Digital Phenotyping and Behaviour Change in Addiction Recovery: Towards Personalized Physical Activity Interventions

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Keywords: Digital Phenotyping, Addiction Recovery, Physical Activity Promotion, Wearable Sensors, Personalized Intervention.

Abstract: This position paper explores the integration of digital phenotyping into addiction recovery through a 3-in-1 mobile application that combines adaptive physical activity, psychological support, and mindfulness. Framed within the clinically applied Change & Grow® Therapeutic Model, the proposal aims to transform real-time behavioural and physiological data into personalized, responsive interventions for individuals recovering from substance use disorders. The primary research objective is to assess whether an intelligent digital companion—driven by wearable data, ecological momentary assessment, and adaptive feedback—can support relapse prevention and emotional self-regulation in high-vulnerability populations. We describe the conceptual design of the Digital-PA Loop, a system that interprets users' daily patterns and delivers tailored interventions aligned with therapeutic goals. Ethical considerations, clinical integration pathways, and implementation strategies are discussed in detail. While the app remains under development, a pilot study involving patients at VillaRamadas is planned to assess feasibility, usability, and early signals of effectiveness. This proposal seeks to foster interdisciplinary collaboration at the intersection of sport science, digital health, and psychotherapy, and sets the stage for a data-driven evolution in addiction rehabilitation.

1 INTRODUCTION

Substance use disorders (SUD) continue to pose a significant challenge to public health, with high relapse rates undermining long-term recovery (Stokes et al., 2018). Among non-pharmacological strategies, physical activity (PA) has consistently demonstrated benefits across physiological, psychological, and social domains (Zupet et al., 2020; Cabral et al., 2024). Regular exercise can alleviate withdrawal symptoms, improve mood regulation, and reinforce self-agency (Boswell et al., 2022; Giménez-Meseguer et al., 2020). Despite this, PA remains poorly integrated into most treatment programs, often lacking personalization and long-term adherence strategies.

The recent evolution of digital phenotyping offers a novel opportunity to bridge this gap (Ebner-Priemer & Trull, 2009). By capturing real-time behavioural and physiological data through smartphones and wearables, it enables the detection of patterns related to mood, sleep, activity levels, and relapse vulnerability. When combined with ecological momentary assessment (EMA) and adaptive feedback systems, this technology can support dynamic, personalized interventions that evolve with everyone's recovery process.

This position paper presents a conceptual model that integrates digital phenotyping with personalized PA promotion, embedded within the Change & Grow® Therapeutic Model — a structured five-phase intervention framework applied clinically at VillaRamadas. While PA is encouraged within this model, its digital personalization remains largely unexplored.

We propose the development of a "3-in-1" mobile health platform that simultaneously supports: (i) adaptive physical activity routines; (ii) motivational and psychological reinforcement; and (iii) mindfulness-based strategies for emotional regulation.

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Morouço, P., Caetano, T. and Ramadas, E.
Digital Phenotyping and Behaviour Change in Addiction Recovery: Towards Personalized Physical Activity Interventions.
DOI: 10.5220/0013739900003988
Paper published under CC license (CC BY-NC-ND 4.0)
In *Proceedings of the 13th International Conference on Sport Sciences Research and Technology Support (icSPORTS 2025)*, pages 223-229
ISBN: 978-989-758-771-9; ISSN: 2184-3201
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Rather than a static solution, the envisioned app functions as a responsive therapeutic companion, adapting its content and intensity based on users' physiological signals and self-reported states.

Recent editorial work has emphasized the need for cross-disciplinary approaches to understanding and promoting physical activity motivation (e.g., Morouço et al., 2024, 2025). Thus, the central research question guiding this work is: Can a digitally augmented, real-time behavioural intervention improve physical activity adherence and emotional regulation during residential addiction treatment?

To explore this, we aim to: (i) conceptualize the system architecture using digital phenotyping; (ii) align it with the Change & Grow® therapeutic process; and (iii) define a roadmap for clinical implementation and future feasibility testing.

2 BACKGROUND AND RATIONALE

SUD are complex conditions that often involve recurring cycles of relapse, difficulties in self-regulation, and diminished motivation to change (Ishino et al., 2020; Colder et al., 2016). Although conventional therapies can initiate abstinence, they often struggle to sustain engagement and prevent relapse over the long term.

In recent years, physical activity (PA) has gained recognition as a valuable non-pharmacological strategy to support recovery. Research points to its benefits for mood stabilization (Mikkelsen et al., 2017; Muskens et al., 2024), anxiety reduction (Zhang et al., 2022; Vancampfort et al., 2018), neuroplasticity (El-Sayes et al., 2019; Dergaa et al., 2025), and the reinforcement of self-efficacy and well-being (Wang et al., 2022; Peng et al., 2025). Despite this evidence, PA remains underutilized in rehabilitation settings. Common barriers include fluctuating emotional states, low motivation, and a lack of personalization—both in design and delivery.

This is where digital phenotyping presents a compelling opportunity. By collecting continuous behavioural and physiological data via smartphones and wearables—such as movement, sleep, heart rate variability (HRV), and mood—digital phenotyping enables a real-time understanding of an individual's recovery journey. When combined with ecological momentary assessment (EMA), these insights can guide timely, tailored interventions that respond to the user's daily needs.

Evidence from mental health research shows that such tools can predict anxiety spikes or disengagement and support adaptive behavioural strategies. Still, their potential in addiction recovery—particularly in reinforcing PA habits—remains largely untapped.

This position paper proposes leveraging digital phenotyping not for surveillance, but for empowerment. The idea is to help individuals reconnect with their bodies, recognize patterns, and receive context-sensitive feedback that promotes motivation and self-regulation. When embedded in a coherent therapeutic model, the potential for meaningful behavioural change increases substantially.

The Change & Grow® Therapeutic Model, implemented at VillaRamadas, offers such a structure. This five-phase approach emphasizes personal development, emotional insight, and behavioural accountability. Although PA is already encouraged within the model, it has not yet been enhanced through technology.

We envision a 3-in-1 digital platform that integrates adaptive PA routines, motivational content aligned with therapeutic goals, and mindfulness-based interventions. By aligning digital feedback with the user's physiological signals and emotional states, the system becomes a responsive companion in the recovery process.

Unlike existing tools like reSET-O or Just-in-Time Adaptive Interventions (JITAIs), our proposal places physical activity at the core of the intervention loop, fully embedded within a residential therapeutic framework. This unique combination supports a more holistic, dynamic, and person-centred path to recovery.

3 CONCEPTUAL FRAMEWORKS: THE DIGITAL-PA LOOP IN ADDICTION RECOVERY

The core concept underlying this proposal is the Digital-PA Loop: a closed, adaptive feedback system that integrates digital phenotyping data with personalized interventions across three synergistic pillars — physical activity, motivational-psychological support, and mindfulness — to support sustained recovery from addiction. This loop is not meant to replace the therapist or the therapeutic process, but to augment it through real-time data, meaningful insights, and behaviourally adaptive prompts that reinforce engagement, autonomy, and emotional regulation.

3.1 Functional Components of the Digital-PA Loop

The system comprises four interconnected components:

(i) Data Acquisition Layer
This layer collects both passive and active data streams from the user, including:

- Passive sensors:
- Step count, GPS-derived mobility patterns, heart rate (HR), heart rate variability (HRV), sleep quality metrics from wearables.
- Active self-reporting:
- EMA-style prompts for mood, cravings, fatigue, motivation levels, or pain/discomfort.
- Short qualitative check-ins reflecting the user's cognitive or emotional state.
- App usage behaviour:
- Frequency of interaction with each module (exercise, mindfulness, motivation), time of use, and abandonment patterns.

These inputs form the real-time digital phenotype of the user — a behavioural and physiological snapshot that continuously evolves.

(ii) Analysis and Interpretation Layer
Using simple rule-based logic or, in future versions, machine learning algorithms, the system analyses incoming data to detect:

- Reduced physical engagement (e.g., <4000 steps for 3 consecutive days)
- Low HRV and poor sleep (as stress proxies)
- Negative mood trends or craving spikes (via EMA)
- Disengagement with the app (reduced interaction, skipped exercises)

This analysis triggers a personalized interpretation of the user's current state, identifying moments of vulnerability, opportunity, or need for reinforcement.

(iii) Adaptive Intervention Engine
Based on the interpreted profile, the system delivers personalized prompts across the 3-in-1 pillars:

1. Physical Activity:

- Adjusted intensity and volume of PA sessions
- Automatic suggestion of low-intensity alternatives when fatigue or negative mood is detected
- "Streak" rewards and milestone notifications aligned with progress

2. Psychological/Motivational Support:

- Short, value-based reflections aligned with the Change & Grow® phase the user is in
- Affirmations or therapeutic micro-tasks based on themes (e.g., responsibility, self-worth, resilience)
- Nudges tied to personalized goals or past effort ("You walked more this week than last – keep building!")

3. Mindfulness Content:

- Suggested meditation based on time of day or physiological state (e.g., HRV drop triggers 5-minute breathing exercise)
- Body scan reminders when self-reported tension is high
- Grounding techniques when location patterns suggest social isolation

(iv) Feedback and Reflection Layer
At the end of each day (or week), users receive a simple visual feedback panel:

- Trends (steps, mood, sleep, app use)
- Positive reinforcements ("You completed 4 mindfulness sessions this week")
- Reflection prompts ("What did you notice in your body this week during PA?")
- Therapist dashboard view (in clinical settings) for tailoring sessions

The personalization of physical activity routines can be informed by social-cognitive models such as Self-Determination Theory or the Transtheoretical Model, which have demonstrated relevance in explaining behaviour change in PA contexts (Rodrigues et al., 2023). Additionally, will be tailored by certified exercise professionals, based on individual assessments of baseline physical fitness, fatigue levels, and health status. Parameters such as perceived exertion, heart rate variability and motivation will guide progression or regression within the program.

3.2 Integration with the Change & Grow® Therapeutic Model

Each of the five phases of the Change & Grow® model provides a distinct psychological and emotional landscape. The app dynamically aligns with these transitions:

Truth & Acceptance:

- Focus on stabilizing routines and normalizing activity
- Encouraging PA not for performance, but for reconnection and rhythm

Gratitude:

- Encouraging reflection on positive aspects of life and recognition of personal achievements
- EMA questions help the user track the relationship between physical and emotional states, fostering an attitude of gratitude and emotional resilience

Love:

- Promoting self-care, compassion, and strengthening interpersonal relationships
- PA metrics focused on emotional well-being and affect regulation

Responsibility:

- Users begin to craft personalized routines
- PA metrics tied to self-regulation and progress ownership
- Introduction of commitment tracking

This modular adaptation ensures that the user journey is matched by the app's behavioural logic, rather than imposing a uniform experience.

3.3 Flowchart of the Digital-PA Loop

```
[Data Collection]
   ↓
[Real-Time Analysis] ← (Personal
History + Context)
   ↓
[Adaptive Intervention Selection]
   ↓
[3-in-1 Response]
   → Exercise Plan (Dynamic)
   → Mindfulness Practice (Targeted)
   → Motivation Prompt (Contextual)
   ↓
[User Interaction + Feedback]
   ↓
[Data Collection (loop restarts)]
```

This loop represents a continuous learning system, where the user's physiological and emotional states inform the system's responses, and those responses, in turn, shape future behaviour.

3.4 Clinical Application: From Concept to Practice

Within the clinical setting (e.g., VillaRamadas), the app can be embedded in the daily therapeutic routine:

- Used during morning check-ins to guide PA plans
- Integrated into one-on-one therapy as a self-monitoring aid
- Applied during transitional phases (e.g., pre-discharge planning) to scaffold independent routines

The app thus acts as a bridge between supervised care and autonomous health management, ensuring that therapeutic gains are sustained beyond the residential setting.

3.5 Future Potential: Towards Predictive Models

As data accumulates across users, the system could evolve into a predictive engine, identifying personalized risk signatures for relapse or disengagement. For example:

- A combination of low HRV, poor sleep, and skipped PA over 5 days may trigger a clinical alert
- Machine learning models could refine thresholds based on longitudinal trends and outcomes

Such insights would enable both early intervention and tailored long-term prevention strategies.

4 CLINICAL AND ETHICAL CONSIDERATIONS

The integration of digital phenotyping into addiction recovery offers a promising path toward more personalized, adaptive, and empowering care. The proposed 3-in-1 mobile application—combining physical activity, psychological support, and mindfulness—has the potential to strengthen the therapeutic alliance, foster autonomy, and extend the reach of treatment beyond the walls of the clinic. Still, its application in vulnerable populations requires a careful balance between innovation and ethical responsibility.

Clinically, one of the most relevant strengths of this model is its capacity to tailor physical activity—an intervention often delivered generically—

according to real-time physiological and emotional data. In many rehabilitation settings, exercise programs are not adjusted to mood, fatigue, or motivation. A digital system that recognizes these fluctuations allows both clinicians and users to co-create routines that are more relevant, achievable, and engaging. It can also reinforce therapeutic insights between sessions, helping individuals carry their progress into daily life, especially during periods of transition or vulnerability.

Yet, such benefits must be weighed against potential risks. Excessive notifications or overly intrusive feedback could lead to digital fatigue, avoidance, or emotional reactivity—particularly in those with a history of surveillance or trauma. For this reason, the app must adopt a minimalist and compassionate design philosophy, avoiding language that suggests failure or non-compliance. All feedback should be framed to encourage reconnection, not reinforce shame.

There is also a need to avoid the over-medicalization of everyday life. While real-time data can highlight relevant trends, not every variation is pathological. Outputs must always be interpreted in clinical dialogue, not treated as standalone diagnostics. A core principle of this proposal is that technology should augment, not replace, human care. Therapists remain central in interpreting digital patterns and contextualizing them within each person's recovery journey.

Ethically, implementation must begin with transparent and ongoing informed consent. Users must understand what data is collected, how it is used, and when it might trigger alerts or recommendations. Data protection must follow strict privacy protocols, and therapist access to dashboards must be limited, consensual, and guided by institutional policy.

Additional attention must be given to digital equity. The system should work on low-cost devices, be usable with minimal connectivity, and respect cultural and linguistic diversity. To prevent dependency on the tool itself, the app will include off-ramping features that encourage progressive autonomy post-discharge.

When thoughtfully designed and ethically applied, this model transforms digital data into a tool for reflection, engagement, and self-regulation—supporting not only clinical progress but a more embodied and sustainable recovery.

5 IMPLEMENTATION ROADMAP AND FUTURE PERSPECTIVES

The successful implementation of the proposed digital system—an adaptive, real-time intervention platform integrating physical activity, psychological support, and mindfulness—requires a phased, interdisciplinary approach. While the conceptual foundation is robust, translating it into clinical practice demands careful coordination between technological development, therapeutic alignment, and user-centred design.

5.1 Phase 1: Prototype Development and Feasibility Testing

The initial step involves the co-design of a functional prototype in close collaboration with clinicians, psychologists, sports scientists, and individuals in recovery. This ensures that the technological solution is not only technically sound but also clinically meaningful. The prototype should include:

- A wearable-compatible interface to collect basic physiological and activity data (e.g., HR, HRV, step count, sleep).
- A mobile application with three core modules: physical activity, mindfulness, and motivational support.
- A basic decision engine capable of adapting prompts based on predefined thresholds (e.g., sustained inactivity or negative mood reports).
- A therapist dashboard for supervised environments like VillaRamadas.

While the present article is conceptual, the system will be evaluated through a pilot study involving 15 participants in a controlled clinical setting, measuring feasibility, user experience, and impact on engagement with physical activity and therapeutic content.

5.2 Phase 2: Clinical Pilot and Integration

Following technical validation, the system should be embedded within the therapeutic workflow of a structured program such as the Change & Grow® model at VillaRamadas. This pilot phase will examine:

- How therapists incorporate app-generated data into sessions.
- Patterns of user engagement and dropout.

- Concordance between physiological data and therapeutic indicators (e.g., mood, motivation, relapse risk).
- Perceived usefulness of the system by patients and staff.

This phase may involve 30–50 participants over 6–12 weeks and can form the basis for a preliminary impact assessment, particularly regarding physical activity adherence and emotional self-regulation.

5.3 Technical and Organizational Requirements

From an infrastructural perspective, implementation requires:

- Basic wearable integration (e.g., with PLUX or equivalent bio signal platforms).
- A secure cloud-based backend to process and store data.
- Data privacy compliance mechanisms (e.g., encryption, anonymization, GDPR-aligned protocols).
- Interoperability with existing clinical records or digital platforms.

At the organizational level, it is essential to train clinical teams in the ethical interpretation of digital data and establish protocols for responding to alerts or disengagement flags. These workflows must be sensitive to patient autonomy and avoid clinical overreaction to system signals. Addressing emotional regulation and promoting adaptive coping strategies through digital tools can significantly impact satisfaction with life, even in working populations (Rodrigues et al., 2023).

5.4 Vision for Future Development

Beyond the initial pilot, the vision is to evolve the system into a predictive and adaptive platform, capable of learning from longitudinal user patterns. Future iterations may include:

- Machine learning algorithms to personalize intervention intensity and anticipate relapse risk.
- Natural language processing (NLP) to interpret open-ended EMA responses or voice notes.
- Integration of gamification mechanics to sustain motivation and reinforce therapeutic goals.
- Use of digital twin models to simulate potential future scenarios based on behavioural trends.

Such evolution would transform the platform from a rule-based companion into a dynamic, learning system—one that evolves with the user and supports increasingly autonomous recovery.

5.5 Scalability and Replication

The model, while conceived within the clinical context of VillaRamadas, has potential for broader application in other residential and outpatient settings, particularly those that already integrate PA and mindfulness into care. By preserving modularity and interoperability, the system can be scaled to other clinical populations (e.g., depression, anxiety, burnout) or adapted to community-based health promotion contexts.

International dissemination may be facilitated through partnerships with academic institutions, digital health startups, and therapeutic networks. Furthermore, its integration into public health strategies for relapse prevention could be explored, particularly in systems where digital therapeutics are gaining regulatory recognition.

6 CONCLUSION

Addiction recovery is a multifaceted process that requires both structure and flexibility, emotional support and behavioural reinforcement. In this landscape, physical activity holds unique potential—not only for its physiological and psychological benefits, but as a behavioural anchor that promotes identity reconstruction, emotional regulation, and resilience. Yet its impact depends on how meaningfully it is integrated into everyday therapeutic practice.

This position paper proposed a digital intervention model designed to support that integration through a 3-in-1 mobile health platform, combining physical activity, mindfulness, and psychological reinforcement. Grounded in digital phenotyping and aligned with the Change & Grow® Therapeutic Model implemented at VillaRamadas, the proposed system aims to deliver real-time, personalized interventions that evolve with the user's physiological and emotional state.

Rather than a theoretical abstraction, this model is being prepared for real-world application. The next phase will involve clinical piloting within a residential setting, with initial feasibility studies assessing usability, acceptability, and short-term effects on activity engagement and emotional regulation. These results will guide iterative refinement and inform a future clinical trial.

Ethical and human-centred design will remain central throughout this process. The goal is not to replace care, but to extend it—bridging the gap between therapy sessions and lived experience. This vision depends not only on technology, but on the values that shape its use: empathy, autonomy, and dignity.

In sum, the Digital-PA Loop represents a pragmatic, ethically conscious step toward a more personalized and embodied model of recovery. Its success will not lie in technological sophistication alone, but in how well it responds to the complexity—and humanity—of those it seeks to support.

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