Psychology & Health

ISSN: 0887-0446 (Print) 1476-8321 (Online) Journal homepage: www.tandfonline.com/journals/gpsh20

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To cite this article: Sascha Thal, Nikos Ntoumanis, Stephen Bright, Bronwyn Myers, Dominika Kwasnicka, Peter Verboon, James Clarke & Eleanor Quested (02 Jan 2026): A group motivational intervention to support motivation for physical activity among adults in residential treatment for substance use disorders: a series of N-of-1 studies, Psychology & Health, DOI: 10.1080/08870446.2025.2610270

To link to this article: https://doi.org/10.1080/08870446.2025.2610270

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A group motivational intervention to support motivation for physical activity among adults in residential treatment for substance use disorders: a series of N-of-1 studies

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ABSTRACT

Objective: Physical activity (PA) may offer health benefits for individuals undergoing substance use disorder (SUD) treatment, yet relapse, comorbidities, and motivational challenges often hinder PA maintenance. This study assessed the impact of a motivational intervention aimed at increasing PA motivation and maintenance in a residential SUD treatment setting.

Methods and Measures: This non-concurrent multiple-baseline N-of-1 study consisted of a six-week baseline and a ten-week intervention period. The study was conducted with 17 participants from a male-only residential SUD treatment facility in Perth, Australia. Seven participants provided sufficient data for statistical analysis. Participants received ten weekly sessions of a motivational face-to-face intervention. Daily data on PA motivation, substance use cravings, and affect were collected through ecological momentary assessments. Non-overlap methods and randomisation tests, and piecewise regression analyses were employed to assess changes in all variables between study phases.

Results: No changes in PA were observed across study phases. However, measures of affect improved, and self-reported craving decreased over time. Notably, the intervention enhanced autonomous motivation in some participants, although its effects on controlled motivation were mixed.

Conclusion: These findings suggest that the motivational intervention may enhance autonomous motivation. Future studies should involve larger samples and diverse SUD treatment settings.

ARTICLE HISTORY

Received 21 October 2024
Accepted 17 November 2025

KEYWORDS

Substance use disorders; physical activity; motivation; self-determination theory; behaviour change; N-of-1 study

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Introduction

Substance use disorders (SUDs) pose a major public health issue, with around 2.6% of the global population meeting the criteria for a 12-month SUD diagnosis (Degenhardt et al., 2017). In 2022–2023, approximately 1 in 200 Australians sought treatment for substance use issues (Australian Institute of Health & Welfare, 2024). Additionally, an estimated 1.6% to 2.9% of Australians require SUD treatment (Ritter et al., 2019). The chronic nature of SUDs (McLellan et al., 2000), high treatment attrition (Brorson et al., 2013), and the high prevalence of physical and psychological comorbidities (Ingram et al., 2023; Kingston et al., 2017; Wu & Blazer, 2014) contribute to the complexity and cost of effective treatment.

Regular physical activity (PA) may support various health aspects, including cardiovascular function, respiratory capacity, endurance, flexibility, neuromotor skills, and the maintenance of physical fitness in individuals with SUDs (Giesen et al., 2015; Hallgren et al., 2017). Nevertheless, the effects of PA interventions on substance use and psychological well-being in SUD treatment remain inconclusive. Some studies reported reductions in craving and substance use (Piché et al., 2023; Rensburg et al., 2009; Van Rensburg et al., 2013), psychological distress and symptoms of mental ill-health (Paluska & Schwenk, 2000; Saxena et al., 2005), along with improvements in quality of life, self-esteem, relapse prevention efficacy, perceived physical health, and psychological well-being (Furzer et al., 2021). Conversely, other studies report no significant changes in anxiety, depression, self-efficacy, or substance use behaviour (Colledge et al., 2018; Giménez-Meseguer et al., 2020; Linke & Ussher, 2015; Piché et al., 2023; Thal et al., 2023a; Thompson et al., 2020a). Generally, studies on PA in SUD treatment exhibit considerable heterogeneity and a significant risk of bias (Piché et al., 2023; Thal et al., 2023a; Thompson et al., 2020b).

The efficacy of PA interventions in SUD populations may be improved by identifying and describing observable and replicable single active components or techniques that modify behaviour, i.e. behaviour change techniques (BCTs; Marques et al., 2023). However, there is limited knowledge about which BCTs are effective for maintaining PA among people with SUDs. A recent review (Thal et al., 2023a) identified *instruction on how to perform the behaviour, social support (unspecified), behavioural practice/rehearsal, problem-solving, pharmacological support, goal setting (behaviour), self-monitoring (behaviour),* and *biofeedback* as the most frequently used promising BCTs in PA interventions for SUD populations. Some of these BCTs overlap with those identified in a review of PA-focused interventions for young people at risk of problematic substance use (Klamert et al., 2023). Notably, none of the included studies provided evidence of long-term PA maintenance (Thal et al., 2023a). A known barrier to long-term PA maintenance in this population is the loss of motivation for PA (Abrantes & Blevins, 2019). None of the studies reviewed by Thal et al. (2023a) specifically targeted the development and sustainment of PA motivation, limiting the potential of these interventions to support long-term PA maintenance.

Motivational Interviewing (MI) is a psychotherapeutic intervention known to effectively increase motivation for behaviour change (Miller & Rollnick, 2023). Preliminary evidence suggests that group-based MI can improve treatment attendance and

engagement (Lincour et al., 2002), participation in aftercare (Santa Ana et al., 2007), problem awareness (Beadnell et al., 2012; Murphy et al., 2002), and readiness to change and self-efficacy (Mendel & Hipkins, 2002; Schmiege et al., 2009). Nearly half of the 16 out of the 38 techniques used in MI (Hardcastle et al., 2017) match BCTs as defined by Michie et al. (2013). However, these BCTs have rarely been applied in PA interventions for SUD populations (Thal et al., 2023a).

Self-Determination Theory (SDT; Ryan & Deci, 2017) also provides an instrumental framework to examine motivated behaviour in the contexts of SUD and PA. A conceptual overlap between SDT and MI has been identified, with both emphasising the intrinsic drive for psychological integration and growth (Patrick & Williams, 2012). In SDT, motivation exists on a continuum, where an individual's motivation can shift from more controlled forms (i.e. amotivation: lack of drive to engage in any behaviour; external motivation: behaviour driven by external rewards; introjected motivation: behaviour driven by a sense of obligation) to more autonomous forms (i.e. identified motivation: behaviour aligned with personal values and goals; integrated motivation: behaviour aligned with one's self-concept; intrinsic motivation: behaviour perceived as interesting or enjoyable) and vice versa. High levels of autonomous motivation are associated with long-term maintenance of health behaviour change, including PA (Ntoumanis et al., 2021; Teixeira et al., 2012). Importantly, many individuals in SUD treatment engage in PA because it is prescribed rather than self-endorsed; such externally driven participation reflects controlled rather than autonomous motivation and is unlikely to sustain long-term PA engagement after discharge.

Current study

We co-designed a motivational group intervention based on MI, SDT principles and effective BCTs. The aim was to increase participants' quality of PA motivation (i.e. promoting a shift in motivation regulation from controlled to autonomous) to foster participants' PA maintenance after SUD treatment completion (Thal et al., 2025a). In this study, we examined the effects of the intervention on trajectories of PA motivation (primary outcome), as well as craving for substance use, affect, and PA levels (secondary outcomes) over a 120-day period among residents of a SUD treatment facility in Western Australia (WA). Given that treatment-as-usual (TAU) at the facility already provides a structured, high-dose PA program (see Methods: Context), we did not anticipate observable increases in participants' PA levels throughout the intervention period. Instead, the intervention focused on enhancing the quality of motivation for PA, aiming to foster more autonomous regulation as a foundation for sustaining PA after treatment. Finally, we evaluated the feasibility and acceptability of the trial and the intervention to gauge its potential for wider application across multiple SUD facilities. Given our focus on individual responses to the motivational intervention over time, we chose to implement an N-of-1 study design. Thereby, we hypothesised that:

1. During the intervention period, when compared to baseline,

    a. autonomous motivation (i.e., identified regulation, intrinsic regulation) and positive affect will significantly increase

b. controlled motivation (i.e., amotivation, external regulation, introjected regulation), craving for substance use, and negative affect will significantly decrease
c. there will be no significant changes in PA levels

2. during the maintenance phase

a. The scores on quality of PA motivation, positive and negative affect, and craving for substance use will not change significantly over the 12-week period

Methods

Study design

We employed a non-concurrent multiple-baseline N-of-1 ABC intervention withdrawal design (McDonald et al., 2017). The design accommodated rolling admissions by permitting variable baseline durations, reflecting pragmatic adaptation to the operational realities of SUD treatment settings. Participants commenced the study on admission to the residential program. The baseline phase (A) was pre-specified to last a minimum of two and up to six weeks, with length determined by bed availability. Afterwards, the 10-week intervention phase (B) was introduced, followed by a 12-week maintenance phase (C) for participants who completed their treatment. Data were collected during all three assessment periods (see Figure 1). Participants received a motivational intervention consisting of ten weekly sessions as an adjunct to TAU. Two booster sessions were integrated into the continued care program that residents received after discharge from the treatment facility. We collected daily data on motivation, craving, and affect through ecological momentary assessment (EMA) surveys. Wireless activity monitors (Fitbit™) were used to measure PA (i.e. steps and active minutes). Results are reported according to *The Single-Case Reporting Guideline In BEhavioural Interventions (SCRIBE) 2016 Checklist* (Tate et al., 2016).

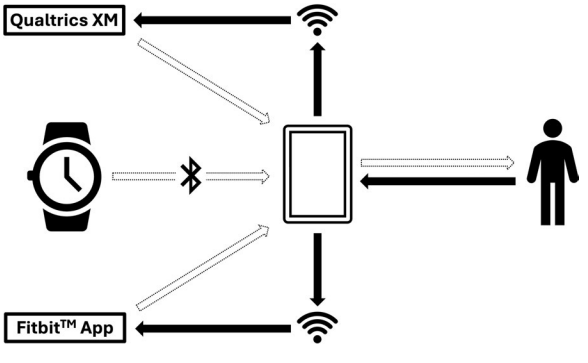


Figure 1. Set up for EMA surveys and physical activity data collection.
Note. Each participant was provided with a Fitbit and an iPad, on which individual EMA surveys were created using Qualtrics. The Qualtrics app and the Fitbit app were pre-installed on the iPads, with the Fitbit devices connected to the iPads via Bluetooth. Participants completed the EMA surveys on the iPads each evening. At that time, the Fitbit automatically synced its activity data with the iPad through the Bluetooth connection. The iPads, connected to the internet, then automatically uploaded both the EMA survey responses and the physical activity data daily. Dotted arrows in the figure represent the Bluetooth connections between devices, while solid black arrows illustrate the flow of data from devices to the cloud.

A study protocol was published on Open Science Framework before the start of the data collection (https://osf.io/jmr38). Several protocol changes were necessary during the study. The first two intervention sessions were conducted in the first week of the intervention phase due to a significant number of participants being affected by the coronavirus, which delayed the start of the intervention phase and extended the baseline phase by one week. Additionally, only one participant entered continued care and thus the maintenance phase during our observation period. As a result, we concluded data collection after 17 wk, instead of the initially planned 28 wk. We also collected data from residents who began treatment at the facility during the intervention phase, despite the original protocol stating that data would only be collected from participants with at least two weeks of baseline data. This adjustment was made at the request of the facility to foster inclusivity and allow all interested residents to participate in the study. Further, a personal trainer (PT) with lived experience in SUD treatment participated in six of the nine group motivational intervention sessions, rather than the two sessions originally outlined in the intervention plan (Thal et al., 2023b). This adjustment was made because a staff member from the treatment facility was required to be present during the group sessions, and the PT also led the group physical activity sessions following the group motivational sessions.

Participants

All residents who were in treatment during the study period were offered the opportunity to participate in the intervention adjunct to their TAU. They were eligible for the study if they had medical clearance for PA (obtained during admission) and provided informed consent.

Individuals are eligible for treatment at this facility if they have a diagnosis of SUD according to the *Diagnostic and Statistical Manual of Mental Disorders* 5th ed., text rev. (DSM-5 TR; American Psychiatric Association, 2022) criteria, are male, and are ≥18 years old. Individuals with comorbid untreated serious mental illness and/or acute symptom relapse within the past three months are not admitted to the treatment facility. More detailed treatment exclusion criteria are outlined in the study protocol (Thal et al., 2023b).

Context

All participants underwent inpatient treatment at a treatment facility in Perth, WA. The facility offers treatment to men in recovery from long-term issues related to substance use and comorbid mental health conditions. The residential treatment period spans six months, followed by a twelve-month outpatient continued care program.

A structured PA program is a key component of TAU at the treatment facility. Weekly PAs included a 30-minute group morning walk four days a week, and weekly 60-minute boxercise group sessions, 60-minute bootcamp group sessions, and 60-minute group yoga sessions. Additional components of TAU include individual and group counselling, support work, involvement in 12-step groups, psychoeducation groups, mindfulness groups, and equine therapy.

Approvals

The study was approved by the Human Research Ethics Committee of Curtin University (HRE2023-0544) and was registered with the Australian New Zealand Clinical Trials Registry (ACTRN12623001261606) prior to recruitment of the first participant.

Prior to baseline data collection, residents had the opportunity to hear about the study from the researchers, discuss their participation, and complete informed consent forms. Newly admitted residents were given the opportunity to opt into the study at any time.

Measures and materials

Sample characteristics

Demographics. Participants provided demographic information, including their age, gender, ethnicity, and relationship status.

Pre-Treatment physical activity. The 16-item Global Physical Activity Questionnaire (GAPQ; Armstrong & Bull, 2006; Bull et al., 2009) was used to collect data on participants' pre-treatment daily PA in three settings (i.e. activity at work, travel to and from places, recreational activities), as well as time spent sedentary each day in a typical seven-day period. The questionnaire comprises 16 items and is well validated (Bull et al., 2009).

Substance use history. Participants were asked to select from a list the substances they have used regularly (i.e. on a weekly basis) before they started treatment.

Ecological momentary assessment

Motivation for physical activity. An adaptation of the 6-item version of the Behavioural Regulation in Exercise Questionnaire 3 (BREQ3; Wilson et al., 2006)—the BREQ3-6 (Rocchi et al., 2023), was used to measure motivation for PA. The BREQ3-6 includes one item per construct aligned with the Self-Determination Theory (SDT; Ryan & Deci, 2017) continuum. We excluded the integrated subscale item ("I consider physical activity a fundamental part of who I am") as it was anticipated that this item would not yield much daily variation. For each item, participants indicated the extent to which each statement reflected their reason to engage in physical activity on that day.

Affect. Participants responded to six items tapping positive and negative affect in the past day. These items have proven feasible for EMA of affective states in depression-prone and control samples (Seidman et al., 2022). Each item followed the stem: "During the past day, how strongly did you feel…?". The listed emotions included four negative emotions (sad/blue, nervous/anxious, irritable, and angry) and two positive emotions (happy, satisfied) from the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988). For the subscale analysis, mean scores were computed by aggregating the relevant items for positive and negative affect.

Craving. The 3-item Craving Scale (Weiss et al., 1995) was used to measure daily craving for substance use. The total craving score was calculated as the average of the three items. The scale is well-validated across SUDs (McHugh et al., 2021).

Physical activity measure. *The PA variables used for analysis were daily step count and active minutes measured by Fitbit™ wireless activity monitors. In addition, participants' attendance at the group exercise sessions run by the facility were recorded by the instructors.*

Trial and intervention feasibility and acceptability. We collected study process data including the number of people who agreed to participate in the study, those who consented, and those who participated in the intervention sessions. At the end of the intervention phase, participants who remained in treatment at this time were asked to complete a 7-item measure of the feasibility and acceptability of the intervention (Kwasnicka et al., 2022) on a 7-point scale (1 = *strongly disagree*, 7 = *strongly agree*).

Intervention

The intervention was based on MI (Miller & Rollnick, 2013) and SDT (Ryan & Deci, 2017) principles and employed an adapted MI protocol for group settings (Wagner & Ingersoll, 2013). It was co-designed with consumers and stakeholders associated with SUD treatment centres in Western Australia (Thal et al., 2025a). The intervention followed a structured progression from engagement to action and maintenance. Early sessions (Weeks 1–3) focused on building rapport, exploring personal values and reasons for being active, and identifying initial goals. Mid-phase sessions (Weeks 4–8) addressed ambivalence, strengths, and future visioning, linking participants' values and identities to more autonomous motives for PA. Later sessions (Weeks 9–10) emphasised planning and commitment, using SMART goals and strategies for overcoming setbacks. Two individual booster sessions during continued care (Weeks 11–12) reviewed progress, adapted plans, and reinforced self-monitoring and problem-solving skills. Across all sessions, core MI processes (engaging, exploring perspectives, broadening perspectives, moving into action) and recurring BCTs such as social support, goal setting, and action planning were used to strengthen internalisation of motivation for sustained PA engagement. An autonomy-supportive communication style (asking permission, offering choice, acknowledging ambivalence), competence support (scaffolded planning, graded tasks, feedback *via* self-monitoring), and relatedness support (empathic group climate, peer input) were implemented across all session (see Thal et al., 2024). The intervention description according to the Template for Intervention Description and Replication (TIDieR) checklist (Hoffmann et al., 2014) can be found in Appendix A and detailed outline of individual intervention sessions can be found in Appendix B.

Data collection

After consenting to participate in the study, participants completed a survey on iPads that covered demographics, pre-treatment PA, and substance use history. Subsequently, they were given wireless activity monitors (Fitbit™) and iPads for completing the EMA

survey in the evenings. Participants were instructed to wear the activity monitor on their wrists daily, from the time they got out of bed in the morning until they returned to bed at night, and to charge the devices overnight. EMA surveys, which assessed daily emotions, cravings, and motivation, were completed each evening using iPads and the Qualtrics app (see Figure 1). Facility staff supervised this process, then stored the devices in a locked filing cabinet. At the end of the intervention phase, participants completed measures of feasibility and acceptability. During the maintenance phase, participants received daily messages with survey links on their mobile phones.

Sample size

The required number of observations were based on simulations with 5,000 replications in four respective conditions: (1) $\alpha = 10\%$, auto-correlation = .50, (2) $\alpha = 5\%$, auto-correlation = .50, (3) $\alpha = 10\%$, auto-correlation = .10, (4) $\alpha = 5\%$, auto-correlation = .10. With assumptions of large auto-correlation (.50), 130 observations were necessary to have 80% power for an ES of .40, with a 5% Type I error.

Analysis

Descriptive data for demographics and pre-treatment PA and substance use were provided for the entire sample. Each participant's data was treated as a distinct dataset and analysed individually. A complete analysis was conducted for the seven participants who provided data for the baseline and intervention phases. Data from the remaining participants were only used to calculate the average PA for both study phases. First, trajectories of all variables across participants and study phases were plotted and visually inspected. Non-overlap methods (Manolov et al., 2016) were used to assess the degree to which observations from the intervention and the maintenance phases showed changes in autonomous motivation and positive affect (Hypotheses 1a/2a), controlled motivation, craving for substance use, and negative affect (Hypotheses 1b/2a), compared to the baseline phase.

Second, randomisation tests (Edginton & Onghena, 2007; Kratochwill & Levin, 2010) were applied for the non-overlap methods to obtain randomisation distributions (non-overlap percentages) and p-values. These allowed us to determine whether the observed differences between study phases for the variables mentioned above were statistically significant. For the plotting, non-overlap methods, and the randomisation tests, we used the 'scda' R-package (Verboon & Peters, 2024).

Eventually, a piecewise regression model was used to model linear trends and to explore non-linear trends for the different phases of the intervention and to provide confidence bands (Huitema & Mckean, 2000; Verboon & Peters, 2020). The piecewise regression model was also used to assess changes in PA between baseline and intervention phases (Hypothesis 1c). Descriptive statistics were used to report feasibility and acceptability measures.

Analysis amendments

As originally outlined in our study protocol (Thal et al., 2023b), we planned to impute missing data. However, due to the high adherence in the completion of EMA surveys

and the collection of PA data from those who remained in the study, we concluded that imputation was not necessary. Furthermore, we originally intended to use non-overlap methods and randomisation tests for Hypothesis 1c but ultimately chose not to rely on p-values for testing a null effect (Lakens, 2017).

Results

Recruitment and participant flow

In total, 17 residents were recruited for the study. Twelve participants (#1-12) commenced at the baseline phase, while five (#13-17) joined during the intervention phase. One participant (#15) withdrew during recruitment, resulting in data collection from 16 participants. Seven participants (#2,3,4,5,7,8,9) provided data for both baseline and intervention phases, making them eligible for inclusion in the hypothesis testing analyses. Only one participant (#3) transitioned to continued care and provided maintenance data (see Figure 2).

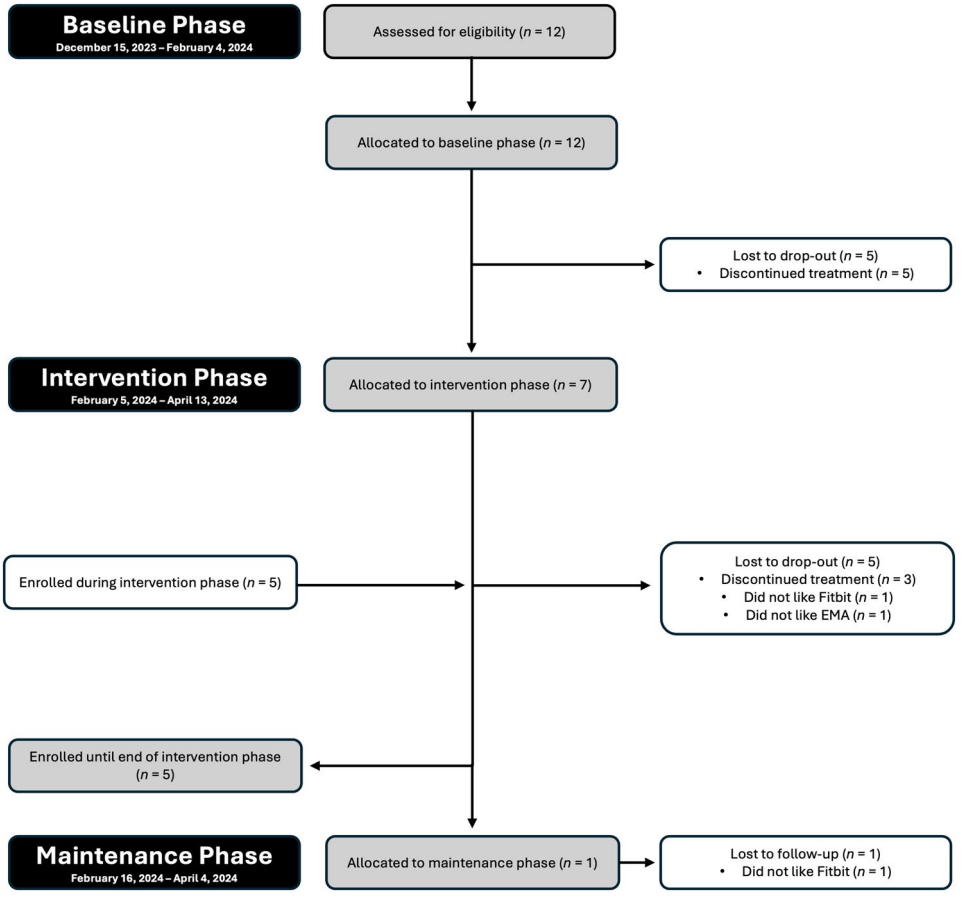


Figure 2. Participant Flow.
Note. Recruitment and baseline data collection commenced on December 15, 2023, and ended on February 4, 2024. The intervention phase started on February 5, 2024, and ended on April 13, 2024. Only one participant entered continued care and thus the maintenance phase (on Feburary16, 2024) during our observation period. Data collection was concluded after 17 weeks, on April 13, 2024.

Baseline data

Demographic information was not provided by one participant (#15). The remaining participants were all male, with a mean age of 39.19 years ($SD = 8.11$). Alcohol (65%) was the most used substance, followed by nicotine (59%), (meth-)amphetamines (53%), and cannabis (41%). Thirteen participants reported poly-substance use of up to eight substances ($Mdn = 3.5$, $M = 3.13$, $SD = 2.22$; see Table 1). Participants' pre-treatment PA differed greatly, with a mean of 823.64 ($SD = 1542.32$) minutes of vigorous intensity physical activity, a mean of 1322.27 ($SD = 1083.19$) minutes of moderate intensity physical activity, and a mean of 2091.82 ($SD = 2338.46$) minutes spent sedentary (see Appendix C).

Study and program attendance

On average, participants remained in the study for 58.18 ($SD = 43.69$) days. Eleven participants (65%) discontinued the study prematurely, with eight (47%) withdrawing due to discontinuing treatment, which automatically ended their study participation. The response rate on the daily EMA surveys was high: 91.76% ($SD = 5.98$). This figure was calculated only for participants who remained in the study, as those who discontinued treatment were no longer prompted to complete EMA surveys and were therefore excluded from the denominator. Participants attended 83.19% ($SD = 20.88$)

Table 1. Demographic information.

	All participants			Participants B&I&F		
Sample Characteristics	*N (%)*	*M*	*SD*	*n (%)*	*M*	*SD*
Age	16 (94.1%)	39.19	8.11	7 (41.2%)	40.29	9.45
Gender						
Male	16 (94.1%)			7 (41.2%)		
Ethnicity						
Aboriginal	1 (5.9%)			1 (5.9%)		
African	1 (5.9%)			1 (5.9%)		
Caucasian	11 (64.7%)			4 (23.5%)		
Latino or Hispanic	1 (5.9%)			0 (0%)		
Other	2 (11.8%)			1 (5.9%)		
Relationship						
Yes	6 (35.3%)			2 (11.8%)		
No	9 (52.9%)			5 (29.4%)		
Prefer not to say	1 (5.9%)			0 (0%)		
Substance Use						
Alcohol	11 (64.7%)			6 (35.3%)		
Benzodiazepines	3 (17.6%)			1 (5.9%)		
Cannabis	7 (41.2%)			4 (23.5%)		
Cocaine	1 (5.9%)			0 (0%)		
Ecstasy/MDMA	2 (11.8%)			0 (0%)		
Heroin	1 (5.9%)			1 (5.9%)		
Nicotine	10 (58.8%)			6 (35.3%)		
(Meth-)Amphetamines	9 (52.9%)			4 (23.5%)		
Painkillers/Opioids	5 (29.4%)			2 (11.8%)		
Psychedelics	1 (5.9%)			0 (0%)		
Prefer not to say	1 (5.9%)			0 (0%)		
None	1 (5.9%)			1 (5.9%)		

Note. $n = 17$ residents participated in the study. Data from one participant is missing. Participants B&I&F = Participants who contributed data during both the baseline and intervention phases, as well as the one participant who provided maintenance data.

Table 2. Feasibility and acceptability data.

Question	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
The motivational program was a worthwhile investment of time for me.	0	0	0	1	0	2	7
The motivational program was beneficial for me.	0	0	0	1	0	4	5
I enjoyed the motivational program.	0	0	0	1	2	2	5
The program helped me to feel confident to use what we learnt to be regularly physically active.	0	0	1	1	0	3	5
The program sufficiently prepared me to be regularly physically active.	0	1	0	2	2	1	4
The program sufficiently prepared me to maintain my physical activity.	0	0	1	1	2	3	3
The program met my expectations.	0	1	0	0	1	5	3

Note. Data from $n = 10$ participants who were in the treatment facility at the end of the intervention phase.

of the motivational sessions during the time they remained in treatment (see Appendix D for more detailed attendance data).

Intervention feasibility and acceptability

The feasibility and acceptability survey indicated that most participants (9/10; 90%) believed that the intervention was a valuable use of their time and that the motivational program was beneficial. They felt that the program met their expectations and left them confident in their ability to apply what they learned to engage in regular PA (8/10; 80%). More than two-thirds (7/10; 70%) enjoyed the program, and more than half (6/10; 60%) thought it prepared them adequately to sustain their PA. However, only half (5/10; 50%) of the participants believed that the program provided sufficient preparation for regular PA engagement (see Table 2).

Physical activity

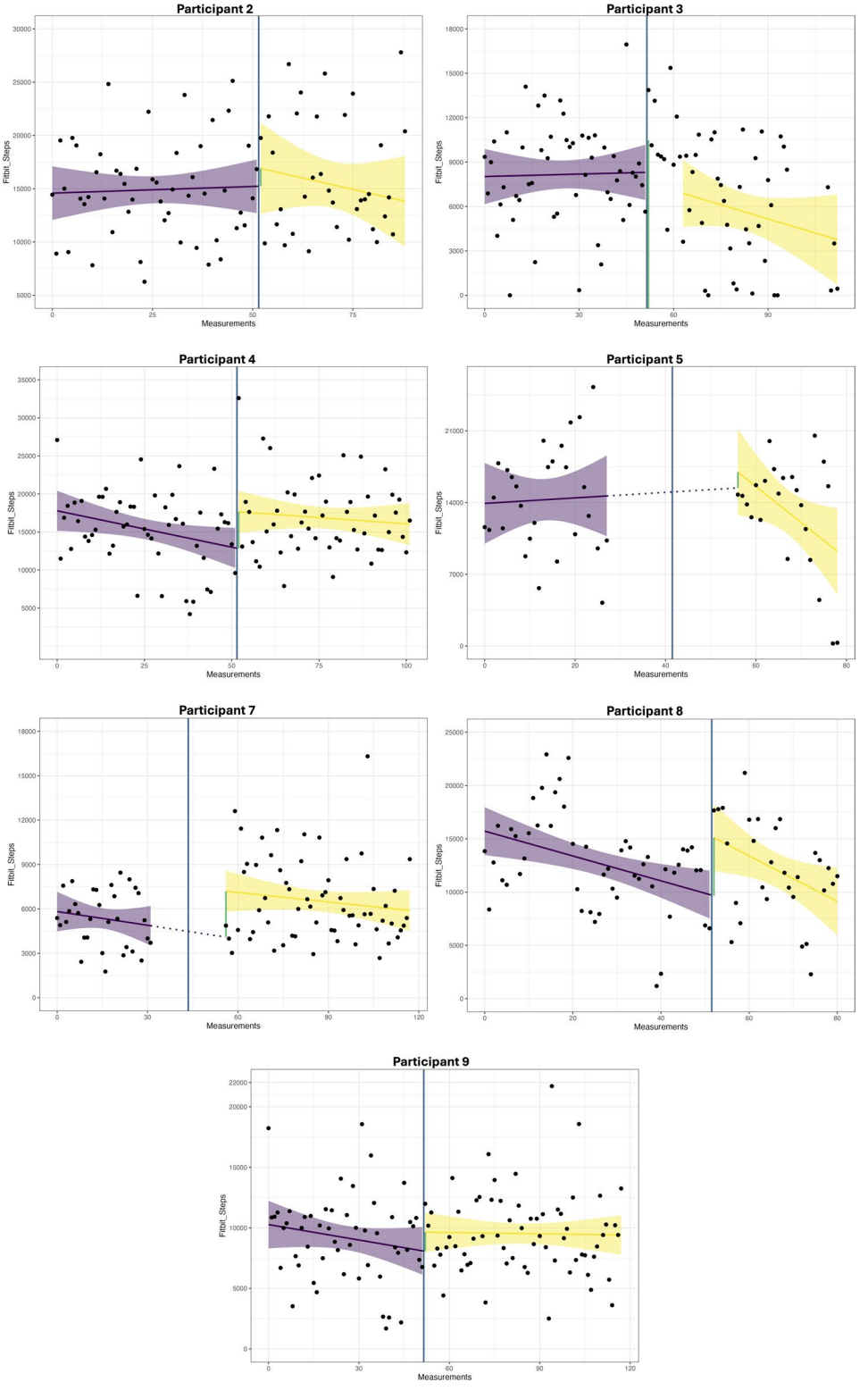
Participants were very active, with average daily step counts ranging between 4,800 and 23,400 steps and daily active minutes ranging between 26 and 228 min across study periods (see Figures 3 and 4). Average step counts and active minutes for individual participants can be found in Appendices E and F, respectively.

Hypotheses testing

We used non-overlap methods and randomisation tests to test our hypotheses. The results of these tests are detailed in Appendix G.

Autonomous motivation

Findings provided partial support for our Hypothesis 1a. Non-overlap methods and randomisation tests showed a significant increase in intrinsic regulation between baseline and intervention phases for participants #7 ($PEM = 0.491$, $p = 0.01$; $NAP = 0.51$, $p = 0.01$) and


Participant 2
Participant 3
Participant 4
Participant 5
Participant 7
Participant 8
Participant 9
Fitbit_Steps
Measurements

participant #9 (*PEM* = 0.927, $p = 0.01$; *NAP* = 0.772, $p = 0.01$; *IRD* = 0.475, $p = 0.05$). Piecewise regression analyses supported these findings for both participant #7 and participant #9 (see Figure 5) and further showed significant increases in identified regulation between the baseline and the intervention phase for participant #2, participant #5, and participant #7 (see Figure 6). However, piecewise regression analyses showed significant decreases of intrinsic motivation and identified motivation for participant #4.

Controlled motivation

Findings did not provide support for Hypothesis 1b. The observed differences in trajectories for controlled motivation were non-significant for most participants. Contrary to our prediction, non-overlap methods and randomisation tests showed a significant increase in introjected regulation between baseline and intervention phases for participant #9 (*PEM* = 0.982, $p = 0.09$; *NAP* = 0.846, $p = 0.02$, *IRD* = 0.636, $p = 0.02$). Similarly, the piecewise regression analysis indicated significant increases between baseline and intervention phases in introjected regulation (see Figure 7) for participant #7, participant #8, and participant #9, in external regulation (see Figure 8) for participant #2, participant #5, participant #7, participant #8, and participant #9, and in amotivation regulation (see Figure 9) for participant #5 and participant #7.

Affect and craving

Non-overlap methods and randomisation tests do not provide support for Hypothesis 1b. Piecewise regression analyses were non-significant but indicated that, for most participants, positive affect increased, and negative affect decreased during the baseline phase. This pattern continued during the intervention phase (see Figure 10 and Figure 11). However, this trend is inverted for participant #5 and participant #8. Similarly, most participants reported a reduction in craving during the baseline phase with a non-significant difference between baseline and intervention phases (see Figure 12).

Physical activity

Consistent with our hypothesis 1c, the observed differences in trajectories for step counts and active minutes for most participants were non-significant (see Figures 3 and 4). However, piecewise regression analyses showed significant increases of step counts between baseline and intervention phases for participant #4 and participant #8. Participant #8 also showed a significant increase in active minutes between baseline and intervention phases.

Motivation, craving and affect maintenance

The findings supported Hypothesis 2, as non-overlap methods and randomisation tests revealed no significant differences in the quality of PA motivation, positive and

Figure 3. Step Counts.
Note. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

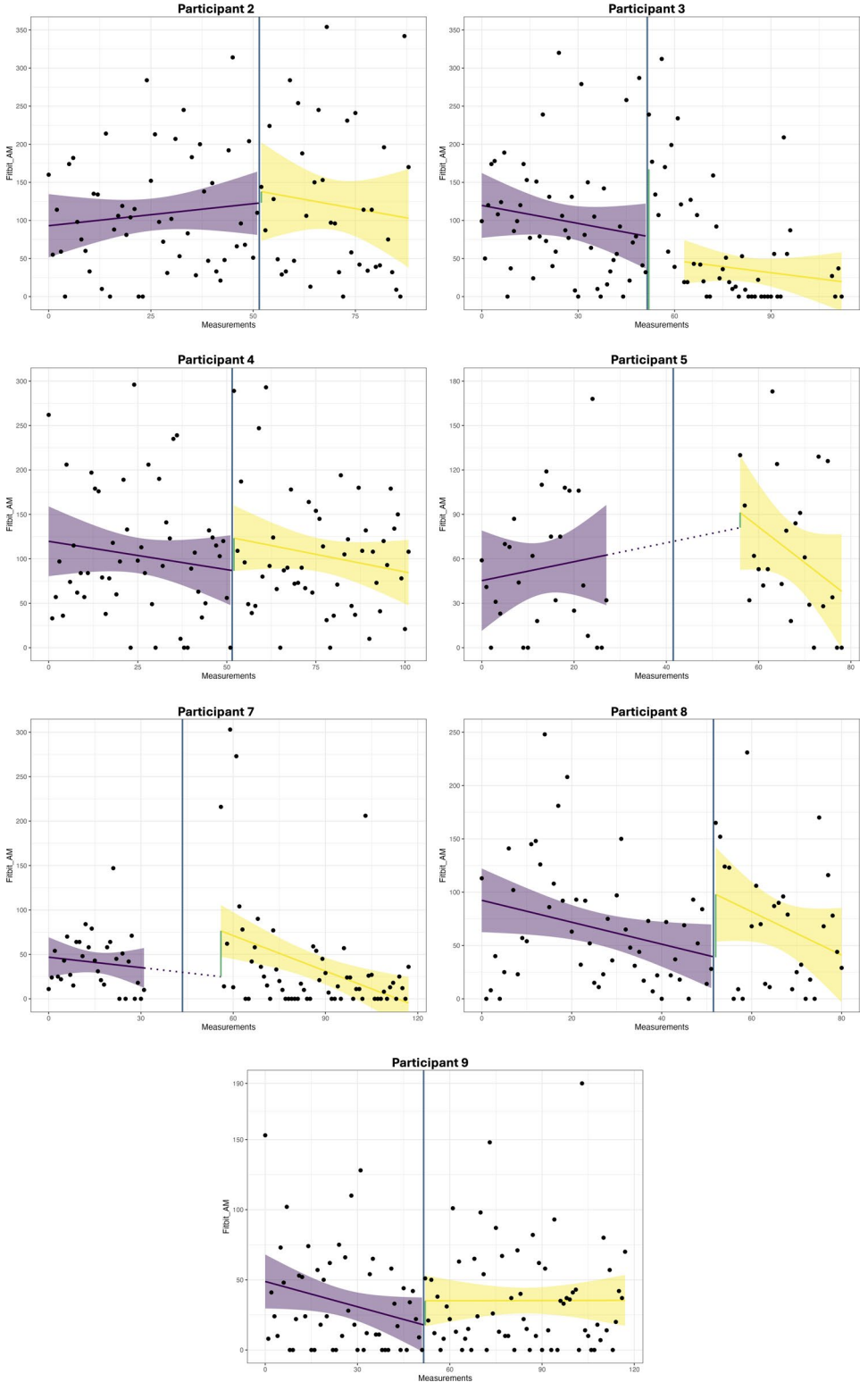


Figure 4. Active Minutes. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

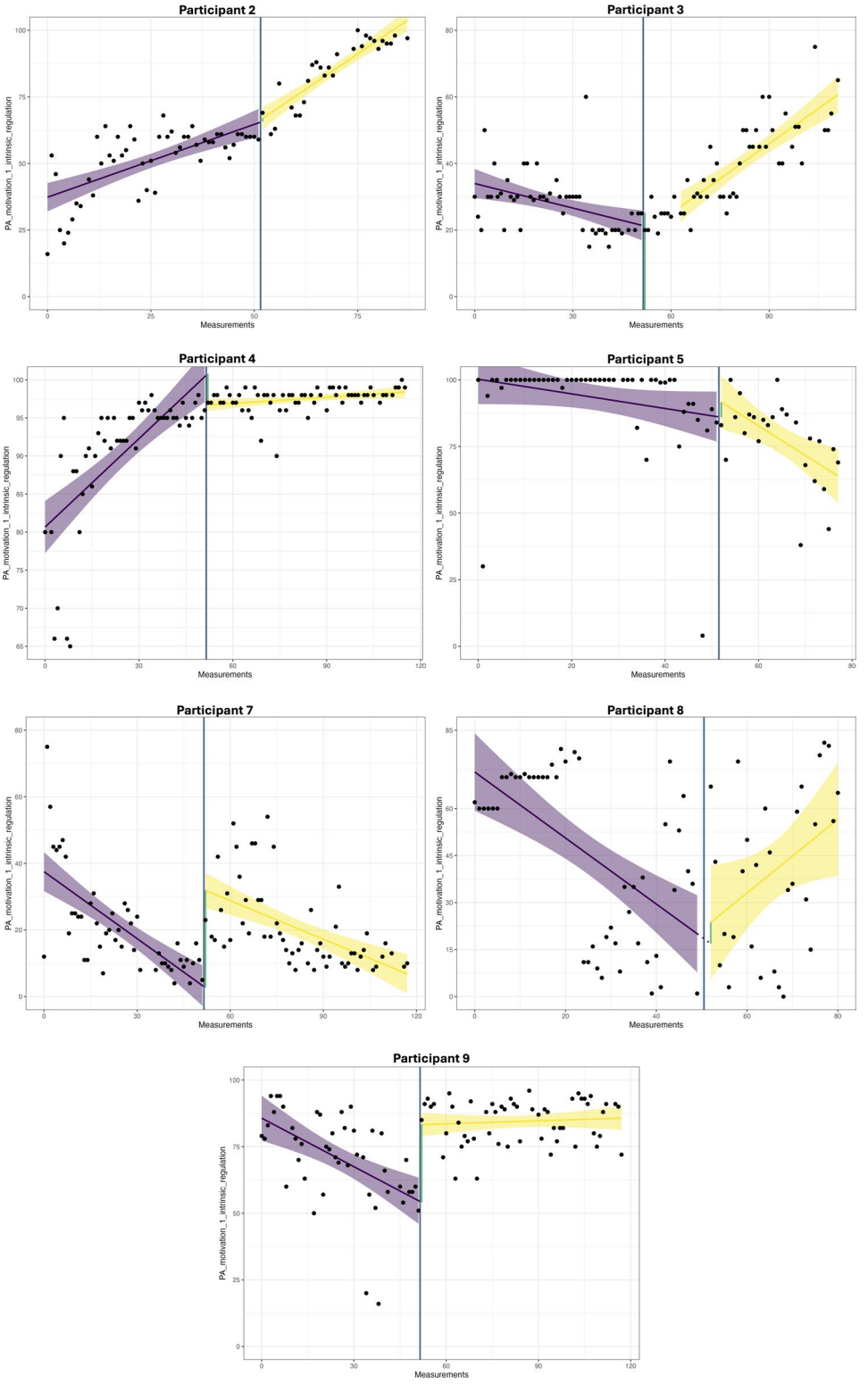


Figure 5. Intrinsic Regulation. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

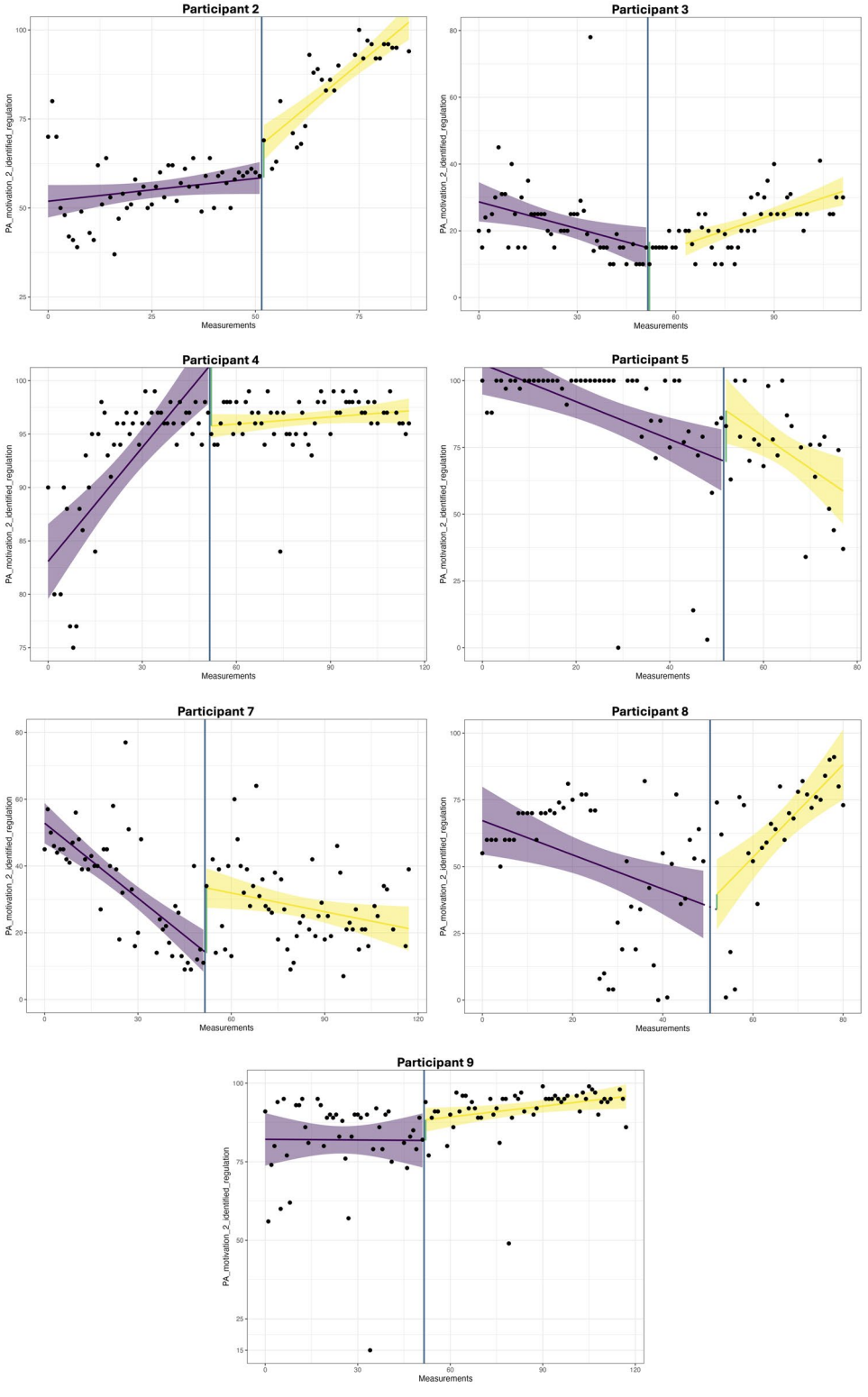


Figure 6. Identified Regulation. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

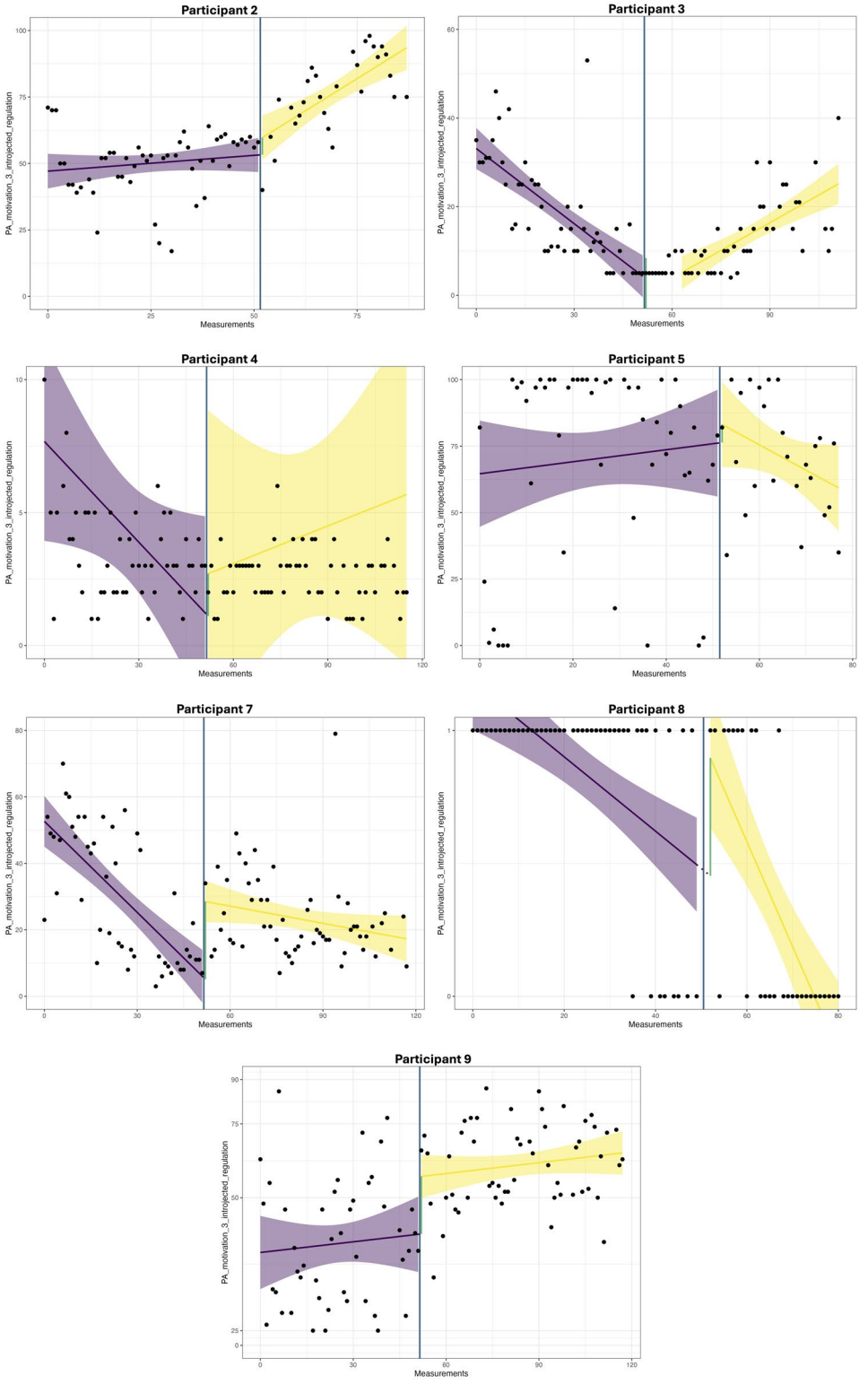


Figure 7. Introjected Regulation. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

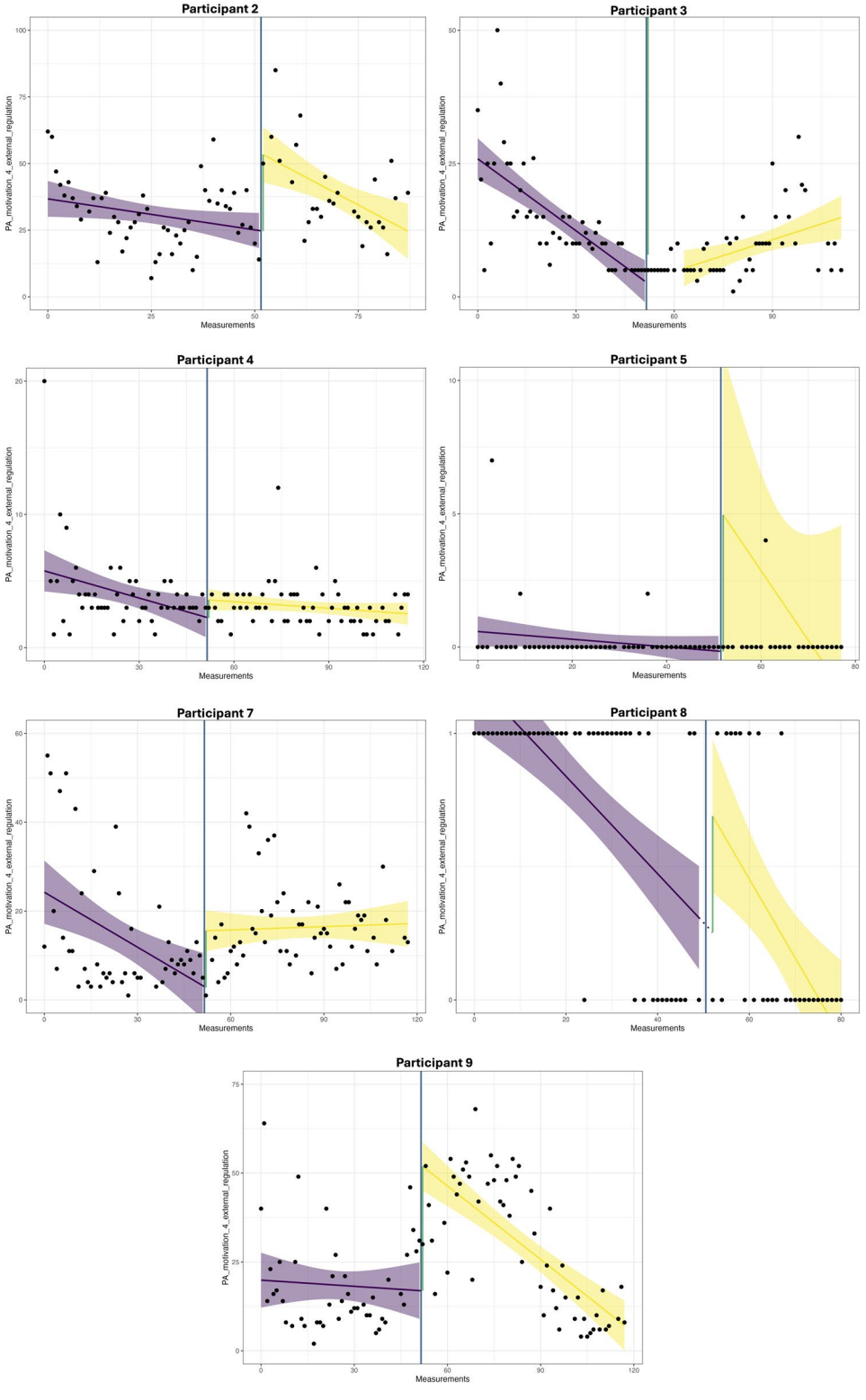


Figure 8. External Regulation. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

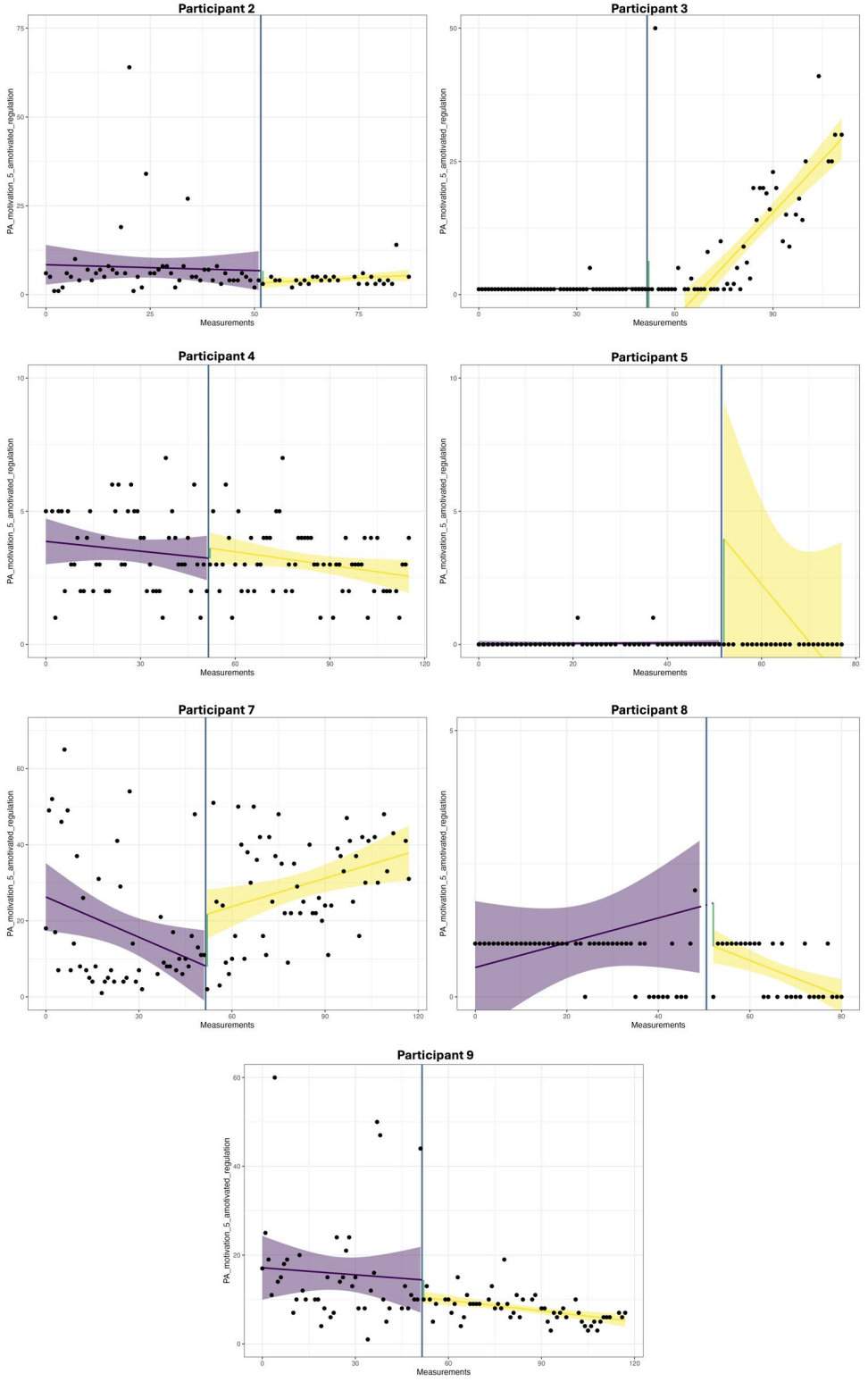


Figure 9. Amotivation Regulation. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

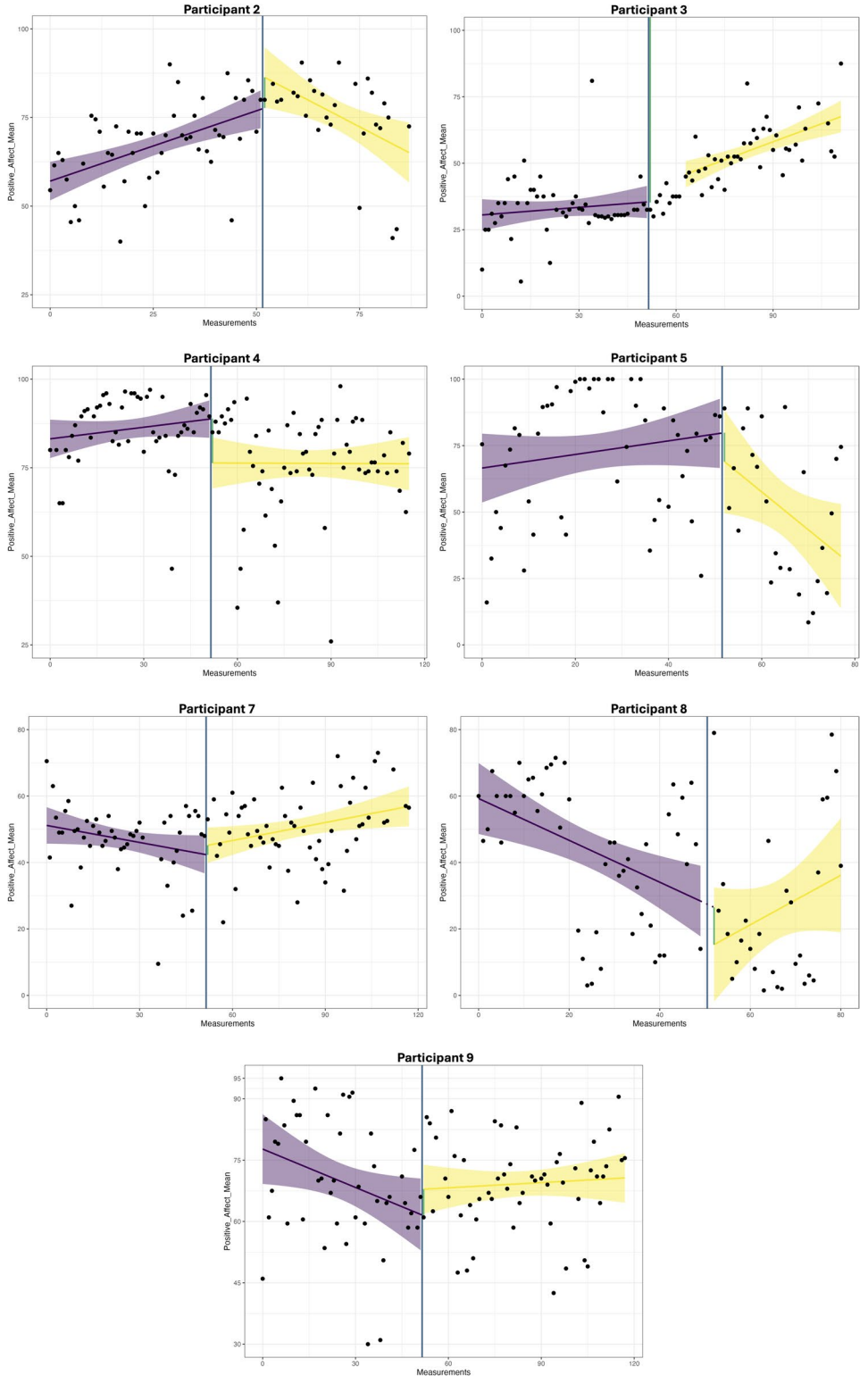


Figure 10. Positive Affect. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

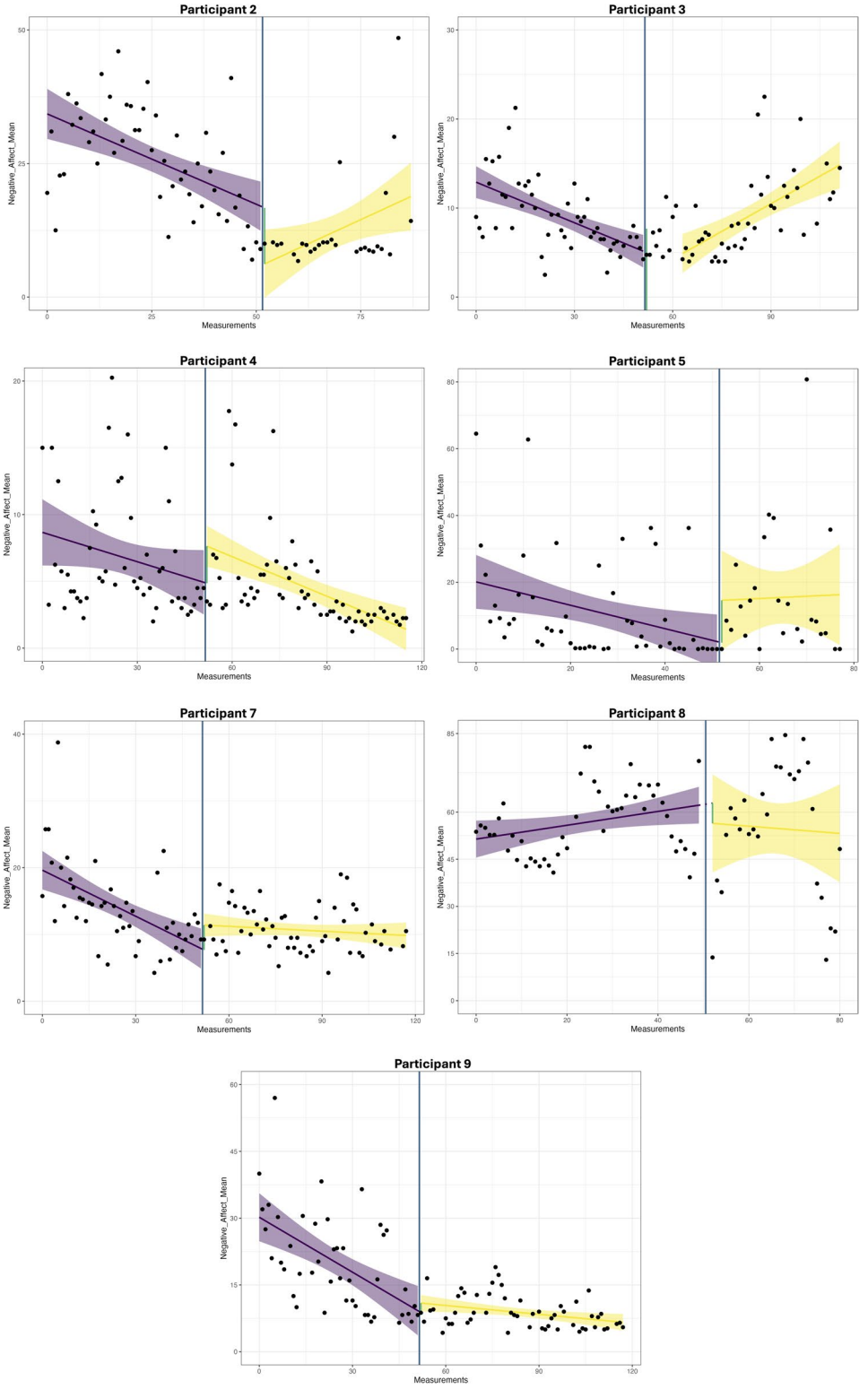


Figure 11. Negative Affect. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

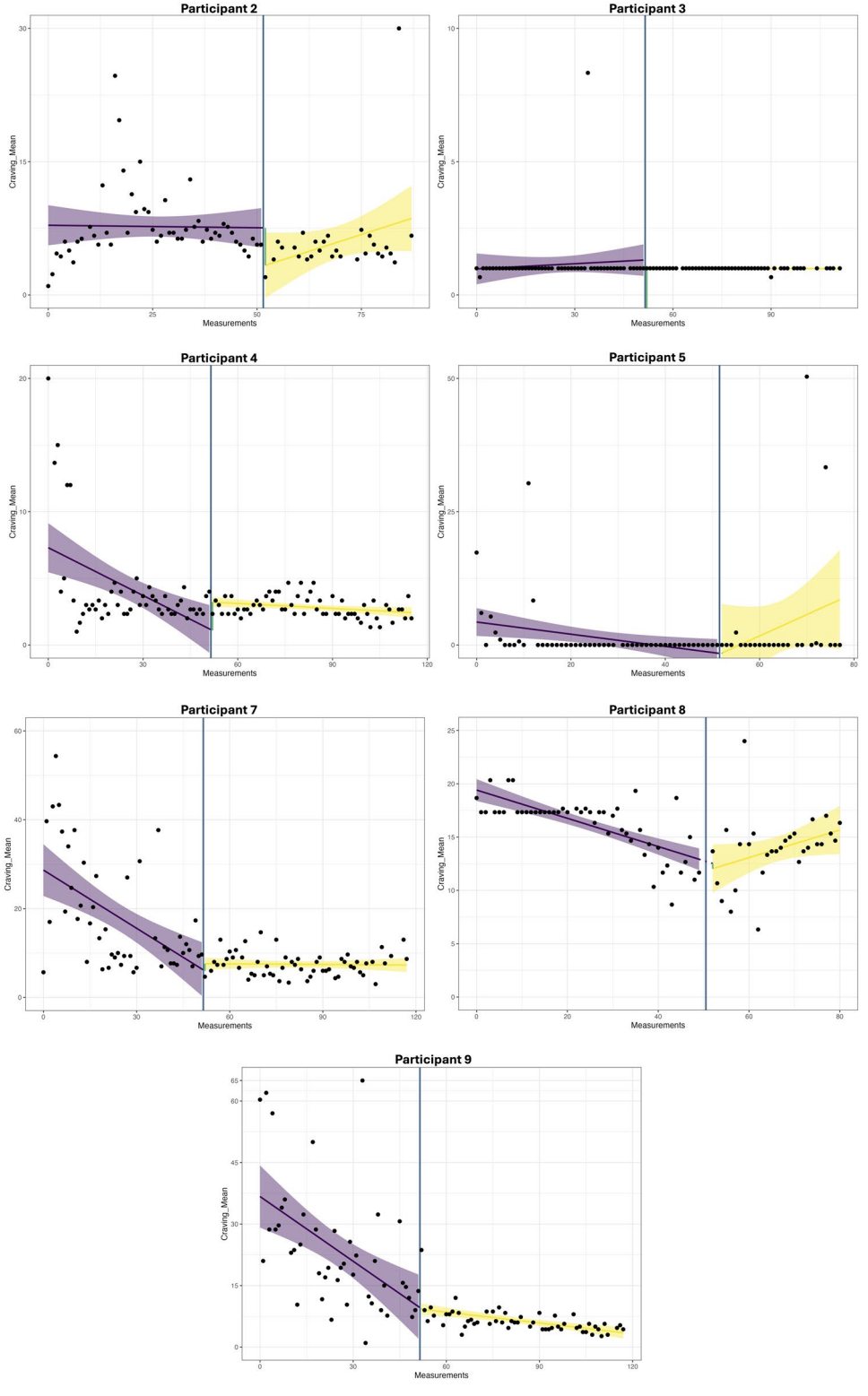


Figure 12. Craving. *Note*. Two slopes with confidence bands are displayed for the seven participants included in the analyses of the hypotheses: the purple slope represents the baseline phase, while the yellow slope corresponds to the intervention phase. Additionally, the green line indicates the phase-shift effect, evaluated at the onset of the intervention phase. The intercept is shown at $t = 0$ in the figure.

negative affect, and craving during the maintenance phase compared to the baseline and intervention phases for participant #3.

Discussion

This is the first study to implement and assess a motivational intervention specifically designed to enhance PA motivation and maintenance among residents at a SUD treatment facility. In this study, the innovative application of N-of-1 methods and the use of EMA allowed for a detailed intraindividual evaluation of study outcomes over the study period. This approach provided some evidence in support of our hypotheses. Several participants showed significant increases in autonomous motivation in line with Hypothesis 1a. However, some participants also demonstrated significant increases in controlled motivation. Thus, Hypothesis 1b was not supported. These findings might align with Deci and Ryan (2012) comparison of SDT and MI, where they acknowledge similarities but note that MI emphasises the quantity of change talk more than its quality. They suggest that encouraging any type of change talk may not only promote autonomy-related change talk (e.g. discussing personal values, available options, and taking responsibility for change) but also controlled change talk (e.g. focusing on what one should do or how others want one to change), potentially affecting the degree of internalisation. Furthermore, the authors argue that the directive approach of MI practitioners in guiding individuals towards more change talk, rather than being autonomy supportive, may inadvertently promote greater interpersonal control, leading to reduced autonomy and a diminished sense of relatedness in the interaction. While some participants in the study reported a significant increase in autonomous motivation, future iterations might aim to specifically limit controlled change talk and thus increases in controlled motivation. Additionally, PA was a mandatory component of TAU at the facility, which may have introduced a non-modifiable degree of perceived external regulation. In future studies, similar interventions could be implemented in treatment contexts in which PA is optional.

On average, participants took 12,523 steps per day and were physically active for 80 min daily (560 min per week). In comparison, adult Australians take on average about 7,400 steps per day (Australian Bureau of Statistics, 2013), and the World Health Organisation (WHO) recommends at least 150 min of PA per week (Bull et al., 2020). This highlights that our participants exhibited significantly higher levels of PA, taking 1.7 times more steps than the average Australian and exceeding the WHO recommendations by 3.75 times. It is important to note that the higher PA levels could be influenced by the mandatory PA program included in the TAU at the treatment facility and may not necessarily represent pre- or post-treatment PA patterns. Hypothesis 1c was confirmed in most instances since differences in PA between baseline and intervention phases were non-significant for all but two of our participants (#4 and #8). This was likely due to the regular PA program that was an integral part of TAU at the treatment facility.

We were unable to fully investigate Hypothesis 2a, as only one participant progressed to the maintenance phase after completing two intervention sessions. However, positive affect increased, and negative affect decreased over time, with a similar decrease observed in craving, for most participants. This pattern was reversed for

participants #5 and #8, who received detrimental diagnoses about their physical health at the start of the intervention phase. Additionally, there was a reduction in self-reported craving during the baseline phase, with no significant difference between baseline and intervention phases across participants. This suggests that most observed changes in affect and craving may be attributed to the TAU at the facility rather than the motivational intervention, per se.

Strengths

Conducting research with individuals with SUDs is challenging due to the reasons outlined in the introduction. Nevertheless, our study demonstrated high levels of retention to both the intervention and EMA protocols, suggesting that the intervention was well-received. In comparison, past studies reported much lower intervention retention rates (Giménez-Meseguer et al., 2020; Thal et al., 2023a; Thompson et al., 2020b). While EMAs are typically resource-intensive, we demonstrated that using a combination of wearable devices and tablets for self-report surveys automated and streamlined the process. We thus conclude that the study design and data collection methods were feasible and acceptable and can be confidently applied in future SUD treatment studies. The high levels of participant engagement with the intervention also reflect the intervention's acceptability. The iterative co-design of this intervention with consumers and stakeholders likely enhanced its acceptability and appropriateness. A detailed qualitative analysis of participants' and facilitators' perspectives on feasibility and acceptability is presented in a separate publication (Thal et al., 2025b).

We employed innovative data analysis methods that highlight the need to personalise data collection, data analysis, and subsequent interventions. Evidence from a participant-level analyses suggest that the motivational intervention was successful in increasing autonomous motivation for PA in some participants. This suggests that relying on generalised theories to predict the behaviour of an "average person"—who, in reality, does not exist—may be redundant and we should question applying theories to group averages instead of individuals (Johnston & Johnston, 2013).

With advances in technology such as predictive analytics, AI, and machine learning, we are now able to implement precision behavioural science at scale (Bucher et al., 2024). This allows us to learn about individuals' unique predictors and design personalised interventions in response. In our study, we were able to show trajectories and changes within participants over time—something few studies have done in SUD populations. For instance, decreases in PA, motivation, and affect observed in some participants after learning of detrimental health diagnoses were immediately visible in their data and could have been addressed through Just-in-time adaptive interventions (Hardeman et al., 2019; Wang & Miller, 2020) where behavioural support is provided in response to real-time needs. These options mark a significant shift from traditional "one-size-fits-all" approaches to more customised, precise and data-driven interventions adapted to the needs of each individual.

Future interventions could benefit from being tailored to individual participants' preferences and needs, allowing for a more personalised and immediate approach to treatment. Our study demonstrates the potential for these novel methods to be effectively implemented in residential SUD treatment contexts.

Limitations

The primary limitation of the study was the high attrition rate, largely due to participants discontinuing SUD treatment. High attrition rates are commonly reported in SUD treatment (Brorson et al., 2013) and PA interventions within SUD settings (Giménez-Meseguer et al., 2020; Thal et al., 2023a). As such, the results must be interpreted with caution, as individuals with lower motivation, higher cravings, or more negative affect may have been more likely to discontinue treatment.

A second limitation is that, although we intended to collect maintenance data, we were unable to do so because all participants who would have qualified for continued care during the observation period discontinued treatment prematurely. Consequently, we cannot determine whether the observed effects, such as the increase in autonomous motivation, were sustained after the intervention ended or when participants transitioned into continued care.

A third limitation is that we did not reach the 130 observations per participant as required by our power calculations, as a consequence of these high attrition rates. Consequently, the study may have been underpowered to detect the effect sizes we were targeting, potentially limiting the ability to draw robust conclusions about the intervention's effects.

Another limitation concerns the difficulty of attributing observed changes over time solely to the intervention. Because all participants were exposed to the same treatment-as-usual environment and external contextual factors, improvements in motivation or affect could partly reflect concurrent influences rather than the intervention itself (Slocum et al., 2022).

The PA levels observed in this study were extraordinarily high likely due to PA participation being mandatory in this closed treatment setting. This limits the generalisability of our findings to other treatment contexts where PA is optional.

Further, some items of the EMA questionnaire may have limited value for daily assessments, as they showed minimal variability for certain participants. This includes the external regulation and amotivation items from our adapted version of the BREQ3-6. Some participants may have misunderstood certain items or instruments, or deliberately provided more favourable responses. This is particularly evident in participants #3, #4, and #5, who reported almost no craving for substance use during the entire observation period, which may warrant closer scrutiny. Participant #4 consistently reported unusually high autonomous motivation and extremely low controlled motivation, which suggests social desirability bias.

Conclusion

Our study showed how N-of-1 designs can be successfully implemented in SUD treatment settings. It further demonstrated that N-of-1 designs provide valuable insights into individual differences in responses to motivational interventions, offering more detailed information compared to traditional sample-level assessments. The design of effective interventions requires a deeper understanding of within person differences. We demonstrated that our intervention successfully increased autonomous motivation in some participants, while its effects on controlled motivation were more variable.

This finding aligns with the suggestions made by the original proponents of SDT. Future motivational interventions aiming to increase PA motivation in SUD contexts should therefore focus not only on increasing autonomous motivation for PA but also on reducing controlled motivation. Furthermore, they should be personalised to individual participants' preferences and allow for more immediate responses to participants' needs.

Acknowledgements

We would like to express our sincere gratitude to Tenacious House and its dedicated staff for their invaluable support throughout this research project. In particular, we extend special thanks to Mark Walker and Ross Slater for their unwavering commitment and assistance. We are also deeply appreciative of all the participants who generously contributed their time and insights to make this study possible.

Ethical statement

Ethics approval for this study was obtained from the Human Research Ethics Committee of Curtin University (HRE2023-0544). All procedures were conducted in accordance with national and international guidelines for research involving human participants (National Health and Medical Research Council, 2023). Informed consent was obtained from all participants prior to their involvement in the study.

Disclosure statement

James Clarke reports receiving payment for his role as facilitator for the physical activity program at Tenacious House, where the study was conducted. All other authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Funding

There is no funding to report for this submission.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

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Appendix A: Intervention description according to TIDieR checklist

TIDieR Checklist Item	
Why	People who suffer from SUDs may benefit from increasing their physical activity and maintaining an active lifestyle. However, motivation for long-term physical activity maintenance is an issue for people with SUDs.
What (materials)	Men participating in the intervention received a Fitbit activity monitoring device and a short presentation outlining the study to them.
What (procedures)	Participants attended twelve motivational counselling sessions (three individual sessions and nine group sessions) which last for approximately 60 min. The intervention was based on MI and SDT principles which have been adapted to a group setting and incorporates BCTs that have been found promising for PA intervention in SUD contexts. These BCTs have further been aligned with BCTs which match MI techniques. The content of the counselling sessions was co-developed in a previous study and a detailed session outline were published in a separate article. Participants took part in short bursts of PA in the group sessions. Participants were be asked to self-monitor their daily step counts and record them alongside other measures daily.
Who provides	Individual and group sessions were provided by a psychologist (ST) with a master's degree in clinical psychology, training in MI and group counselling. A PT (JC) significantly contributed to and co-facilitated six of the nine sessions
How	The intervention was delivered face-to-face. It was estimated that approximately twelve men attended each group session. The spirits of the MI model are fundamental to the delivery of both individual and group sessions and there will be a strong emphasis on optimism, respect and autonomy across all sessions.
Where	The program was delivered in an SUD treatment facility in the greater Perth region in Western Australia. A suitable in-door area for individual and group counselling sessions was provided by the treatment facility.
When and how much	Participants engaged in a structured program consisting of twelve 60-minute sessions. This program included an initial one-on-one counselling session, followed by nine consecutive weekly group sessions during the intervention phase. Additionally, during the maintenance phase, participants received two individual counselling sessions (four weeks apart).
Tailoring	The intervention follows evidence-based MI principles for group intervention and was adapted for the purpose of PA maintenance in SUD populations. The group sessions followed a support group format: Participants were supported and supported each other in behaviour change processes. Participants were supported by a personal trainer in creating and adapting individual change plans. During the follow-up sessions, participants received feedback on their individual goals and change plans were adapted to individual and contextual needs.

Appendix B: Intervention content

Week #	Content	Aim	MI phase	SDT targets	PA	BCTs*
1	Individual pre-group meetings follow MI principles. The discussion revolves around the group's purpose, confidentiality, and attendance norms, the use of activity monitors for self-monitoring and the emotional benefits of PA) emphasising that any PA is beneficial). The group aims are communicated, and participants' histories, goals, strengths, and values are explored.	Get acquainted, build trust, and introduce MI communication style	Individual pre-group meeting	Relatedness, autonomy	N/A	Social support (emotional)
2	A brief introduction allows participants to get to know each other, followed by a sharing of positive aspects in their lives and favourite recreational activities. Afterward, an overview of the group is provided, emphasising its positive and forward-looking nature, with a focus on individual choices for change rather than pressure. The concept of PA is discussed, encompassing various forms of PA. Incidental PA examples are brainstormed. Eventually, group guidelines/rules are discussed.	Foster a secure and nurturing environment that actively involves group members in the collaborative process	Engaging the group	Relatedness, autonomy	Stretching	Social support (unspecified)
3	General goals and motives for joining the group are discussed. A barometer image is introduced to explore individual reasons for increasing physical activity. Participants share their strongest motives for PA maintenance. Afterwards, specific initial goals for post-treatment physical activity are discussed, considering various types of activities.	Encourage active participation within the group and establish initial personal objectives for participants.	Engaging the group	Autonomy, competence	Walking around the room	Social support (unspecified), Goal setting (behaviour), Goal setting (outcome)
4	A peer worker shares their personal history and answers participants' questions. Participants discuss the consequences of sedentary behaviour compared to increased PA. Afterwards, participants' daily routines and habits are explored, including PA and sedentary behaviour, and how these affect their health. The potential for PA as a healthy habit is discussed, followed by a conversation about lifestyle changes.	Offer a positive role model for inspiration, share information about the positive outcomes of behaviour change and the negative consequences of maintaining the current status quo, encourage reflection on adopting healthier habits and routines	Exploring perspectives	Relatedness, competence	PA provided by peer worker	Information about health consequences, Information about emotional consequences, Credible source

(*Continued*)

Continued

Week #	Content	Aim	MI phase	SDT targets	PA	BCTs*
5	The concept of ambivalence and the "circle of change" model are introduced briefly. The main activity involves a group game where participants brainstorm the pros and cons of becoming less physically active after treatment and maintaining high physical activity levels. Subsequently, the facilitator summarises the content, explaining temptations to maintain the status quo and motivations for change. Participants share one meaningful observation from the exercise and discuss how it relates to their own goals.	Explore ambivalence about behaviour change	Exploring perspectives	Autonomy	Balloon volleyball	Pros and cons, Anticipated regret, Comparative imagining of future outcomes
6	The concept of values is introduced. Core values are explored, and the group discusses how different values can be used for guidance, work together or be in conflict. Subsequently, discussions revolve around how participants can align their choices with their values and how values can guide them in maintaining physical activity) also in relation to other participants' stories).	Explore participants' values	Exploring perspectives	Autonomy, relatedness	Bodyweight squats	Focus on past success, Valued self-identity
7	The Shift from exploring to broadening perspectives is introduced. Participants are asked if they are familiar with the Stages-of-Change model. Depending on their familiarity: • Option 1 (Not familiar): The facilitator introduces the Stages-of-Change model, discussing past changes and the gradual nature of change. They explain the model in everyday language and how it relates to participants' change goals. • Option 2 (Familiar): A quick recap of the Stages-of-Change model is provided, followed by a discussion of past attempts to change physical activity behaviours, exploring barriers and common perspectives. Afterwards, participants explore their personal strengths as tools for change, identifying strengths and discussing how they have helped in the past and how they can support their desired changes.	Introduce heuristic model(s), familiarising participants with stages of change, exploring participants' strength	Broadening perspectives	Competence, autonomy	Stretching	Focus on past success

(*Continued*)

Continued

Week #	Content	Aim	MI phase	SDT targets	PA	BCTs*
8	Participants are invited to envision and share their ideas about their future, including desired changes. The facilitator links the content, themes, feelings, or identities shared by participants and asks key questions about how to achieve their visions. Afterwards, participants focus on a specific behaviour change related to physical activity in their daily lives after treatment. They rate the importance of this change and discuss their ratings. Confidence in making the change is also rated and discussed.	Explore participants' visions for the future and their subjective importance and confidence for behaviour change	Broadening perspectives	Autonomy, competence	Silent ball	Comparative imagining of future outcomes, Problem solving, social support (unspecified)
9	A professional with an exercise background joins the session. The main focus of the session is change planning. Participants are introduced to SMART goals as a framework for formulating goals. Participants draft their change plans individually. The exercise professional provides feedback and additional information on their plans, and participants discuss strategies to handle challenges and setbacks. Afterwards, participants engage in goal attainment scaling (importance and confidence).	Develop a change plan	Moving into action	Competence, autonomy	PA provided by exercise professional	Goal setting (behaviour), Goal setting (outcome), Problem solving, Action planning; Graded tasks
10	Participants are introduced to statement of commitment. Those ready to make a commitment share their statements, and the group reflects on each participant's statement. Participants who are not ready yet share their developing commitment statements, and a debrief follows, discussing potential setbacks and strategies to overcome them. Subsequently, participants discuss potential changes and come up with easily achievable steps. These small steps are then presented to the whole group.	Strengthen commitment to change	Moving into action	Autonomy, relatedness	Walking around the room	Goal setting (behaviour), Goal setting (outcome)
11 & 12	In both individual follow-up sessions, the focus is on addressing each participant's specific concerns and needs. The facilitator reviews the participant's goals, assesses progress using goal attainment scaling, and evaluates the effectiveness of their change plan. If necessary, adjustments are made to the plan to better align with personal resources and the participant's environment. Strategies for continued self-monitoring are developed, and prompts/cues are discussed to help the participant maintain their physical activity goals.	Review the goals and change plan and make adaptations if necessary	Post-group meeting (when participants are in continued care): Moving into action	Competence, autonomy, relatedness	N/A	Prompts/cues, Review behaviour goal(s), Review outcome goal(s). Problem solving, Action planning; Graded tasks

Note. **Framing/reframing, Credible source, Self-monitoring of behaviour, Social support (unspecified), Social support (emotional)* and *Valued self-identity* will be used in all sessions and are thus only listed separately in the table if there is a specific focus on the particular BCT, as well.

Appendix C: GPAQ data

P#	VIPA Work	MIPA Work	MIPA Travel	VIPA Recreation	MIPA Recreation	Sedentary	VIPA Total	MIPA Total
1								
2	1500	1800	0	0	140	2100	1500	1940
3	0	180	240	60	30	5040	60	450
4	0	0	0	0	0	840	0	0
5	4320	1140	0	90	120	420	4410	1260
6								
7	0	2400	0	0	0	210	0	2400
8	0	720	0	0	135	7560	0	855
9	0	2400	210	0	45	1260	0	2655
10								
11								
12								
13	1200	600	45	1890	1680	1260	3090	2325
14	0	120	0	0	0	3360	0	120
15								
16	0	0	0	0	0	480	0	0
17	0	2520	0	0	20	480	0	2540
Mdn	0	720	0	0	30	1260	0	1260
M	638.18	1080.00	45.00	185.45	197.27	2091.82	823.64	1322.27
SD	1336.88	1024.93	90.25	566.17	494.96	2338.46	1542.32	1083.19

Note. Values indicated in minutes per week; missing data from $n = 6$ participants; P# = Participant number; VIPA = Vigorous Intensity Physical activity; MIPA = Moderate Intensity Physical Activity.

Appendix D: Attendance data

				Self-report EMA			Attendance Bootcamp			Attendance MI session			
P#	Entered Study	Ended study	Days in study	*n* days reported	*n* days not reported	% report	*n* sessions attended	*n* sessions missed	% attendance	*n* sessions attended	*n* sessions missed	% attendance	Reason for end of data collection
1	15-Dec-23	18-Dec-23	3	3	0	100.00	N/A	N/A	N/A	N/A	N/A	N/A	Discontinued treatment
2	15-Dec-23	13-Mar-24	89	80	9	89.89	10	2	83.33	5	1	83.33	Discontinued treatment
3	15-Dec-23	4-Apr-24	111	101	12	89.38	7	1	87.50	3	0	100.00	Did not like Fitbit
4	15-Dec-23	13-Apr-24	120	112	8	93.33	15	1	93.75	10	0	100.00	End of data collection period
5	15-Dec-23	3-Mar-24	79	76	3	96.20	10	2	83.33	5	0	100.00	Did not like Fitbit
6	15-Dec-23	1-Jan-24	17	16	1	94.12	3	0	100.00	N/A	N/A	N/A	Discontinued treatment
7	15-Dec-23	13-Apr-24	120	106	14	88.33	11	6	64.71	7	3	70.00	End of data collection period
8	15-Dec-23	5-Mar-24	81	78	3	96.30	11	1	91.67	5	0	100.00	Discontinued treatment
9	15-Dec-23	13-Apr-24	120	100	20	83.33	16	1	94.12	10	0	100.00	End of data collection period
10	15-Dec-23	28-Dec-23	13	12	1	92.31	2	0	100.00	N/A	N/A	N/A	Discontinued treatment
11	15-Dec-23	26-Jan-24	42	39	3	92.86	5	1	83.33	N/A	N/A	N/A	Discontinued treatment
12	15-Dec-23	17-Jan-24	33	31	2	93.94	4	0	100.00	N/A	N/A	N/A	Discontinued treatment
13	2-Feb-24	13-Apr-24	71	60	4	93.75	9	0	100.00	8	1	88.89	End of data collection period
14	9-Feb-24	26-Mar-24	46	45	1	97.83	4	3	57.14	3	4	42.86	Discontinued treatment
15	1-Mar-24	1-Mar-24	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Did not like EMA
16	5-Apr-24	13-Apr-24	8	6	2	75.00	1	1	50.00	1	1	50.00	End of data collection period
17	8-Mar-24	13-Apr-24	36	33	3	91.67	5	0	100.00	4	1	80.00	End of data collection period
Mdn			46.00	52.50	3.00	93.10	7.00	1.00	91.67	5.00	1.00	88.89	
M			58.18	56.13	5.38	91.76	7.53	1.27	85.93	5.55	1.00	83.19	
SD			43.69	37.84	5.69	5.98	4.61	1.58	16.35	2.91	1.34	20.88	

Appendix E: Step counts

	Step Count During Baseline Period					Step Count During Intervention Period					Step Count During Maintenance Period					Step Count Across Study Period				
P#	*Min*	*Max*	*Mdn*	*M*	*SD*	*Min*	*Max*	*Mdn*	*M*	*SD*	*Min*	*Max*	*Mdn*	*M*	*SD*	*Min*	*Max*	*Mdn*	*M*	*SD*
1	7821	16048	15868	13245.67	4698.76	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7821	16048	15868	13245.67	4698.76
2	6270	25121	14492	14906.73	4537.33	0	27799	14187	15364.70	6513.32	N/A	N/A	N/A	N/A	N/A	0	27799	14344	15097.12	5416.44
3	0	16946	8210	8165.17	3363.43	4427	15367	9818.5	10591.60	3130.16	0	11198	5921	5623.79	3879.07	0	16946	7884	7461.12	3843.89
4	4207	27088	15954.5	15346.69	4952.51	7897	32592	16119	16840.46	4914.92	N/A	N/A	N/A	N/A	N/A	4207	32592	15990	16078.93	4966.66
5	4227	25272	14084.5	14282.39	5110.63	250	20530	14775	13106.39	5444.34	N/A	N/A	N/A	N/A	N/A	250	25272	14658	13752.04	5243.59
6	3531	13204	6418	7196.18	2960.82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3531	13204	6418	7196.18	2960.82
7	1766	8450	5323	5343.56	1886.20	2681	16310	5789	6543.37	2766.16	N/A	N/A	N/A	N/A	N/A	1766	16310	5605	6134.93	2555.67
8	1183	22921	12584.5	12745.63	4424.51	2284	21185	11814	12108.97	4562.96	N/A	N/A	N/A	N/A	N/A	1183	22921	12250	12517.69	4456.61
9	1688	18560	9867.5	9185.35	3596.92	2509	21702	9273.5	9525.02	3346.12	N/A	N/A	N/A	N/A	N/A	1688	21702	9342.5	9375.33	3447.97
10	4825	21366	14000	14551.77	4664.72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4825	21366	14000	14551.77	4664.72
11	0	32155	17770	17404.62	6713.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	32155	17770	17404.62	6713.83
12	11129	34131	23918	23411.85	5966.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11129	34131	23918	23411.85	5966.78
13	N/A	N/A	N/A	N/A	N/A	5021	27973	16261	16148.16	5731.75	N/A	N/A	N/A	N/A	N/A	5021	27973	16261	16148.16	5731.75
14	N/A	N/A	N/A	N/A	N/A	297	27878	8084	8881.46	4562.30	N/A	N/A	N/A	N/A	N/A	297	27878	8084	8881.46	4562.30
15	N/A	N/A	N/A	N/A	N/A	4806	4806	4806	4806.00	N/A	N/A	N/A	N/A	N/A	N/A	4806	4806	4806	4806.00	N/A
16	N/A	N/A	N/A	N/A	N/A	10194	21833	14027	15552.83	4733.18	N/A	N/A	N/A	N/A	N/A	10194	21833	14027	15552.83	4733.18
17	N/A	N/A	N/A	N/A	N/A	8306	31633	19796	20035.85	6236.86	N/A	N/A	N/A	N/A	N/A	8306	31633	19796	20035.85	6236.86
2,3,4,5,7,8,9	0	27088	11032	11590.87	5337.81	0	32592	10834	11556.63	5722.22	N/A	N/A	N/A	N/A	N/A	0	32592	10996	11574.95	5515.20
Overall	0	34131	12163	12999.79	6520.31	0	32592	11177.5	12085.13	6466.90	N/A	N/A	N/A	N/A	N/A	0	34131	11571	12523.02	6504.97

Appendix F: Active minutes

	Active Minutes During Baseline Period					Active Minutes Intervention Period					Active Minutes During Maintenance Period					Active Minutes Across Study Period				
P#	*Min*	*Max*	*Mdn*	*M*	*SD*	*Min*	*Max*	*Mdn*	*M*	*SD*	*Min*	*Max*	*Mdn*	*M*	*SD*	*Min*	*Max*	*Mdn*	*M*	*SD*
1	8	59	11	26	28.618	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8	59	11	26.00	28.62
2	0	314	98	107.77	75.37	0	354	97.00	120.30	98.14	N/A	N/A	N/A	N/A	N/A	0	354	98	112.98	85.27
3	0	320	83.5	99.58	77.71	39	312	173.50	167.00	84.70	0	209	19	35.18	48.52	0	320	59	82.24	79.55
4	0	296	94.5	103.46	71.46	0	293	92.50	103.86	66.30	N/A	N/A	N/A	N/A	N/A	0	296	92.5	103.66	68.64
5	0	168	43	53.89	44.26	0	173	53.00	64.65	47.82	N/A	N/A	N/A	N/A	N/A	0	173	53	58.75	45.75
6	0	211	30	48.94	58.29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	211	30	48.94	58.29
7	0	147	42.5	40.78	31.52	0	303	14.00	35.85	62.56	N/A	N/A	N/A	N/A	N/A	0	303	21.5	37.53	53.89
8	0	248	53	66.15	56.00	0	231	68.00	69.45	61.09	N/A	N/A	N/A	N/A	N/A	0	248	57	67.33	57.51
9	0	153	23	33.50	35.81	0	190	23.00	35.20	37.00	N/A	N/A	N/A	N/A	N/A	0	190	23	34.45	36.34
10	11	188	71	72.85	53.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11	188	71	72.85	53.89
11	0	207	86.5	87.64	58.55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	207	86.5	87.64	58.55
12	52	460	203	228.21	99.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	52	460	203	228.21	99.15
13	N/A	N/A	N/A	N/A	N/A	0	217	77.00	75.31	53.13	N/A	N/A	N/A	N/A	N/A	0	217	77	75.31	53.13
14	N/A	N/A	N/A	N/A	N/A	0	279	40.50	54.37	54.99	N/A	N/A	N/A	N/A	N/A	0	279	40.5	54.37	54.99
15	N/A	N/A	N/A	N/A	N/A	50	50	50.00	50.00	N/A	N/A	N/A	N/A	N/A	N/A	50	50	50	50.00	N/A
16	N/A	N/A	N/A	N/A	N/A	0	118	60.50	60.17	47.03	N/A	N/A	N/A	N/A	N/A	0	118	60.5	60.17	47.03
17	N/A	N/A	N/A	N/A	N/A	18	400	141.50	172.06	117.24	N/A	N/A	N/A	N/A	N/A	18	400	141.5	172.06	117.24
2,3,4,5,7,8,9	0	320	60	75.49	67.19	0	354	41.00	65.88	72.10	N/A	N/A	N/A	N/A	N/A	0	354	52.5	70.72	69.78
Overall	0	460	68.5	86.98	79.88	0	400	51.00	73.66	77.37	N/A	N/A	N/A	N/A	N/A	0	460	58	80.04	78.82

Appendix G: Non-overlap methods and randomisation tests

P#	Non-overlap Method	Fitbit Steps		Fitbit Active Minutes		Intrinsic Regulation		Identified Regulation		Introjected Regulation		External Regulation		Amotivated Regulation		Positive Affect		Negative Affect		Craving	
		Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
2	PEM	0.459	0.38	0.486	0.34	1	0.68	1	0.51	0.929	0.58	0.679	0.1	0.054	0.95	0.893	0.25	0.071	0.76	0.161	0.81
	NAP	0.515	0.29	0.511	0.49	0.992	0.28	0.981	0.28	0.923	0.35	0.652	0.06	0.302	0.8	0.756	0.59	0.129	0.65	0.232	0.89
	IRD	0.237	0.76	0.26	0.76	0.917	0.2	0.862	0.27	0.779	0.25	0.336	0.47	0.225	0.8	0.474	0.46	0.253	0.7	0.253	0.72
3	PEM	0.449	0.21	0.306	0.03	0.765	0.55	0.549	0.55	0.294	0.55	0.157	0.55	0.0804	0.55	0.951	0.63	0.471	0.55	0.49	0.66
	NAP	0.414	0.25	0.333	0.17	0.745	0.55	0.529	0.55	0.32	0.55	0.282	0.55	0.798	0.54	0.907	0.47	0.454	0.55	0.49	0.67
	IRD	0.049	0.95	0.029	0.98	0.386	0.68	0.109	0.94	0.01	1	0.01	1	0.584	0.54	0.683	0.32	0.049	1	0.01	1
4	PEM	0.52	0.25	0.48	0.74	0.939	0.81	0.622	1	0.367	0.52	0.51	0.11	0.561	0.27	0.296	0.76	0.388	0.11	0.418	0.27
	NAP	0.553	0.08	0.505	0.3	0.913	0.38	0.69	0.8	0.362	0.58	0.397	0.25	0.447	0.32	0.29	0.82	0.372	0.21	0.406	0.32
	IRD	0.137	0.98	0.078	0.92	0.7	0.36	0.26	0.99	0.04	0.97	0.02	1	0.04	0.97	0.04	0.97	0.04	0.97	0.02	1
5	PEM	0.565	0.55	0.587	0.48	0.04	0.58	0.06	0.59	0.28	0.3	0.54	0.06	0.52	0.48	0.2	0.65	0.64	0.04	0.58	0.29
	NAP	0.472	0.65	0.57	0.55	0.149	0.46	0.211	0.3	0.431	0.71	0.512	0.06	0.501	0.46	0.262	0.71	0.593	0.13	0.504	0.3
	IRD	0.129	0.9	0.248	0.83	0.255	0.62	0.255	0.62	0.255	0.32	0.285	0.58	0.285	0.58	0.255	0.62	0.285	0.58	0.315	0.55
7	PEM	0.581	0.42	0.226	0.54	0.491	0.01	0.14	0.39	0.307	0.26	0.86	0.3	0.912	0.65	0.596	0.51	0.246	0.34	0.07	0.56
	NAP	0.602	0.28	0.338	0.36	0.51	0.01	0.37	0.19	0.449	0.06	0.68	0.19	0.737	0.39	0.593	0.5	0.331	0.35	0.175	0.8
	IRD	0.313	0.71	0.242	0.74	0.156	0.84	0.137	0.85	0.252	0.75	0.405	0.5	0.52	0.17	0.175	0.97	0.117	0.89	0.079	0.92
8	PEM	0.448	0.06	0.552	0.15	0.259	0.49	0.707	0.35	0.172	0.62	0.138	0.56	0.241	0.69	0.19	0.56	0.517	0.72	0.034	0.83
	NAP	0.463	0.07	0.505	0.17	0.429	0.35	0.684	0.35	0.254	0.31	0.26	0.17	0.334	0.23	0.27	0.49	0.516	0.73	0.224	0.38
	IRD	0.221	0.69	0.248	0.65	0.259	0.68	0.396	0.45	0.204	0.73	0.204	0.73	0.204	0.77	0.259	0.63	0.314	0.65	0.232	0.7
9	PEM	0.424	0.48	0.5	0.39	0.927	0.01	0.909	0.33	0.982	0.09	0.727	0.13	0.073	0.6	0.582	0.47	0.018	0.82	0.018	0.39
	NAP	0.517	0.19	0.519	0.17	0.772	0.01	0.831	0.32	0.846	0.02	0.665	0.14	0.212	0.43	0.494	0.45	0.158	0.37	0.056	0.85
	IRD	0.175	0.89	0.123	0.88	0.475	0.05	0.515	0.29	0.636	0.02	0.313	0.73	0.111	0.88	0.152	0.88	0.091	0.9	0.111	0.88

Note. PEM (Percentage Exceeding the Median) measures the proportion of scores in phase B that surpass the median of phase A, when the goal is an increase. If the goal is to decrease scores, PEM is the percentage of phase B scores falling below the median of phase A. NAP (Nonoverlap of All Pairs) is calculated by forming pairs of scores from phases A and B. A score from phase B greater than that of phase A counts as 1, equal scores count as 0.5, and a lower phase B score counts as 0. NAP is the sum of these scores divided by the total number of pairs. IRD (Improvement Rate Difference) is the difference in improvement rates between phases A and B. It is the difference between the proportion of non-overlapping data points in phase B (NPD) and the proportion of non-overlapping points in phase A.