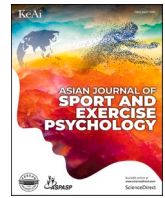


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Effects of supervised physical exercise on emotions among adult women with a diagnostic of borderline personality disorder: A series of mixed method single-case experimental trials combined with ecological momentary assessment[☆]

Samuel St-Amour^{a,b,*}, Elizabeth Brunet^c, Lionel Cailhol^{b,d}, Dario Baretta^e, Guillaume Chevance^f, Paquito Bernard^{a,b}

^a Department of Physical Activity Sciences, Université du Québec à Montréal, Montreal, Quebec, Canada

^b Mental Health University Institute of Montreal Research Center, Montreal, Quebec, Canada

^c Department of Psychology, Université du Québec à Montréal, Montreal, Quebec, Canada

^d Department of Psychiatry and addictology, Medicine Faculty, University of Montreal, Montreal, Quebec, Canada

^e Institute of Psychology, University of Bern, Bern, Switzerland

^f ISGlobal, Barcelona, Spain

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ABSTRACT

Borderline personality disorder (BPD) is thought to be shaped around emotional dysregulation. Physical exercise is an effective way to improve emotional regulation in individuals both with and without mental disorder. However, to this day no study examined the effect of regular physical exercise on emotion regulation in adults with BPD. This study used a series of single case experimental design (A-B-A) combined with ecological momentary assessment and individual interviews to explore and analyze the effect of physical exercise on emotion regulation in adults with BPD. Emotions of participants were monitored thrice daily with an app that prompted them to report their emotions on a 0–100 analogue scale. Both A (control) phases lasted 2 weeks and the B phase (intervention) lasted 4 weeks (3 1-hour supervised sessions of physical exercise weekly). Emotion-related data were analyzed by piecewise linear regression and qualitative data with thematic analysis. Seven women with BPD completed this study and five of them participated in the interviews. Three participants showed an increase in positive emotions and four participants showed a decrease in negative emotions throughout the study and those results are confirmed with interindividual analyses. Participants reported enjoying the exercise program and the trainer they were assigned. Finally, participants also reported being less reactive and more patient when encountering irritating or stressing events. In conclusion, adult women with BPD found that physical exercise decreases their negative emotions and reactivity to psychological stressors.

1. Introduction

Borderline personality disorder (BPD) is characterized by instability of self-image, goals, interpersonal relationships, and affects (Gunderson et al., 2018). The annual prevalence of this disorder in the United States is evaluated at 1.6 % of the general population and up to 28 % of individuals in outpatient psychiatric setting (Volkert et al., 2018). Individuals with BPD frequently present psychiatric comorbid disorders (up to 96 % will also present a major depressive disorder over their

lifetime; Shah & Zanarini, 2018). Moreover, they are also more at risk of presenting somatic comorbid disorders than the general population (15.3 % of individuals with BPD also present cardiovascular diseases compared to 8.1 % in the general population; El-Gabalawy et al., 2010). Finally, a poor sleep quality is highly prevalent among individuals with BPD and could exacerbate their symptoms (Winsper et al., 2017).

Among the treatments for these disorders, physical exercise (PE) has been linked to improvements in many of their components and symptoms. The last Canadian treatment guidelines for mood disorders

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* Corresponding author at: 141 avenue du Président-Kennedy (SB-4290), Montréal, QC H2×1Y4, Canada.

E-mail address: st-amour.samuel.2@courrier.uqam.ca (S. St-Amour).

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included PE as mono- or adjunct therapy for every level of depression severity (Ravindran et al., 2016). Moreover, PE was also found efficient in preventing and reducing risk factors of obesity, cardiovascular diseases, and diabetes in individuals with mental illnesses (Vancampfort et al., 2013).

Among BPD's pathogenesis models, the biosocial model suggests that emotion dysregulation is the core component of the disorder and underlies many characteristic behaviours (Crowell et al., 2009). According to this model, BPD's emotion dysregulation is characterized by a heightened sensitivity and intense reaction to emotional stimuli, and delayed return to an emotional baseline (Crowell et al., 2009; Linehan, 1993). Moreover, emotional dysregulation has also been described as a great daily variability and instability of emotions (i.e., more extreme emotions varying more quickly; Houben et al., 2016). Difficulties regulating emotions in BPD are linked to maladaptive behaviours, which presumably function to reduce negative affect (Daros et al., 2018). A higher level of emotion dysregulation has also been associated with lower quality of life and daily functioning (Gratz et al., 2016) and a poorer therapeutic relationship (Gunderson et al., 2018). Therefore, finding diagnosis specific interventions to improve emotion regulation and help regulate negative emotions should be among the priorities for research on BPD.

It is important to note that individuals with BPD tend to remember their emotions more negatively and less positively (Ebner-Priemer et al., 2006). Therefore, ecological momentary assessments (EMA) have been recommended to measure this phenomenon in this population (Santangelo et al., 2014). More concretely, EMA study participants self-report their emotional intensity with an application in their daily life context. Previous EMA studies confirmed that individuals with BPD felt more intense emotions, reacted more intensely to emotional stimuli and returned more slowly to emotional baseline than the general population (Santangelo et al., 2014).

PE has shown great benefits in regulating negative emotions, improving emotion regulation and sleep quality. Indeed, two meta-analyses regrouping more than 150 studies and 13,000 participants indicated that a single bout of PE significantly increase positive affects in general population (Ekkekakis et al., 2011; Reed & Ones, 2006). Similar results have also been found in adults with anxiety, mood, and obsessive-compulsive disorders (Abrantes et al., 2009; Herring et al., 2019; Meyer et al., 2016; Stanton et al., 2016). Moreover, a recent pilot study with PE found promising results in increasing positive affects in adults with BPD (St-Amour et al., 2022). Another EMA study analyzing the relation between regular PE and emotion dynamic in general population found a better negative emotions regulation in active than inactive adults (Bernstein et al., 2019). Finally, a meta-analysis including 66 studies and over 2800 participants showed that acute and regular PE improve sleep quality with a small-to-medium effect size (Kredlow et al., 2015). However, to this day no study examined regular PE's effect on emotion regulation in adults with BPD (St-Amour et al., 2021, 2023).

Being volatile and unstable, emotions, and therefore emotion regulation, are complex to observe and measure in individuals with BPD, particularly in interventional context (Santangelo et al., 2014). Previous intervention effects have been assessed pre and post with retrospective questionnaires (Nauphal et al., 2021). They tend to measure the general tendency of participants to emotion regulation instead of how they react to emotions in their day-to-day environment (Aldao et al., 2010). Moreover, questionnaires are subject to recall bias and generally disagree with direct or ecological observation of emotion regulation (Aldao et al., 2010; Ebner-Priemer & Trull, 2009). Consequently, EMA has been recommended to measure treatment outcomes in emotional dysregulation interventions (Nauphal et al., 2021). EMA can also be combined with single-case experimental design (SCED), providing an in-depth description of interventional effects (Bentley et al., 2019; Kingsbury & Bernard, 2023; Nauphal et al., 2021). SCED studies consist in collecting data regularly from participants as they progress through

different phases of the study to test one or more intervention. The first phase allows measuring the baseline of the interest variable and the subsequent phases serve to introduce the intervention(s). The data from the intervention phase are then compared to the baseline phase, providing strong internal validity for each participant. Therefore, conducting multiple SCED combined with EMA is a solid methodological approach to investigate the effects of an intervention on emotion regulation in adults with a BPD diagnostic.

The goals of the present study were to examine (1) the feasibility and acceptability of a supervised 4-week PE intervention in adults with BPD; (2) the subjective effect of a 4-week PE intervention in adults with BPD; (3) the effect of a 4-week PE intervention on daily levels and variability of positive and negative emotions in adults with BPD; and (4) the effect of a 4-week PE intervention on daily self-reported sleep quality in adults with BPD.

We hypothesize that (1) a supervised 4-week PE intervention will be feasible and acceptable; (2) daily level of positive emotions will increase and (3) daily level of negative emotions will decrease during the intervention; variability of both (4) positive and (5) negative emotion will decrease during the intervention; and (6) the self-reported sleep quality will improve during the intervention. For hypotheses from 2 to 6, we also expected that intervention effects were maintained 2 weeks after its end. Hypotheses 2–6 were tested at intraindividual and interindividual levels. Being exploratory through an inductive qualitative method, goal 2 was not associated with a hypothesis.

2. Methods

This research protocol has been approved by the Ethics Boards of the *Université du Québec à Montréal* (2022–4385) and the *Eastern Montreal Integrated University Health and Social Services Centre* (2022–2671). This manuscript was written according to the *Single-Case Reporting Guideline in BEhavioural Interventions (SCRIBE; Tate et al., 2016)*. The SCRIBE checklist is provided in supplementary material (Table S1). This study was not preregistered.

2.1. Study design

This SCED study followed an A-B-A design (representing the 3 phases of the study) and lasted 8 weeks. Ten participants were to be recruited to allow replication of the study. No randomization nor blinding was used due to the nature of the study. Each A phase (2 weeks each) represent the pre- and post-intervention baseline measures and the B phase (4 weeks) represents the intervention phase. A 4-week duration was chosen to ensure both effects apparition and optimal participation of the participants. For the whole 8 weeks, participants received 3 daily EMA prompts to report their emotions' intensity. Every two weeks, participants were prompted via email to fill out another series of online questionnaires (described below). The intervention (B phase) consisted of three 1-hour supervised PE sessions weekly. At the end of the B phase, participants were invited to participate in an online individual semi-structured interview to give their opinion on the intervention. The study design is illustrated in Fig. 1.

2.2. Recruitment

Patients from the *Relational and Personality Disorders Service* of the *University Institute of Mental Health in Montreal* were contacted while on the waitlist for treatment in this service after being referred by their physician or psychiatrist and after giving the consent to be contacted by research teams. Recruitment and data collection spanned from November 2021 to April 2022. Participants were screened by telephone and included if they: 1- received a BPD diagnosis from a psychiatrist; 2- were waiting for a treatment for BPD; 3- were considered inactive (complete less than 150 min of PE weekly; Tremblay et al., 2011); and 4- had a smartphone allowing to install the app *Ethica* for the EMA. They

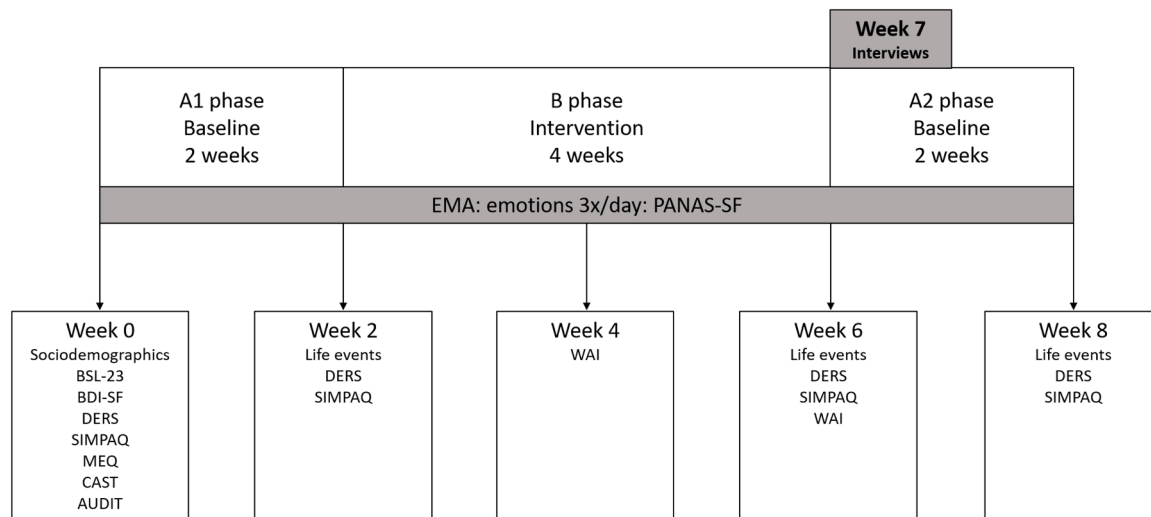


Fig. 1. Study protocol.

Note: Week 0 represent the inclusion meeting. EMA = Ecological Momentary Assessment. PANAS-SF = Positive and Negative Affect Schedule-Short Form. BSL-23 = Borderline Symptoms List-23. BDI-SF = Beck Depression Scale-Short Form. DERS = Difficulties in Emotion Regulation Scale. SIMPAQ = SIMple Physical Activity Questionnaire. MEQ = Morningness-Eveningness Questionnaire. CAST = Cannabis Abuse Screening Test. AUDIT = Alcohol Use Disorder Identification Test. WAI = Working Alliance Inventory.

were excluded if: 1- they needed a cane or a wheelchair to move; 2- had at the time of recruitment or had had in the previous week a psychotic episode; 3- had a severe substance use disorder (other than nicotine); or 4- presented a contraindication to PE evaluated by the *Physical Activity Readiness-Questionnaire* (PAR-Q+; Warburton et al., 2016). If participants developed a psychotic episode during the study, they were to be oriented to appropriate mental health resources (including their attributed mental health specialist if applicable) before being excluded from further participation in the study.

To confirm participants' diagnosis and ensure they match BPD criteria at inclusion, they were evaluated by a research assistant (either psychiatry resident or doctorate level psychology student) with a specific training to assess BPD with the Structured Clinical Interview for DSM-IV Axis II (Lobbetael et al., 2011). Following confirmation of the diagnosis, a research assistant helped them to fill out the information and consent form and the first series of questionnaires, install and test the Ethica app on their smartphone, and plan the PE sessions. Upon reception of the last filled out questionnaires at the end of the study, participants received a CAD 60 compensation.

2.3. Ecological momentary assessments

All EMA data was collected through the Ethica Data platform which allow researchers to create and personalize EMA tools in a practical and useful way that is linked to the Ethica app on participants' smartphones (<https://avicennaresearch.com/>).

2.3.1. Daily emotion measures

Daily prompts were sent out on participants' smartphone through the Ethica app at random moments during 3 periods: in the morning (between 8AM and 10:30AM), in the afternoon (between 1:30PM and 4PM), and in the evening (between 7PM and 9:30PM). At every prompt, participants had to rate how much they felt 10 different emotions during the 2 previous hours on a scale from 0 (Not at all) to 100 (Extremely). The emotions presented were the 10 emotions from the Positive and Negative Affect Schedule – Short Form (PANAS-SF; Thompson, 2007): Alert, Inspired, Determined, Attentive, Active, Upset, Hostile, Ashamed, Nervous, and Afraid (ex: In the last 2 h I felt alert). A recent study demonstrated that PANAS-SF can be used as EMA tool to measure within person difference with moderate to substantial reliability in adults with

BPD ($\omega = 0.68\text{--}0.87$; Haney et al., 2023; Houben & Kuppens, 2020; Mneimne et al., 2018; Trull, 2018)

2.3.2. Sleep quality

During the first daily prompt, participants self-reported their sleep quality for the previous night on a scale from 0 (Bad) to 100 (Excellent) ("Last night, my sleep quality was"). This item was chosen from the Consensus Sleep Diary (Carney et al., 2012). This measure has demonstrated favourable psychometric properties (Cappelleri et al., 2009). All EMA items are presented in Tables S2-S3 in supplementary files.

2.4. Questionnaires

In line with the SCRIBE, we used validated questionnaires to describe participants demographic characteristics and clinical features (Tate et al., 2016). Participants had to fill out validated questionnaires at the beginning, every two weeks during, and at the end of the study (see Fig. 1 for details) through the LimeSurvey platform. At the beginning (week 0), participants had to provide the following sociodemographic information: sex, age, education, marital status, height, weight, household income, psychiatric follow-up duration, and current medication use. Then, they filled out the *Borderline Symptoms List-23* (BSL-23; $\alpha = 0.97$; Bohus et al., 2009), the *Beck Depression Inventory-Short Form* (BDI-SF; $\alpha = 0.74$; Furlanetto et al., 2005), the *Morningness-Eveningness Questionnaire* (MEQ; $\alpha = 0.94$; Taillard et al., 2004), the *Cannabis Abuse Screening Test* (CAST; $\alpha = 0.81$; Legleye et al., 2007), and the *Alcohol Use Disorder Identification Test* (AUDIT; $\alpha = 0.93$; Dawson et al., 2005). According to the SCRIBE recommendations, we measured control variables that could change during the study at the beginning, at each phase change, and at the end of the study (Tate et al., 2016). Therefore, at weeks 0, 2, 6, and 8 (every change of phase) participants had to fill out the *Difficulties in Emotion Regulation Scale* (DERS; $\alpha = 0.92$; Dan-Glauser & Scherer, 2012) and the *SIMple Physical Activity Questionnaire* (SIMPAQ; $\rho = 0.25$; Rosenbaum et al., 2020). Finally, at weeks 4 and 6, participants had to report their perceived relationship with the research assistant that supervised their PE sessions with the *Working Alliance Inventory* (WAI; $\alpha = 0.93$; Horvath & Greenberg, 1989). A detailed description of the questionnaires is available in supplementary material. The protocol is presented in Fig. 1.

2.5. Physical exercise intervention

Telehealth PE intervention was preferred due to the uncertainty of having in-person meeting because of COVID-19 restrictions. Participants and research assistants used any internet-connected device at their disposition (computer, tablet, smartphone) to attend telehealth sessions via Zoom. This mode of delivery of PE intervention has been previously noted as feasible, safe, and acceptable in many populations including patients with cancer, Parkinson's disease, and schizophrenia (Flynn et al., 2021; Paterson et al., 2020; Tréhout, 2022).

Prior to the study, three research assistants completed a 3-hour training session on BPD, telehealth PE intervention safety, and how to supervise PE sessions for individuals with mental disorders given by SS and PB. It was adapted from the guidelines for PE intervention for individuals with mental disorders (Romain & Bernard, 2018). Every session followed the same exercise plan designed to be completed at home without training equipment at self-paced intensity (see supplementary files Table S4 for the detailed exercise plan; Williams et al., 2016). The supervisor noted what was done at each session in a file and could adjust the exercise plan's intensity (making it harder/easier) to adjust to participants' capacity by adding/removing repetitions or exercising time.

Procedural fidelity was evaluated by analyzing sessions reports made by supervisors. If needed, corrections were given for the following sessions.

2.6. Internal validity

SCED studies may be subject to rival hypotheses that could explain changes in the dependent variable like maturation, question-behavioural effect, and other external factors (Kwasnicka & Naughton, 2020). To ensure the internal validity (i.e., the observed change is attributable to the intervention rather than other factors), participants were questioned at weeks 2, 6, and 8 about important event having occurred in their life during the phase they just finished that could have a prolonged (positive or negative) impact on their emotions.

2.7. Individual interviews

After the intervention phase, an optional online individual semi-structured interview was suggested to each participant to further detail their experience of the intervention. The interview was optional to ensure greater participation in the study as some patients were reluctant to participate due to the interview. The interview focused on how they appreciated or not the intervention (acceptability of the intervention), how it integrated in their daily life and what change they observed during it. They were also asked to describe the ideal setting for them to stay active (see supplementary files Table S5 for the complete interview guide). Interviews were conducted by SS who was not involved in supervising PE sessions. The interviews were recorded and transcribed by the SS and a research assistant. Pseudonyms were attributed to the participants to ensure anonymity.

2.8. Qualitative analyses

The qualitative analyses addressed the acceptability and the global impact of the intervention from the participants' perspective (goals 1 and 2). The qualitative analysis portion of this research follows the post-positivism epistemological paradigm. We believe there exists an objective reality that can be better represented through repeated observations (Morrow, 2005). We chose this paradigm because the clinical context of the research requires the study of the common experience of one intervention. Considering that the research in its entirety is based on the usefulness and the accessibility of a clinical program, the post-positivism paradigm was more appropriate to frame the generality of the experience, because of its stance of objectivity and reality (Ponterotto, 2005). Thus, the data was approached through repeated themes and common

experience to give a general portrait of the experience of the participants. The data were analyzed using a thematic analysis of the interviews. The thematic analysis used was inspired by Braun and Clarke (2019) with a deductive and inductive approach. This approach was conducted by the coding of series of words and creating categories inductively and regrouping them under broader themes. Beforehand, we created broad themes based on the research question to guide the analytical process, putting forward the deductive part of the analysis. These themes were then developed through the analysis of the data, putting forward the more inductive part of the analysis to better capture the semantic meaning behind certain verbatim quotations (Braun & Clarke, 2023). Therefore, both deductive and inductive analyses were made to answer different questions. To ensure rigour, two qualitative post-positivism criteria were used to evaluate trustworthiness: credibility and dependability (Morrow, 2005). To ensure credibility, peer debrief was used by SS and EB (Braun & Clarke, 2023; Morse, 2015). They conducted separated thematic analysis of every verbatim with the NVivo software (Dhakal, 2022). They then met to discuss their analysis and agree on a final set of themes. This method is particularly interesting, especially with an inductive approach to thematic analysis, to make sure both peers extracted the same ideas behind their chosen themes. Then to ensure dependability, such as described by Anney (2014), an audit trail was used with PB throughout the process, where he was made aware of every step, every document and every observation of every theme and subtheme (Anney, 2014; Bowen, 2009; Li, 2004).

2.9. Quantitative analyses

The WAI score and the adherence to PE sessions were used to assess the feasibility and acceptability of the intervention (goal 1). Moreover, quantitative analyses addressed our goals 3 and 4 (hypotheses 2–6) regarding the change in levels and variability of positive and negative emotion and the change in sleep quality during the intervention. A daily mean and variability (i.e., difference between maximal and minimal score during a day) of positive and negative emotions was computed. For each day, we computed a mean value if at least one EMA response was provided and a variability value if at least 2 EMA response were provided. Each day that did not fill these criteria was considered as missing data. Our dependent variables were: 1) the daily mean and 2) variability of positive, 3) the daily mean and 4) variability of negative emotions and 5) daily sleep quality.

2.9.1. Feasibility and acceptability

The feasibility of the intervention was assessed by the dropout rate during the intervention. A dropout rate of under 40 % was considered good (Stubbs et al., 2016; Vancampfort et al., 2021).

The acceptability was assessed by the adherence rate to the intervention and the strength of the therapeutic alliance as measured by the WAI. An adherence rate of 60 % or more or 80 % or more was considered good or very good respectively (Romain & Bernard, 2018). Moreover, a WAI score of at least 60 throughout the intervention was attributed to a good alliance (Pierò et al., 2013; Wnuk et al., 2013).

Being the first study testing PE intervention in this population and with the small sample size (and incidentally large relative percentage for each participant) we opted for more flexible thresholds assessing feasibility and acceptability.

2.9.2. Intra-individual analyses

Five piecewise linear regressions (one for each dependent variable) with an autocorrelation structure (lag = -1) were carried out for each participant to investigate the effects of 4 weeks exercise intervention for each study participant (Huitema & Mckean, 2000; Lapointe et al., 2023; Wilbert et al., 2022c, 2022b). Since no guidelines on SCED with EMA exist to this day (Bentley et al., 2019), we chose that set of analyses as they best suit our design. Piecewise regressions calculate regressions for the whole study's data and for each phase's data (i.e., for the current

study, 3 regressions calculated). Each piecewise regression brings at least 3 different results: the trend (the slope of the regression for the whole study's data), the level (the difference between the predicted regression's intercept at the beginning of the phase and the actual regression's intercept at the beginning of the phase), and the slope (the difference between the trend's slope and the phase regression's slope; Wilbert et al., 2022c). Therefore, if a positive trend is statistically significant, the variable increase continuously through the study; if a positive level is statistically significant, the phase's regression starts higher than predicted by the trend; if a phase's slope is statistically significant, the variable behaves differently in this phase than through the rest of the study (depending on the size and direction of the slope compared to the trend). A graphical representation of those values is presented in supplementary material (see Figure S1). Since we consider the effect of our intervention to be delayed from the beginning of the B phase, the trend and the slope effect for phases B and A2 were tested, and the level effect was not computed in our piecewise regressions.

2.9.3. Inter-individual analyses

To examine the effect our intervention had on our sample as a whole, 5 multilevel piecewise linear regressions were carried out to analyze the average phase difference for all the participants pooled together (Wilbert et al., 2022a).

Finally, SIMPAQ, DERS AND WAI scores were graphically reported. Analyses have been performed with R 4.2 and tidyverse, scan, and splot packages (Wilbert, 2023). Data, open materials and R scripts are available online (<https://osf.io/6gxd2/>).

3. Results

3.1. Participants characteristics

Sixty-four patients men and women were contacted from the waitlist. After screening for inclusion and exclusion criteria, ten adult women with BPD accepted to participate in this study but three of them dropped out either before the intervention or after two sessions. Participants dropped out due to lack of time, lack of interest in the intervention or loss of contact. Therefore, seven participants completed the study. A recruitment flowchart is presented in supplementary material (Figure S2). Participants were aged between 23 and 45 years old with a mean of 32.43 (SD = 7.79). Baseline sociodemographic and health measures of each participant are presented in Table 1. Participants answered between 52 % and 94 % of EMA prompts with a mean of 69.44

Table 1
Baseline description of participants.

ID	Sexe	Age	Education	Marital status	BMI (kg/m ²)	Income (CAD)	Follow-up (yrs)	AP	AD	BSL-23	Depression risk	CIR	CUD	AUD
KARCY	F	24	College	Single	25.8	20,000 - 40,000	1	No	No	Very-High	Yes	Mid-morning	Yes	No
PAMOR	F	37	High school	Married	31.9	40,000 - 60,000	0	No	Yes	Very-High	Yes	Evening	No	No
KARBE	F	45	College	Single	34.7	20,000 - 40,000	1	No	No	Mild	Yes	Mid-evening	No	No
SANFO	F	29	College	Single	22.4	20,000 - 40,000	2	No	No	Mild	Yes	Mid-evening	No	No
KRYCO	F	33	High school	Civil union	32.8	Don't know	3	Yes	No	High	Yes	Mid-morning	No	No
FALME	F	36	College	Single	42.3	40,000 - 60,000	17	No	Yes	High	Yes	Mid-evening	No	No
MARVI	F	23	College	Single	22.4	Don't know	0	Yes	Yes	High	Yes	Evening	Yes	Yes

Note: BMI = Body mass index; Follow-up = Duration of psychiatric follow-up; AP = Antipsychotic medication use; AD = Antidepressant medication use; BSL-23 = Severity of borderline personality disorder symptoms assessed with the *Borderline Symptoms List-23* questionnaire (mean score between 0 and 0.28 = none or low; 0.28–1.07 = mild; 1.07–1.87 = moderate; 1.87–2.67 = high; 2.67–3.47 = very high; and 3.47–4 = extremely high); Depression risk = Risk of depression assessed with the *Beck Depression Inventory* (score of 10 and higher indicating risk of depression); CIR = Morning- or eveningness assessed with the *Morningness-Eveningness Questionnaire*; CUD = Risk of problematic cannabis use assessed with the *Cannabis Abuse Screening Test* (score of 3 and higher associated with problematic use); AUD = Risk of problematic alcohol use assessed with the *Alcohol Use Disorder Identification Test* (score of 3 and higher for women associated with problematic use).

(SD = 15.55). Three participants (KARCY, PAMOR, KARBE) had a relatively steady high (over 70 %) EMA response rate for all three phases. Two participants (SANFO, KRYCO) had a relatively steady medium response rate (40–60 %) for all three phases. Two participants had a decreasing response rate throughout the study. Participants attended between 4 and 12 out of 12 sessions (with 5 participants attending at least 8 out of 12 sessions). Description of EMA and PE sessions adherence is found in Table 2. Numbers of data points per variable for each phase are presented in Table 3. Baseline description and EMA/PE adherence of dropout participants are found in supplementary material (Tables S6 and S7). Some participants postponed the beginning of their intervention phase due to events out of their control making some A1 phases longer for some than others.

3.2. Internal validity

PAMOR and FALME reported significant life events (with ambiguous emotional valence) happening during phase A1 and B of the study and KARBE reported a significant negative life event during phase A2. Detailed life events are reported in Table S8 of the supplementary material.

Table 2
EMA and physical exercise sessions adherence.

ID	EMA (Phase A1)	EMA (Phase B)	EMA (Phase A2)	EMA total	Sessions
KARCY	38/39 (97.4 %)	82/87 (94.3 %)	34/39 (87.18 %)	155/165 (93.94 %)	12/12 (100.0 %)
PAMOR	35/42 (83.3 %)	63/84 (75.0 %)	28/39 (71.8 %)	127/165 (76.97 %)	11/12 (91.7 %)
KARBE	36/42 (85.7 %)	71/84 (84.5 %)	27/39 (69.2 %)	136/165 (82.4 %)	12/12 (100.0 %)
SANFO	21/39 (53.8 %)	50/87 (57.5 %)	19/39 (48.7 %)	91/165 (55.2 %)	12/12 (100.0 %)
KRYCO	37/60 (61.7 %)	36/75 (48.0 %)	12/30 (40.0 %)	86/165 (52.1 %)	4/12 (33.3 %)
FALME	29/39 (74.4 %)	59/87 (67.8 %)	22/39 (56.4 %)	110/165 (68.0 %)	5/12 (41.7 %)
MARVI	31/42 (73.8 %)	51/84 (60.7 %)	15/39 (38.5 %)	97/165 (58.8 %)	8/12 (66.7 %)
MEAN (%)	75.7 %	69.7 %	58.8 %	69.6 %	76.2 %

Note: EMA = Ecological momentary assessment.

Table 3
Number of data points per variable for each phase and total.

ID	Daily mean emotions				Daily variability emotions				Sleep Quality			
	A1	B	A2	Tot	A1	B	A2	Tot	A1	B	A2	Tot
KARCY	13	29	14	56	12	12	12	36	13	26	12	51
PAMOR	14	28	14	56	13	26	13	52	9	13	12	34
KARBE	14	28	14	56	13	16	8	37	9	24	9	42
SANFO	12	26	14	52	7	19	8	34	3	12	4	19
KRYCO	20	22	9	51	15	12	5	32	1	6	1	8
FALME	12	27	14	53	7	17	7	31	3	15	6	24
MARVI	14	26	11	51	12	19	5	36	6	9	3	18

Note: For each day, we computed a mean value if at least one EMA response was provided and value if at least 2 EMA response were provided. Each day that didn't fill these criteria was considered as missing data.

3.3. Feasibility and acceptability (Goal 1)

Three participants (30.0 %) dropped out from the study with only 1 of the remaining 8 (12.5 %) after beginning the intervention phase indicating a good feasibility of this intervention.

All interviewed participants declared having appreciated the intervention to some extent with few to no suggestion of changes. Participants who completed the study had an adherence rate of 76.2 % which is considered good (over 60 %). Moreover, they had a mean WAI score of 76.4 halfway through the intervention and 78.1 at the end, describing overall good alliances (over 60). Only one participant had a score under 60 halfway through the intervention but had a score over 60 at the end.

3.4. Qualitative analysis

Five of the seven participants who completed the protocol accepted to participate in the interview which ranged from 14 to 48 min. The analysis revealed four main themes regarding their experience in the study and their will to be active. However, only two themes were linked to the present research goals (1 and 2): 1) the characteristics of the trainer; and 2) the changes attributed to PE. The thematic trees for all 4 themes are presented in supplementary material Figures S3-S6. All verbatims presented have been translated from French by SS for the purpose of this article.

3.4.1. The characteristics of the trainer (Goal 1)

The relation with the trainer is shown to have a positive impact in participants' experience of the program. The individualized relationship with the professional helped to build a sense of being appreciated to most participants. Some elements contributed to the building of a positive relationship between the trainer and the participant. Participants highlighted the guidance and adaptability of their trainer as important characteristics. Mostly, KARBE, PAMOR and SANFO enjoyed being able to question their trainer about the exercises, talk about their discomfort and adapt the exercises to their limitations or capacities. PAMOR found it particularly reassuring to have someone look over her and correct her if she did the exercises wrong:

"I did exercise alone before. I had the motivation to do exercises and all. I was always criticizing and doubting myself about doing it correctly or how it was supposed to be done. Even if I did the exercises [...] I always had that lingering doubt. But with someone else, all of a sudden, AH! Sometimes I did something the wrong way in the exercises, [my trainer] told me: "No, you will do it this way." And that gave me a security that I didn't have when I was alone."

Moreover, KARBE really enjoyed the encouragements she received among the guidance from her trainer: "Sometimes I said to [my trainer] "Damn! I think I don't progress", [she answered] "No, no. You progress at a snail's pace, but in the end you will win. You will win!"."

Overall, participants really appreciated their trainer. KARCY said: "[...] also the fact that I got a good trainer, that we had the same personality and a good energy, that was nice. At the same time doing it with

someone liking sport as well."

3.4.2. Changes attributed to physical exercise (Goal 2)

Moreover, throughout the intervention, our participants noticed many changes in their lives. We regrouped those observed changes in three categories: physical, psychological, and of general state. For the physical changes noticed by our participants, KARCY reported having more stamina, KARBE, KRYCO, and PAMOR reported losing weight and KARBE, KARCY, and SANFO reported more muscle tone. KARBE, KRYCO, and SANFO who previously expressed the fear of exercise being painful, also reported a decrease in their pain. SANFO said: "I maybe have a little more muscle tone and my back hurts less because my legs are more toned and my shoulders too. So it reflects less in my back. It's good for my scoliosis probably."

For the psychological changes, KARCY, KARBE and PAMOR noticed cognitive changes such as better focus, better organization skills and having a better memory. KARBE also noticed she was better suited to make decisions and to prioritize her tasks:

"[...] making decisions as well. Listen, there are a lot of things that happened in the last month, it's crazy! And I think it was easier for me to make decisions. You know, sometimes for me making decisions, it has always been hard. But sometimes the connection was made quicker. Ah yes, I should do that. [...] it helped me to... OK, what is important today? [...] And then I went step-by-step."

KARBE, KARCY and KRYCO noticed improvement in their mood. They reported finishing their sessions with a good mood and being less anxious. KARBE said: "It made me realize that I like being active because I always finished the sessions with a smile, you know. So I liked it sure."

Finally, KARBE, KRYCO and PAMOR noticed being more patient and less reactive to negative emotions. PAMOR said:

"Physical exercise made me less reactive. It causes fewer conflicts at home because fewer arguments for nothing, for little things that happen when I didn't exercise. It really bothered me, it really irritated me. With the sessions, I really noticed that even if it offended me, I didn't react in the same way. And that's the impact of the sessions I see in my daily life."

For the changes in general state, some participants noticed a change in their overall levels of energy. SANFO even noticed she slept better when she exercised:

"When I began the sessions, then I slept better you know. I got asleep more quickly. That was my big problem in general, but sometimes I happened to wake up during the night because of my digestion or nightmares. But at least, I got asleep so at least I didn't do sleep anxiety before going to bed anymore."

Although it was generally a positive thing, she also said it led her to impulsively take bad decisions:

"I don't think I had that much energy in my life, you know. Except after that, something happened. So I was so euphoric, you know, that I wanted to do a lot of things so I told myself, "My god, I feel well, my digestion is

good. Super!" I ate things I am a bit intolerant to, so it affected my digestion, and I was like "Ah, it's ok." And I also drank alcohol, more than I should have. So it unsettled me a bit."

3.5. Quantitative analyses

Visual analyses suggested that PE, as assessed by the SIMPAQ at each phase change, stayed relatively low throughout the study with an increase during phase B. Difficulties in emotion regulation decreased

throughout the study. Working alliance increased for all but two participants between the middle and the end of the intervention (more details are presented in Figures S7-S9 of the supplementary material).

3.5.1. Intraindividual analyses

Daily mean levels of positive and negative emotions (goal 3, hypotheses 2 and 3) for each participant are respectively presented in Figs. 2 and 3. Daily variability of positive and negative emotions (goal 3, hypotheses 4 and 5) for each participant are respectively presented in

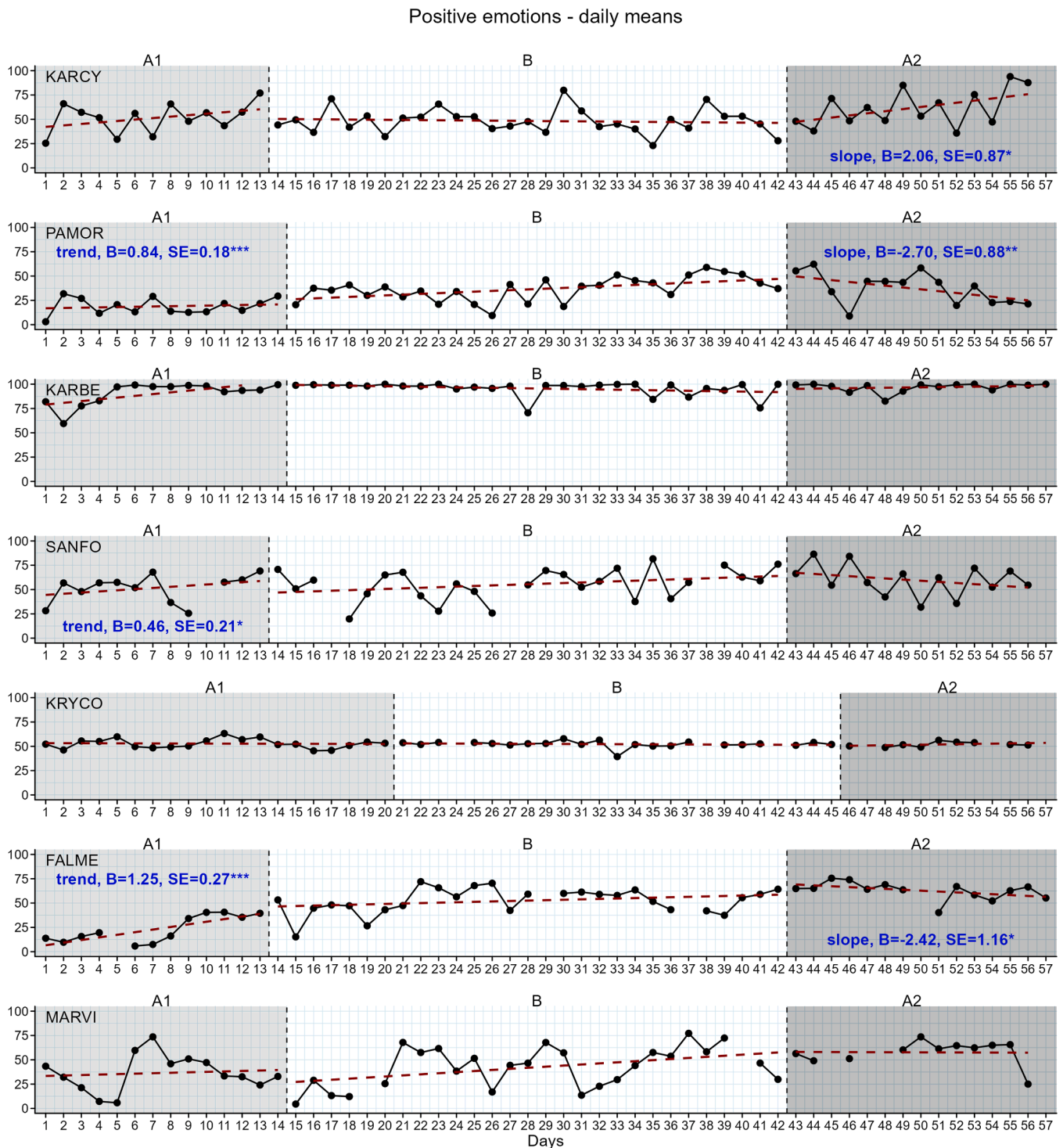


Fig. 2. Daily mean level of positive emotions by participant. Note: Dashed lines are phase trends; Blue text present statistically significant piecewise regression results; SE = Standard error; * $p < .05$; ** $p < .01$; *** $p < .001$.

Negative emotions - daily means

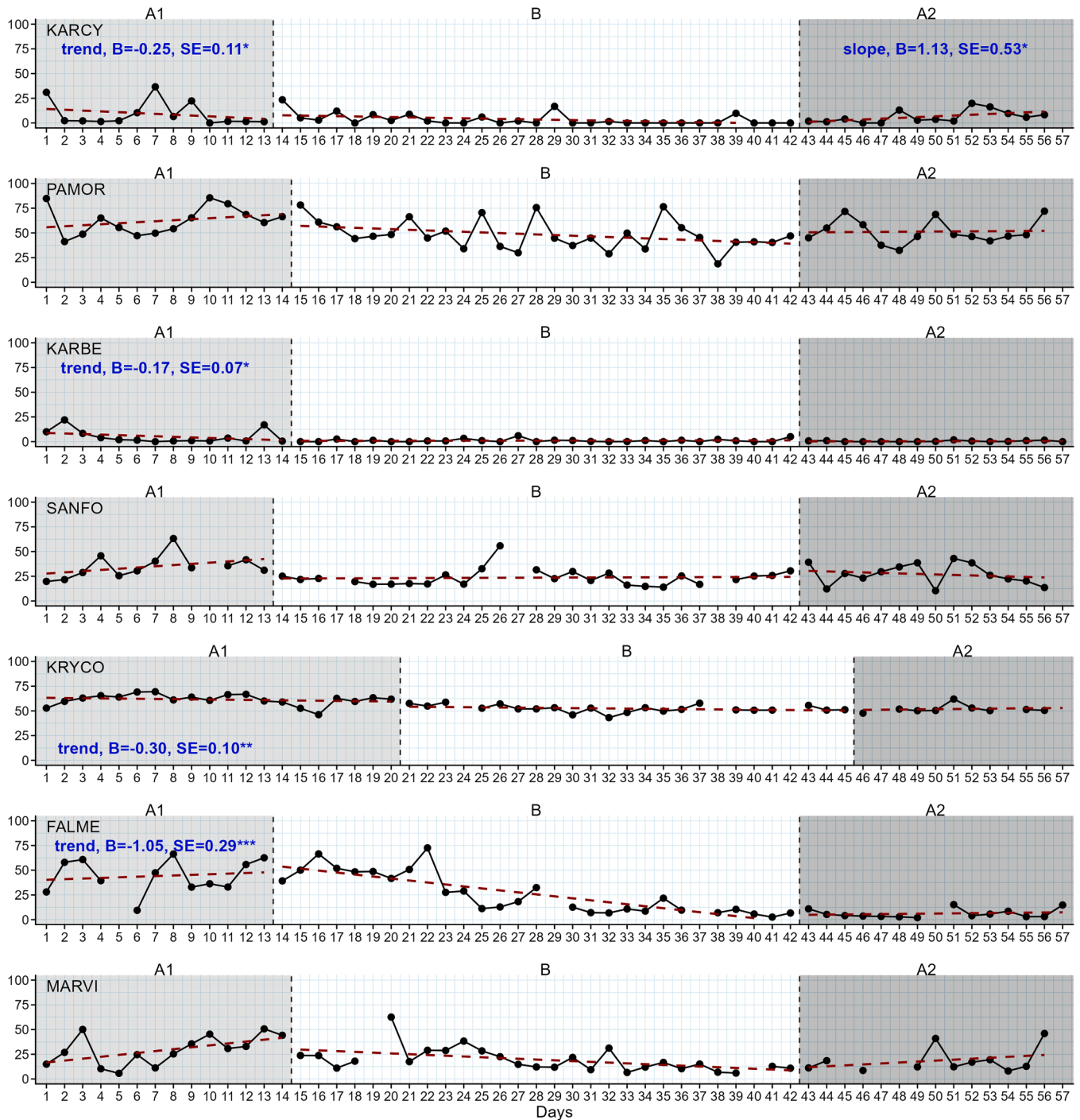


Fig. 3. Daily mean level of negative emotions by participant. Note: Dashed lines are phase trends; Blue text present statistically significant piecewise regression results; SE = Standard error; * $p < .05$; ** $p < .01$; *** $p < .001$.

Fig. 4 and 5. Daily sleep quality (goal 4, hypothesis 6) for KARCY, PAMOR, and KARBE are presented in Fig. 6. Sleep quality for the other participants (SANFO, KRYCO, FALME, and MARVI) included too many missing data, they were not analyzed and are therefore not represented.

Three participants presented an increase in positive emotions (goal 3, hypothesis 2) throughout the study with two of them presenting a decrease in the last phase (A2). Another participant presented an increase in positive emotions in the last phase (A2). Four participants presented a decrease in negative emotions (goal 3, hypothesis 3)

throughout the study with one of them presenting an increase in the last phase (A2). One participant presented an increase in positive emotions variability and one presented a decrease throughout the study (goal 3, hypothesis 4). Two participants presented a decrease in negative emotions variability throughout the study (goal 3, hypothesis 5). Finally, one participant presented an increase of sleep quality during the intervention phase (B; goal 4, hypothesis 6). Significant findings from piecewise linear regressions for daily mean positive emotions, daily mean negative emotions, daily variability of positive emotions, daily variability of

Variability of daily positive emotions

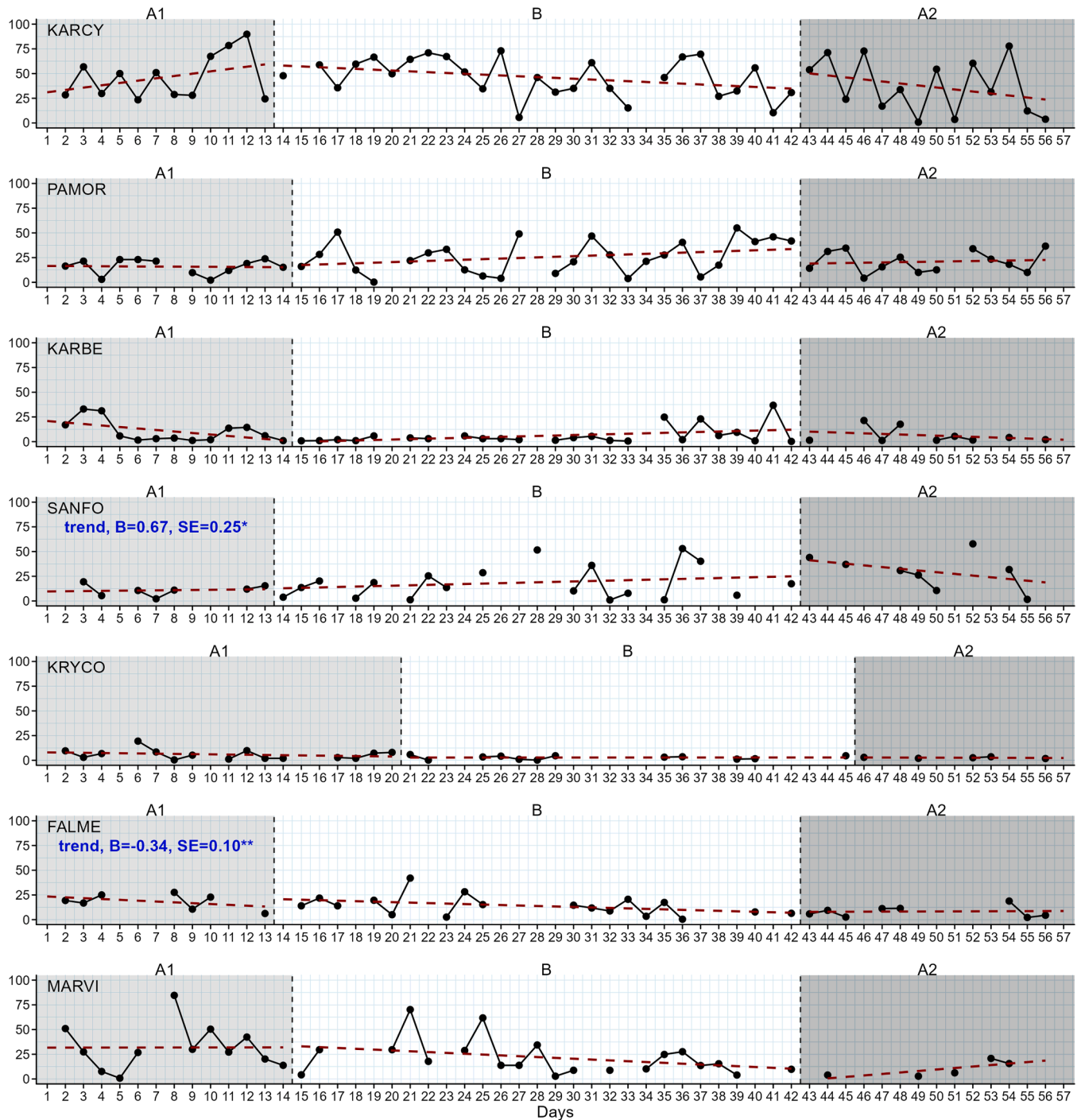


Fig. 4. Daily variability of positive emotions by participant.

Note: Dashed lines are phase trends; Blue text present statistically significant piecewise regression results; SE = Standard error; * $p < .05$; ** $p < .01$.

negative emotions, and sleep quality are included in their respective Figs. (2-6). Figures represented the pattern of dependent variables at intraindividual level.

3.5.2. Interindividual analyses

Multilevel piecewise linear regressions are significant for the trend of mean positive emotions $\beta = 0.44$ (SE = 0.08), $p < .001$ (goal 3, hypothesis 2); for the trend of the negative emotions $\beta = -0.32$ (SE = 0.07), $p < .001$ (goal 3, hypothesis 3); and the phase B slope of the

negative emotions $\beta = -0.24$ (SE = 0.10), $p < .05$ (goal 3, hypothesis 3). Details from piecewise linear regressions and multilevel piecewise linear regressions are also available in Table S9 in supplementary material.

4. Discussion

This study is the first to our knowledge to analyze the effect of regular PE on emotion regulation in adults with BPD. We hypothesized that PE (1) would be feasible and acceptable; that it would (2) increase the

Variability of daily negative emotions

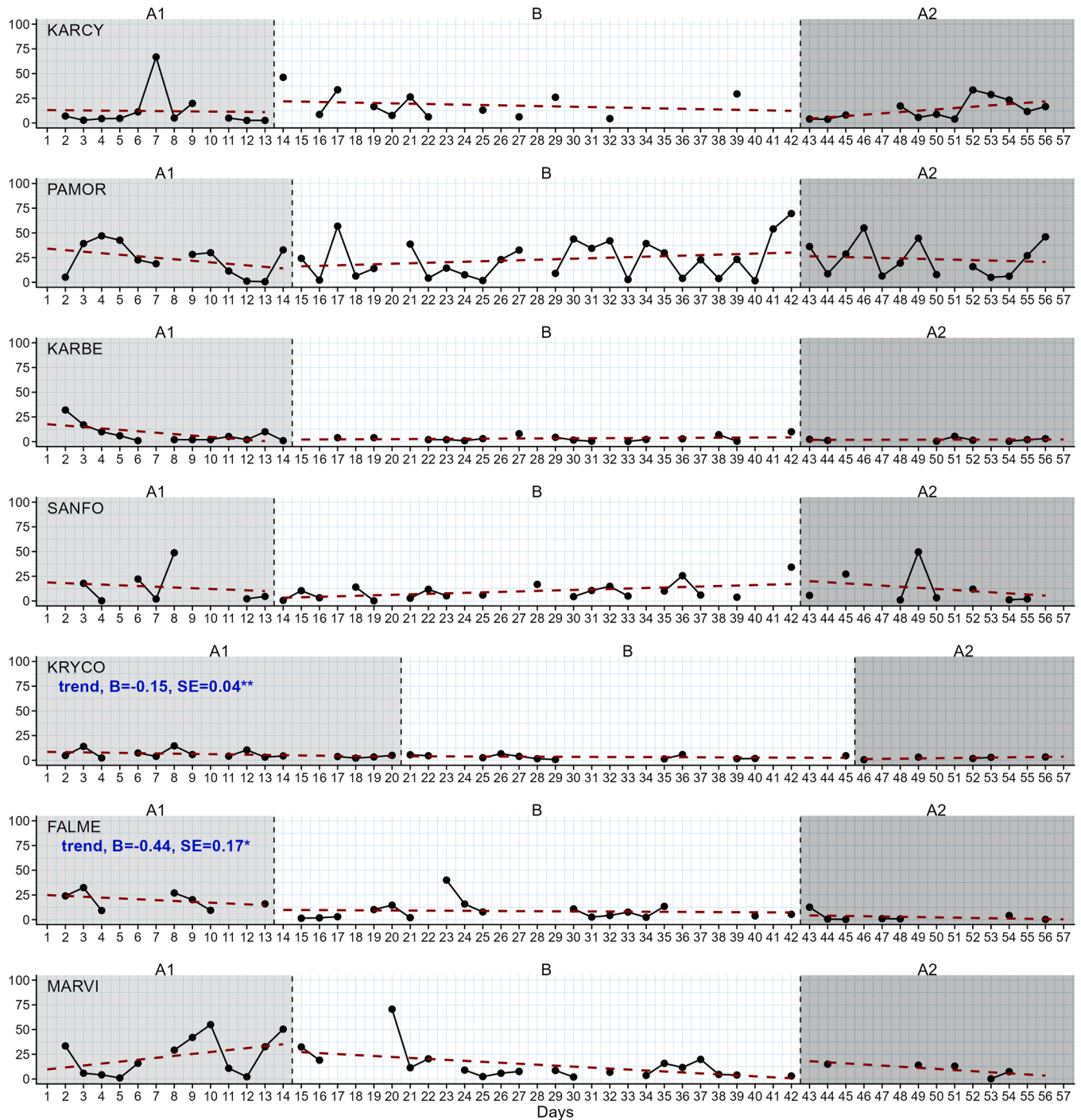


Fig. 5. Daily variability of negative emotions by participant.

Note: Dashed lines are phase trends; Blue text present statistically significant piecewise regression results; SE = Standard error; * $p < .05$; ** $p < .01$.

daily mean positive emotions, and (3) decrease the daily mean negative emotions and the daily variability of (4) positive and (5) negative emotions; and that it would (6) improve sleep quality. Our findings show that (1) it is feasible and acceptable; (2) it increases the daily mean of positive emotions; (3) it decreases the daily mean negative emotions; (4) it can both increase and decrease the variability of positive emotions in some individuals; (5) it decreases the variability of negative emotions in some individuals; and (6) it improves sleep quality in one participant and reportedly improves sleep quality in another. Moreover, the design

of our study provides a rich set of result allowing us a more in-depth analysis of the intervention.

Our results confirm our hypotheses with different levels of confidence. The acceptability of our intervention was strongly confirmed by the interviews and the adherence to the intervention. Furthermore, working alliance scores were relatively high during the intervention.

The main goal of conducting the qualitative portion of this research was to better understand the unique experience and the appreciation of the participants after completing the program (goal 1 and 2).

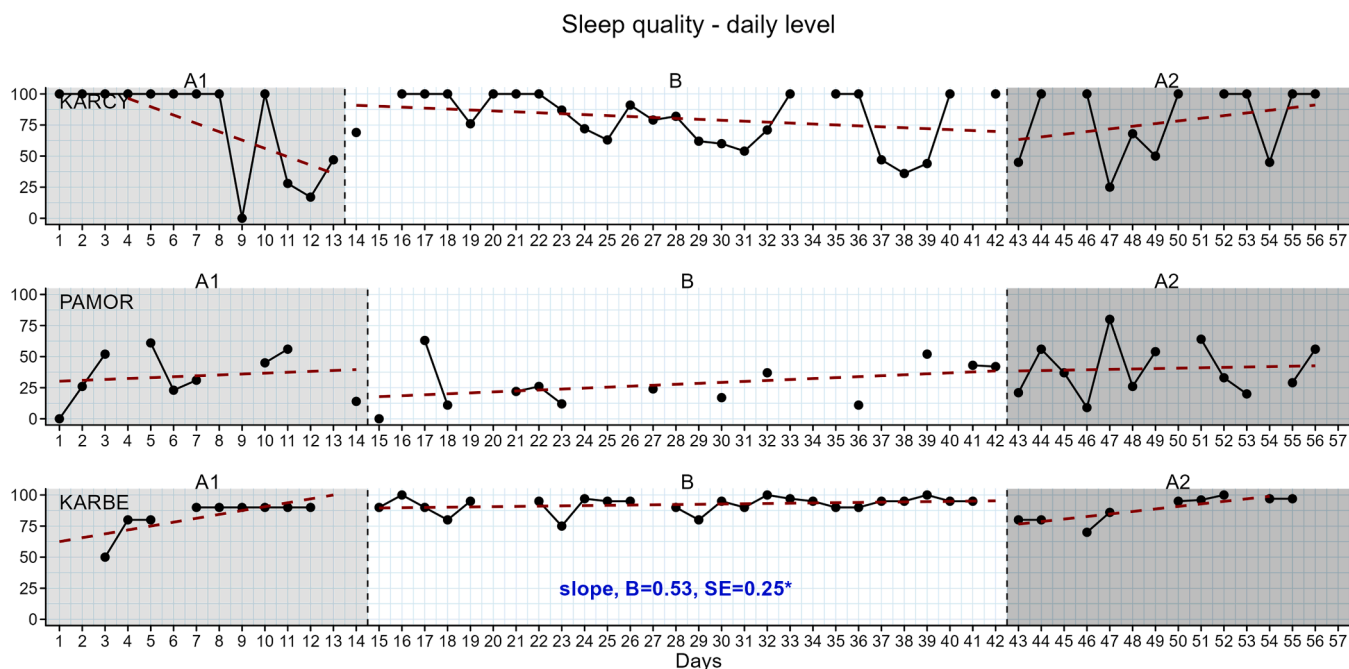


Fig. 6. Daily sleep quality by participant.

Note: Dashed lines are phase trends; Blue text present statistically significant piecewise regression results; SE = Standard error; * $p < .05$.

Regarding the appreciation of the program (goal 1), we see that the relationship with the trainer is very important to the participants. Having a positive relationship made the experience much more enjoyable. Trainers were seen as empathic, nice, and helpful, which made it easier to complete the program. This also echoes the previous online study (St-Amour et al., 2024). Indeed, results indicated that most adults with BPD preferred supervised sessions of PE by a trainer or PE specialist. Moreover, they reported a preference to exercise alone at moderate intensity and for a long single session rather than many little (St-Amour et al., 2024). The relationship and the support provided by professionals are also important in individuals with other mental illnesses. Indeed, it was found in numerous studies that the research or medical staff supervising or encouraging individuals in their PE participation had an important impact on participants adherence (Chen et al., 2017; Dobbins et al., 2020; Hassan et al., 2020; Mason & Holt, 2012; Rezaie et al., 2017; St-Amour et al., 2024).

Finally, the changes perceived by our participants gave us a more detailed view of what they experienced outside the scope of the quantitative instruments we used (goal 2). For example, the theme of patience and reduced reactivity expressed by most participants was not measured by any questionnaire or instrument we used. However, it is an important result since heightened reactivity to emotional stimuli is one of the components of the emotional dysregulation found in individuals with BPD (Crowell et al., 2009). Moreover, mood reactivity and intense anger are both diagnosis criteria for BPD (American Psychiatric Association, 2013). Therefore, having an effect on this reactivity could have significant clinical impact. Improvement in mental illness symptoms has also been noted in individuals with other diagnoses. It ranges from modifications or diminution in auditory hallucinations (Mason & Holt, 2012; Schebesch-Ruf et al., 2019) to an improvement in mood and a distraction from their symptoms (Alexandratos et al., 2012).

Regarding the quantitative results of this study (goal 3), both the increase in positive emotions (3/7 participants; hypothesis 2) and the decrease in negative emotions (4/7 participants; hypothesis 3) are partially supported at intra-individual level. At this moment, it is unclear which factor is associated with responsiveness to the intervention. One of the possible explanations for the absence of response from one participant (KARBE) is that she experienced significant negative

personal events during our study. It is therefore possible that these events limited the increase in positive emotions she could have got from the intervention.

At inter-individual level (goal 3), our exercise intervention increased the level of positive emotions as a continuous trend throughout the study (hypothesis 2). It also decreased the level of negative emotions as a continuous trend throughout the study and with a greater effect during the intervention phase (hypothesis 3). These results suggest that the effect of our intervention was delayed from its beginning and spilled over after the intervention ended.

The decrease in emotion variability (goal 3) was partially supported (2/7 participants) for negative emotions (hypothesis 4) but both partially supported (1/7 participant) and contradicted (1/7 participant) for positive emotions (hypothesis 5). Once again, it is still unclear what could explain those results. However, during the interviews, one participant (SANFO) reported feeling particularly euphoric, which led to some excess in food and alcohol consumption. This intense change in mood could have explained the increase rather than decrease of variability in positive emotions. It also suggests that some comorbid mood disorders (e.g., bipolar disorder) might explain this particular result. Indeed, a previous study analyzing the impact of PE on affective experiences in individuals with bipolar disorder found that they are particularly sensitive to an increase in positive affect following PE (Stanton et al., 2016). At the interindividual level, no effect of the intervention was found on the emotion variability.

Our results on mean daily levels of emotions (goal 3; hypotheses 2 and 3) are in line with those of previous studies demonstrating similar emotion dynamics with PE in adults both with and without emotion regulation difficulties (Bernstein et al., 2019; Bernstein & McNally, 2018). Indeed, in both studies, participants saw their negative emotions decrease and positive emotion increase when regularly active as shown by our interindividual analyses. However, our hypotheses on emotion variability are less supported by results (goal 3; hypotheses 4 and 5). Few participants showed statistically significant effect on emotion variability. This heterogeneity of results is again in line with results from previous studies where no effect of PE was found on emotion variability at interindividual level (Bernstein et al., 2019).

Finally, one participant had an increase in sleep quality during the

intervention phase (goal 4; hypothesis 6), and another reported a better sleep during the interview (goal 2), although it was not possible to quantitatively confirm what the latter reported due to missing data. There was also no effect found at the interindividual level. The absence of clear results for these analyses is surprising considering the extensive literature showing an effect of PE on sleep quality (Kredlow et al., 2015). However, Atoui et al. (2021) found that possible PE-related benefits on sleep quality were very heterogeneous in adults.

This study suffers from many limitations but possesses many strengths as well. The insights through the participants' experiences given by the qualitative part of this study help us understand the human experience behind the benefits of the program. Though rigorous, the nature of qualitative part makes it have certain limits. Mostly, because of the small size of the sample, it is hard to expand our results to other contexts. Also, having only the participants who completed the entire program makes the perceptions expressed in this article centred around one type of experience. Although those limits exist, choosing to complete a qualitative portion help us understand in more detail what part of the program works best and how we can change it in the future to make it even more efficient. Otherwise, only women were included. Therefore, the results cannot be generalized to men with BPD. Moreover, our EMA morning prompt was associated with a high level of non-response, preventing us from analyzing the effect on sleep quality in 4 participants. Since individuals with BPD are known for having sleep problems and to wake late, we could have adapted our prompt schedule accordingly. In addition, the selected thresholds and the small sample size might have produced biased results regarding feasibility and acceptability. Finally, the collection of information regarding impactful life events that could influence our result was not systematic nor active (e.g., calling participants during the study). Rather, it was a question in the biweekly online survey participants decided to answer or not. Therefore, we could lack information that can explain our results and some information we collected had ambiguous emotional value preventing us from using them in explaining observed effect (or the absence of). On the other hand, it is the first study analyzing the effect of regular PE in adults with BPD. With its SCED mixed method design, our results are rich and allow us an in-depth analysis of the many effects of PE in these individuals. Moreover, the EMA measurement gives us a detailed view of the emotion dynamic rather than a few data collected through questionnaires.

These results are really encouraging as they clearly show the feasibility, acceptability and the benefits from regular PE in adults with BPD. Therefore, medical professionals should encourage their patients in engaging in PE to help them cope with their emotions and reduce the negative emotions they live daily in addition to the other benefits they could get from it (e.g., improve cardiovascular health, decrease depression). Future research could replicate these results with randomized controlled trials and a greater and more diverse (e.g., including men and individuals with other gender identity) sample. Such studies should also pay a particular attention to emotional reactivity and try to quantitatively measure it as it seems to be an important effect in our sample.

5. Conclusion

In conclusion, this study suggests that supervised PE is feasible and acceptable in adults with BPD. In a 4-week intervention, it might also help reduce the level of negative emotions and increase positive emotions in these individuals. Many factors could influence the PE adherence rate such as the characteristics of the professional supervising exercise sessions and the diversity of exercises. Adults with BPD might also feel they are less reactive to irritating stimuli when they exercise regularly. It may therefore help them cope with daily stressors.

Declaration of competing interest

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

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.ajsep.2024.05.002](https://doi.org/10.1016/j.ajsep.2024.05.002).

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