Model 2: Mean PA at *t*	Intercept	47.70	11.71	4.07	<0.001
	Age	0.08	0.55	0.15	0.883
	Gender	6.81	2.70	2.52	0.012
	Time	0.87	0.18	4.96	<0.001
	Time-squared	−0.03	0.01	−2.24	0.025
	Group	−15.93	2.58	−6.17	<0.001
	Mean PA at t-2	0.13	0.03	4.40	<0.001
	Group* (Mean PA at t-2)	0.05	0.02	2.51	**0.012**
Model 3: Mean PA at *t*	Intercept	52.71	12.54	4.20	<0.001
	Age	0.09	0.58	0.16	0.874
	Gender	7.07	2.90	2.44	0.015
	Time	0.83	0.18	4.68	<0.001
	Time-squared	−0.02	0.01	−1.68	0.093
	Group	−17.73	2.74	−6.46	<0.001
	Mean PA at t-3	0.05	0.03	1.73	0.083
	Group* (Mean PA at t-3)	0.06	0.02	3.15	**0.002**

Note: Covariates in the model consisted of age, gender, time of day and time of day square.

Discussion

The current study combined two measurement approaches – laboratory-based and EMA – to identify the typical PA dynamics in individuals with StD. Specifically, we aimed to characterize the emotional profile of individuals with StD when faced with positive stimuli, and to determine the trend and extent of their affective alterations in daily life.

At the laboratory level, we found reduced overall PA in participants with StD compared with HC through continuous affect ratings. Similar results were found in real life using EMA, where the StD group showed lower daily PA compared with the HC group. These results correspond with previous demonstrations of elevated anhedonia in individuals with StD compared with healthy people (Yamashita & Yamamoto, 2021), including prior EMA studies (Bylsma, Taylor-Clift & Rottenberg, 2011).

The significantly lower overall PA found in the StD group is consistent with the PA characteristics in MDD. Previous studies investigated the differences in PA between HC and individuals with MDD using materials including positive images and sounds (Jin, Steding & Webb, 2015). The results showed that the self-reported happiness of MDD patients was significantly lower than that of the control participants, irrespective of the presentation of positive images or sounds. Similar results were found in a study that used normative and idiographic positive stimuli (Rottenberg, Gross & Gotlib, 2005). However, such studies typically hold a static view of emotion, only considering PA intensity at one point in time and ignoring temporal fluctuation.

While group differences in static affect can be informative, additional insights may be derived from studying the dynamic nature of affective responses, for example, by assessing the reactivity or duration of the response. For that, we compared the two groups on the affective reactivity obtained by PA rating at T1 after stimulus presentation minus that at baseline (e.g., T0) (Gruber, Oveis, Keltner & Johnson, 2011). We observed that the two groups generated the same degree of PA reactivity in the face of positive stimuli. Our findings suggest that individuals with StD can experience an immediate positive reaction to positive stimuli. The difference in PA intensity from their own baseline was similar to that of HC, though StD participants showed lower continuous PA ratings. Similarly, EMA analysis revealed that individuals with StD reported experiencing significantly fewer PE each day than HC, consistent with the findings of Bylsma et al. (2011). This highlights the particular importance of the presence of positive stimuli for individuals with StD, which was further illustrated by the results of the two groups in terms of NA, even though NA was not the primary focus of the current study. In the laboratory context, NA intensity was not able to significantly differentiate between the two groups, possibly because the video-watching task caused individuals in both groups to focus more on perceiving positive stimuli in the present moment, resulting in no differences in NA. In EMA, the average NA over 7 days for participants with StD was significantly lower than that of HC, reflecting that, in the absence of high-frequency specific positive stimuli in daily life, individuals with StD are consistently disturbed by negative emotions, in addition to the lack of pleasure.

Another finding from the laboratory-based task was that participants in the StD group had a significantly shorter duration of PA maintenance, and piecewise analysis revealed that affective recovery mainly occurred in the first three minutes after emotional elicitation, indicating reduced ability to maintain PA in StD. Previous fMRI studies similarly reported reduced ability to sustain PA among individuals currently or previously diagnosed with MDD, which was associated with altered frontal-striatal brain connectivity (Admon & Pizzagalli, 2015; Heller et al., 2009). Such reduced ability to sustain PA may be explained by resistance to change in original emotional states, as supported by previous findings (Funkhouser et al., 2021). Current EMA findings further support this notion. To this end, emotional inertia under three parameters was calculated in EMA, revealing that individuals with StD had higher PA inertia. Importantly, high inertia is considered to account for maladaptive emotion dynamics (Kuppens et al., 2010). Therefore, high PA inertia is not beneficial for individuals with StD. Their inherent levels of PA are significantly lower than those of healthy people and the high PA inertia implies that their positive emotional state remains relatively unaffected by external stimuli or their own attempts at emotional regulation over an extended duration. Based on this, we speculate that in individuals with StD, high PA inertia drives them back to the original emotional state quickly, resulting in reduced capacity to sustain PA despite the significant increase in PA after the positive video stimulation. Kuppens et al. (2012) found that greater inertia in positive emotional behavior predicted the emergence of clinical depression two and a half years later.

A potentially related mechanism that drives the observed effects may be related to impaired emotional regulation. Impaired emotion regulation has been associated with high emotional inertia (Zheng & Asbury, 2019). Hence, emotion regulation might be another reason behind the aberrant PA dynamics of individuals with StD (Vanderlind, Everaert & Joormann, 2022). Previous work on emotion regulation strategy use showed that participants with elevated depressive symptoms reported greater use of dampening (Werner-Seidler, Banks, Dunn, & Moulds, 2013), and that dampening was associated with lower levels of momentary PA (Vanderlind et al., 2022). Therefore, individuals with StD may be habituated to the frequent use of dampening, like patients with depression. Such a coping style, in turn, suppresses the emotional response that might otherwise have occurred after experiencing a positive event, manifested in short PA maintenance and high levels of emotional inertia. At the extreme, the result of such a process could be the development of more severe depressive symptoms. Nevertheless, we did not find significantly high or low NA inertia in individuals with StD – a finding that is inconsistent with the commonly observed high NA inertia in previous studies of individuals with MDD – suggesting potential differences in the ability and efficiency of negative emotion regulation between people with StD and MDD (Funkhouser et al., 2021; Kuppens et al., 2012).

Limitations and future directions

Several limitations of the study should be acknowledged. First, given that smartphone-based EMA requires familiarity with mobile technology, the sample comprised mainly university students, limiting the generalizability of findings to larger populations. A wider range of age groups should be recruited in the future with standardized measures used regarding familiarity with the mobile technology (Liu & Lou, 2019). Second, considering the cyclical nature of emotional changes and the potential fatigue effects of the experiment, the current EMA was only conducted for 7 days. However, it remains uncertain whether individuals with StD exhibit novel patterns in PA dynamics in the real world over a longer time. Therefore, it would be worth implementing long-term EMA sampling, such as on a weekly or bi-weekly basis, continuously collecting data for six months or a year, in future research. Third, our primary interest was in capturing and depicting the positive affective dynamics of individuals with StD, although factors such as behavior activation may also play a role in PA in daily life (Takagaki et al., 2014). More efforts should be devoted to the exploration of interaction between PA and behavior. Fourth, the findings revealed high PA inertia in individuals with StD. However, despite researchers linking high emotional inertia to inappropriate use of dampening (i.e., emotion dysregulation), it is unclear whether this resistance to altered emotional states is a proactive or reactive process. Recent studies have pointed out that emotion dysregulation is related to cognitive bias, which suggests a need to examine the nature of high emotional inertia (Gao, Yan & Yuan, 2022).

Conclusion

PA in individuals with StD was consistently lower than for HC participants in both laboratory and real-world settings. However, individuals with StD experienced intense subjective emotions when facing the positive stimuli. Nevertheless, their high positive emotional inertia and short PA duration might indicate aberrant information processing and emotion regulation. The current findings contribute to understanding the aberrant positive emotional profile of StD. This work may pave the way for more detailed research on emotion in psychopathology and help to develop more effective detection methods for depressive disorders.

Supplementary material

Additional information can be found in the supplementary material.

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Declaration of Competing Interest

The authors report no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijchp.2023.100427.

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