Integrating Mobile Apps and Wearables for Health Behavior Change: A Systematic Review

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ABSTRACT

This systematic review evaluates the comparative effectiveness of mobile phone-based Persuasive Technologies (PTs) in promoting Physical Activity (PA) and reducing Sedentary Behavior (SB). By synthesizing findings from 62 studies published over the past 19 years (2006–2025), this review highlights the differential impact of mobile apps, wearable devices, and hybrid interventions on health behaviors. The results from the descriptive synthesis demonstrate that hybrid PTs, combining apps with wearables, yield a higher aggregated efficacy than app-only interventions in increasing PA and reducing SB, particularly in sustaining habits over the long term (6 months). Key Behavior Change Techniques (BCTs), such as self-monitoring, goal-setting, and real-time feedback, were identified as critical to maintaining user engagement. However, challenges such as long-term adherence remain, particularly with app-only interventions where engagement drops significantly due to manual entry fatigue. This review contributes to the field of mobile health (mHealth) engineering by quantifying engagement decay rates and offering evidence-based insights for designing robust, multi-sensor digital interventions.

Keywords-mobile health; persuasive technologies; physical activity; sedentary behavior; hybrid interventions; engineering technology

I. INTRODUCTION

The escalating global prevalence of physical inactivity and Sedentary Behavior (SB) constitutes a critical public health challenge, significantly contributing to the morbidity of chronic conditions such as cardiovascular disease, type 2 diabetes, and obesity [1]. In the United States, data indicate that the average Physical Activity Level (PAL) remains suboptimal at approximately 1.63, with only 39% of adults achieving moderate activity thresholds. This trend is further stratified by demographics, where older adults and women generally exhibit lower activity levels compared to their counterparts [2]. Compounded by poor dietary habits, this inactivity has precipitated a worldwide rise in obesity rates, leading to substantial economic burdens and increased mortality linked to chronic hypokinetic diseases [3]. Consequently, the development of scalable, preventive interventions that effectively promote Physical Activity (PA) and reduce SB is imperative.

Persuasive Technologies (PTs), which leverage digital platforms to reinforce behavioral modification through strategies such as goal setting, reminders, and social support, represent a promising avenue for intervention [4]. Mobile phone-based PTs, in particular, have garnered significant research attention due to their ubiquity, portability, and capacity to deliver real-time, context-aware feedback via integrated sensors and Global Positioning Systems (GPS) [5]. These technologies are particularly potent as they provide consistent and timely feedback, a critical component in the behavioral feedback loop [6]. Furthermore, the integration of these technologies with other platforms, such as wearables or social networks, creates a multi-platform ecosystem that enhances user engagement and adapts interventions to individual needs, offering a significant advantage for promoting long-term behavioral change [7].

Despite the proliferation of mHealth interventions, the literature reveals a dichotomy between short-term efficacy and long-term sustainability. Previous systematic evaluations indicate that while mobile applications are generally effective in eliciting immediate behavioral improvements, maintaining user engagement over extended periods remains a pervasive challenge [8]. For instance, in [9], it was found that although the apps successfully improved diet and PA in the short term, the engagement metrics declined significantly over time. Similarly, in [10], it was highlighted that although smartphone-based interventions led to short-term increases in activity, the long-term effectiveness remained ambiguous. This "engagement erosion" is further corroborated in [11], which concluded that the overall effectiveness of smartphone apps is often limited by low user adherence, and in [12], which noted that persuasive features like rewards often fail to sustain motivation once the novelty effect wears off.

From an engineering perspective, recent technological advances have sought to address these limitations through enhanced sensor integration and system architecture. Although mobile apps offer convenience, wearable devices provide objective continuous data collection, which has been shown to increase motivation through constant feedback [13]. However, comparative studies between mobile apps used in isolation versus those combined with wearables (hybrid interventions) are limited. In [14], it was emphasized that combining mobile apps with wearables generally shows better user engagement, yet the optimal configuration of these hybrid systems requires further investigation. Furthermore, addressing the technical constraints of continuous monitoring, recent studies have highlighted the critical role of AI-driven energy efficiency optimizations [15] and advanced sensor architectures [16] in extending the operational viability of mHealth systems, which is a key factor in sustaining long-term user engagement.

A significant research gap persists regarding the comparative effectiveness of these technological platforms. Although numerous studies have examined mobile apps [17, 18], fewer have directly compared them to wearable devices or hybrid systems [19, 20]. Understanding how different combinations of technologies work together is crucial for optimizing interventions [21]. Additionally, the existing evidence base is limited by demographic homogeneity, focusing primarily on young healthy adults while underrepresenting older adults, children, and individuals with health conditions [22, 23]. Moreover, research in low- and middle-income countries remains scarce, limiting the generalizability of findings across diverse socioeconomic contexts [24]. Although specific strategies such as self-monitoring and goal setting have shown short-term success [25-27], there is a lack of comprehensive data on how advanced techniques, such as gamification and social influence [28], contribute to lasting behavioral change in hybrid environments.

The scientific novelty and primary contribution of this systematic review lie in its comparative methodological approach. Unlike preceding reviews, this review focuses on 62 studies published in the past 19 years to explicitly compare the efficacy and engagement decay rates between app-only, wearable-only, and hybrid interventions. The review seeks to (i) assess the success of these interventions, (ii) identify emerging trends in sensor integration, (iii) evaluate the strengths and weaknesses of existing frameworks, and (iv) provide evidence-based recommendations for the engineering of future mHealth systems. This study hypothesizes that hybrid interventions will yield superior long-term adherence compared to standalone applications due to the integration of passive objective data collection.

II. MATERIALS AND METHODS

This systematic review investigates the role of mobile phone-based PTs in encouraging physical activity and minimizing sedentary behavior. The study design and reporting protocols were conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological transparency and reproducibility [29]. The primary objective was to critically assess the effectiveness of these technologies in promoting long-term behavioral change while identifying emerging trends, common strategies, and potential areas for improvement in public health interventions.

A. *Search Strategy and Study Selection*

To ensure reproducibility in accordance with PRISMA guidelines, a systematic search was executed across PubMed, Springer, Elsevier Scopus, EBSCOHost, Google Scholar, ACM Digital Library, and IEEE Xplore. The search utilized the following Boolean string: ("mobile health" OR "mHealth" OR "smartphone app" OR "wearable") AND ("persuasive technology" OR "behavior change" OR "gamification") AND ("physical activity" OR "sedentary behavior").

Study eligibility was strictly defined using the PICOS framework:

1. Population (P): Adults and youth capable of physical activity, including both healthy individuals and those with chronic conditions.
2. Intervention (I): Mobile phone-based persuasive technologies (standalone apps or hybrid app-wearable systems).
3. Comparison (C): Baselines, non-digital interventions, or alternative digital modalities.
4. Outcome (O): Quantifiable changes in PA duration and SB reduction, as well as user engagement metrics.
5. Study Design (S): Randomized Controlled Trials (RCTs) and quasi-experimental longitudinal studies published in English between 2006 and 2025.

The initial search yielded 722 articles. After removing 204 duplicates, 518 unique titles were screened. Abstract screening excluded 354 articles. The remaining 164 underwent full-text assessment, excluding 102 due to insufficient outcome data or lack of focus on persuasive mechanisms. Ultimately, 62 articles were included (Figure 1).

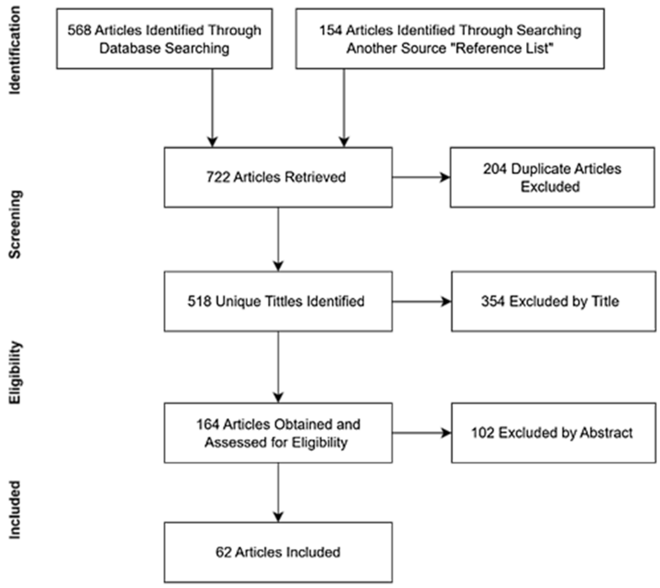

Fig. 1. Study selection workflow by PRISMA.

B. Data Extraction and Behavior Change Technique (BCT) Coding

To address the reproducibility of the methodology, a standardized data extraction protocol was developed and piloted before the full review. Data were extracted regarding study characteristics (author, year, country), study design (Randomized Controlled Trials, quasi-experimental), participant demographics (sample size, age, health status), intervention details (type of technology, duration), and primary outcomes (changes in PA duration and SB reduction). Furthermore, to formalize the analysis of intervention content—addressing previous methodological limitations—the specific BCTs embedded within the apps and wearables were coded using the taxonomy developed by Michie et al. [30]. Two independent reviewers coded the presence of BCTs (e.g., self-monitoring, goal setting, feedback), and any discrepancies were resolved through discussion and consensus with a third senior reviewer. This rigorous coding process ensured that the frequency analysis presented in the results reflects an accurate and standardized categorization of the persuasive strategies employed.

C. Quality Assessment and Risk of Bias

The methodological quality of the included studies was critically assessed to validate the reliability of the synthesized findings. Unlike previous illustrative assessments, this review employed validated tools: the Cochrane Risk of Bias tool (RoB 2) was used for randomized controlled trials, and the Risk Of Bias In Non-randomized Studies - of Interventions (ROBINS-I) tool was applied to quasi-experimental designs [31]. Studies were evaluated across five key domains: bias arising from the randomization process, deviations from the intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. The aggregate scores derived from these standardized tools formed the basis for the quality evaluation, the results of which are detailed in Section III (see Figure 9). This assessment identifies potential limitations regarding detection bias in self-reported studies versus the robustness of sensor-based data collection in hybrid interventions.

D. Data Synthesis and Operational Definitions

Due to the high methodological heterogeneity among the included studies (variations in sample sizes, specific outcome metrics, and intervention durations), a formal meta-analysis was not feasible. Instead, a descriptive quantitative synthesis was performed. Continuous outcomes (e.g., minutes of PA) were standardized to common units (minutes/week or per day) and aggregated using a sample-size-weighted average. Following the well-established Hunter-Schmidt meta-analytic approach [32], which assigns greater weight to studies with larger samples to minimize sampling error, the aggregation utilized the following formula:

$$\bar{x}_{weighted} = \frac{\sum(\bar{x}_i \times n_i)}{\sum n_i}, \qquad (1)$$

where $\bar{x}_{weighted}$ is the aggregated weighted mean, $\bar{x}_i$ is the mean outcome of study i, and n_i is the sample size.

Furthermore, "Engagement" is a highly variable construct in the literature. For this review, engagement was operationalized as the study-defined completion or retention rate (the percentage of participants actively using the technology at the specified follow-up timeline). The aggregated percentages presented in the results represent trends rather than absolute statistical probabilities, serving to highlight relative differences between standalone and multi-component (hybrid) architectures.

E. Data Availability Statement

This study is a systematic review and did not generate any original datasets; all analyses are based on previously published studies cited in the references.

III. RESULTS

A. Spatiotemporal Trends and Study Characteristics

The systematic search identified 62 studies that met the inclusion criteria, focusing on mobile phone-based PT interventions for PA and SB. As illustrated in Figure 2, the temporal distribution of the publications exhibits a fluctuating trajectory over the 19-year period. Following a nascent phase between 2011 and 2014, a significant surge in research output was observed in 2016, reflecting the initial proliferation of consumer health technologies. Although a decline occurred between 2018 and 2021, likely attributable to the saturation of early app-based studies and shifting research priorities, a notable resurgence is evident from 2022 to 2025. Geographically, Figure 3 highlights a disparity in global research distribution, with the United States, Australia, and the United Kingdom dominating the field. This concentration suggests that current evidence is heavily skewed toward high-income contexts, underscoring a critical need for validation in low- and middle-income countries, where smartphone penetration is rapidly increasing, but health infrastructure differs significantly.

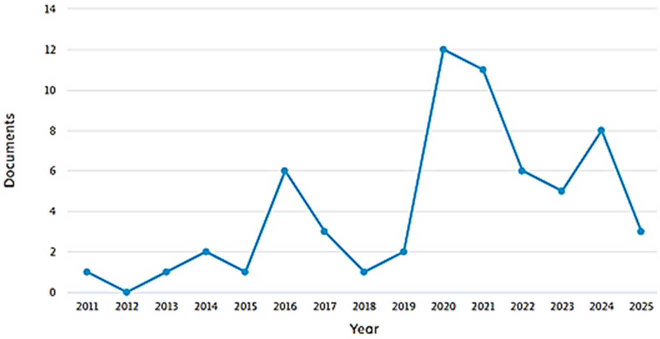

Fig. 2. Trends in mobile phone-based PT for PA and SB by year.

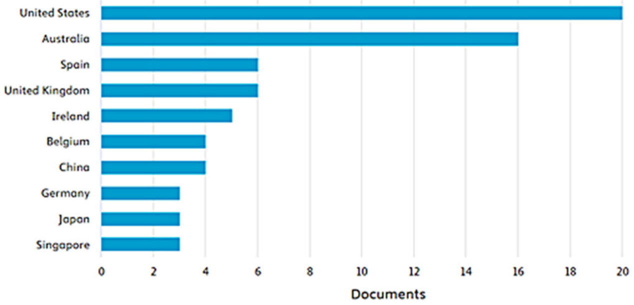

Fig. 3. Mobile phone-based PT for PA and SB by region.

B. Intervention Typologies and Behavior Change Techniques (BCTs)

Regarding the technological modalities employed, Figure 4 demonstrates that smartphone applications remain the most prevalent intervention tool, utilized in the majority of the reviewed studies due to their ubiquity and cost-effectiveness. However, hybrid interventions and standalone wearables represent a growing proportion of the research landscape, indicating a shift towards multi-sensor approaches.

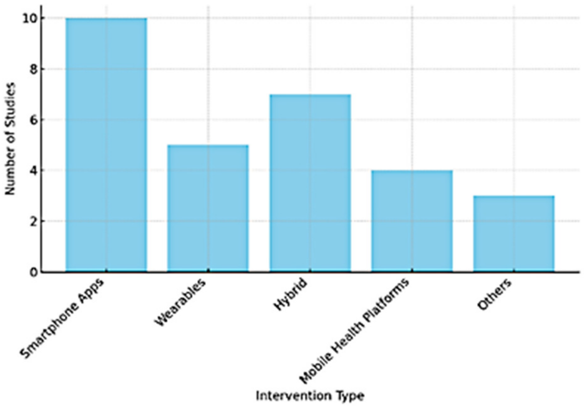

Fig. 4. Types of interventions by category.

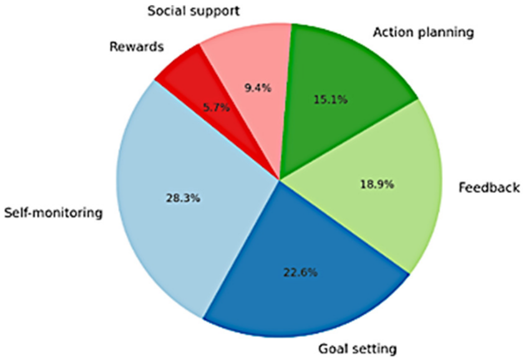

Fig. 5. Frequency of BCTs used across interventions.

Figure 5 presents the frequency analysis of the BCTs embedded within these systems. Consistent with the taxonomy by Michie et al. [30], Self-monitoring (28.3%) and Goal Setting (22.6%) emerged as the dominant strategies, fundamental for tracking progress and maintaining motivation. Real-time Feedback (18.9%) and Action Planning (15.1%) were also integral, whereas social support features were less frequently implemented, suggesting an underutilization of community-based persuasive dynamics in current designs.

C. Comparative Effectiveness on Health Outcomes

Figure 6 depicts the core findings regarding intervention efficacy. While Smartphone Apps yielded moderate improvements in physical activity (approximately 40–45 minutes/session), Hybrid Interventions demonstrated superior efficacy, with participants achieving significantly higher activity levels (60–65 minutes). This suggests that the combination of manual app interaction and passive wearable tracking creates a more robust feedback loop than either technology in isolation. A critical divergence in long-term sustainability is observed in the analysis of SB reduction (Figure 7). At the 3-month mark, all intervention types successfully reduced SB from the baseline average of 300 minutes/day. However, longitudinal data at 6 months reveal a "rebound effect" in app-only interventions, where sedentary time began to increase again. In contrast, Hybrid Interventions maintained a consistent reduction in SB, validating the hypothesis that multi-component systems are more effective at sustaining long-term behavioral change, preventing relapse.

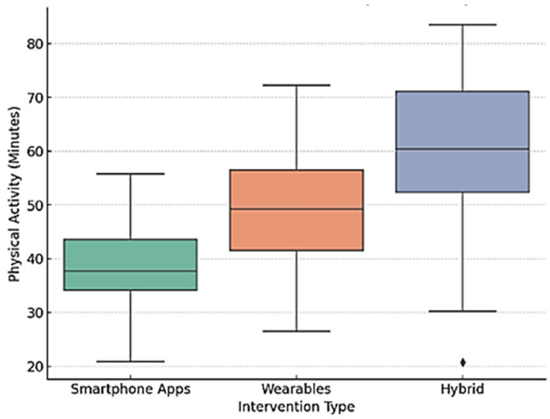

Fig. 6. Effectiveness of interventions on PA.

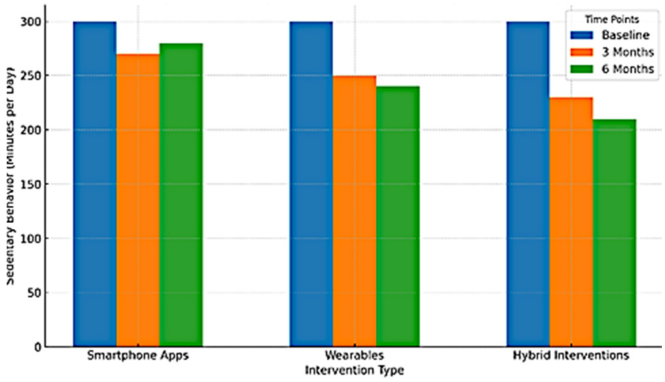

Fig. 7. Changes in SB over time by type of intervention.

D. *User Engagement and Methodological Quality*

User engagement metrics, stratified by demographics in Figure 8, indicate that Hybrid Interventions sustained the highest engagement rates (~70-75%) across both younger (18-40) and older (41-60) cohorts. Conversely, app-only interventions suffered from significant attrition, particularly among older adults and female participants, highlighting usability barriers in manual-entry systems.

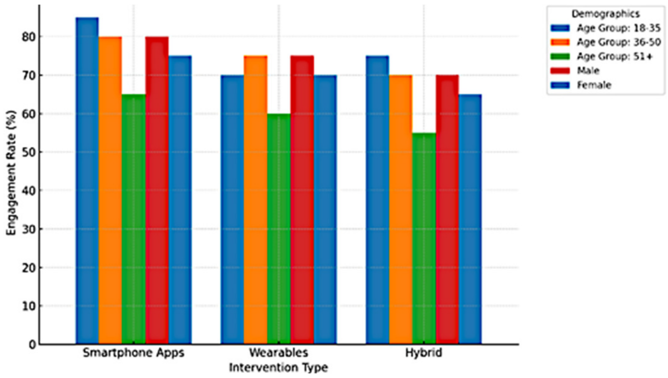

Fig. 8. User engagement by intervention type and demographic factors.

Regarding the standardized risk of bias assessment, the application of the Cochrane RoB 2 tool for RCTs revealed that approximately 45% of the studies exhibited a 'low risk' of bias overall. However, 35% raised 'some concerns', primarily within the domain of measurement of the outcome (Domain 4), as app-only interventions frequently relied on self-reported PA questionnaires, which are susceptible to recall and detection bias. The ROBINS-I assessment for quasi-experimental designs indicated a moderate risk of confounding. Hybrid studies consistently exhibited lower risk in data collection domains due to the objective nature of passive sensor data. These aggregated quality dynamics are visually summarized in Figure 9, demonstrating that multi-component interventions yield methodologically more robust evidence bases.

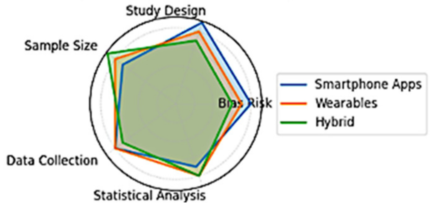

Fig. 9. Quality of studies by intervention type.

IV. DISCUSSIONS

A. *Principal Findings and Theoretical Alignment*

The systematic synthesis of evidence across randomized and quasi-experimental evaluations indicates that mobile phone-based PTs consistently improve PA and, to a lesser extent, reduce SB. Aligning with the initial hypothesis, the data corroborates that while theory-informed smartphone apps elicit meaningful short-term gains—particularly among midlife and older adults [33] and cardiometabolic populations [34]—their long-term efficacy is tempered by engagement erosion.

At the feature level, this synthesis confirms that Self-monitoring and Goal Setting are the most widely implemented BCTs. This observation aligns with prior independent meta-regression analyses [35, 36], which established a strong positive association between these specific techniques and quantifiable improvements in PA. However, the reliability of these techniques is heavily dependent on monitoring fidelity. Validation studies utilizing "gold standard" devices such as the activPAL have demonstrated that complementary device-based approaches (hybrid systems) significantly enhance data accuracy compared to self-reported measures, supporting more reliable, real-time feedback loops [37].

B. *The Challenge of Durability and Heterogeneity*

Despite the evident benefits, two critical cross-cutting issues undermine the durability of standalone app interventions. First, disengagement and non-compliance are pervasive. For instance, an RCT targeting office workers documented that smartphone-prompted interventions yielded only marginal, non-sustained changes, with a marked decline in compliance over 6 months [38]. Similarly, interventions relying solely on vibration feedback in medical students successfully reduced sitting time, but failed to translate this into an overall increase in PA [39].

Second, demographic heterogeneity dictates adoption rates. Although mental health cohorts show high initial uptake, usage varies significantly by sociodemographic factors [40]. Notably, studies in COPD populations reveal a paradox where younger, fitter users engage more with apps, yet still accumulate high sedentary time [41], while passively sensed screen time in youth correlates negatively with Moderate-to-Vigorous Physical Activity (MVPA) [42]. This evidence underscores that early gains in PA are likely to diminish without sustained engagement mechanisms, necessitating the shift towards adaptive, multi-component designs.

C. Interpretation: The Superiority of Hybrid Interventions

The findings of this review provide robust evidence that Hybrid Interventions—integrating mobile apps with wearable sensors—consistently outperform standalone apps in sustaining long-term behavior change (as shown in Figures 6-8). Theoretically, this aligns with Fogg's Behavior Model and the Transtheoretical Model, which posit that behavior change requires a convergence of motivation, ability, and triggers [41, 42]. Hybrid systems reduce the 'ability' barrier by automating data collection, thereby maintaining the 'trigger' for behavior change even when user motivation fluctuates [43, 44].

This contrasts with the findings of previous systematic reviews on smartphone-only interventions, which reported initial increases in PA that plateaued or diminished over time due to a lack of ongoing support [45, 46]. Wearables mitigate this by providing continuous passive feedback, effectively reducing reliance on subjective user self-reports [47, 48]. Consequently, trials involving older adults and patient populations have confirmed that wearable-integrated designs maintain significantly higher engagement rates than app-only alternatives [49, 50]. This dual mechanism is particularly effective in complex contexts such as chronic disease management and workplace wellness, where precision monitoring is critical [51, 52].

From an engineering perspective, the viability of hybrid systems is further reinforced by recent advances in sensor architecture. As demonstrated in [53], the integration of Photoplethysmography (PPG), Galvanic Skin Response (GSR), and temperature sensors with embedded machine learning algorithms (CNN and LSTM) now enables the accurate, real-time monitoring of physiological states. This technological maturity validates the potential of hybrid systems to capture complex health data beyond basic activity tracking, offering a distinct advantage over software-only solutions.

D. Strengths and Limitations of the Evidence Base

A primary strength of this review is the comprehensive inclusion of diverse intervention types, spanning 19 years of research. The analysis leverages robust methodologies from hybrid platform trials, many of which employed large-sample RCTs [53-55] and objective monitoring tools such as accelerometers and GPS [56]. This methodological rigor provides high confidence that the reported superiority of hybrid interventions is not an artifact of detection bias or recall error. Furthermore, consistent application of evidence-based BCTs—specifically self-monitoring (28.3%) and goal-setting (22.6%)—across these platforms highlights a consensus in the design of effective digital interventions [56, 57].

However, several limitations persist within the reviewed literature. The most significant is the short follow-up duration (commonly 3–6 months), which restricts definitive conclusions regarding the permanence of behavior change [58, 59]. Additionally, population homogeneity remains a concern; the overrepresentation of young, healthy adults leaves vulnerable groups—such as older women and individuals with multiple chronic conditions—understudied [60-62]. Differential adoption patterns, where women and older adults exhibit lower engagement with app-only solutions [63], suggest that current "one-size-fits-all" designs are insufficient. Finally, variability in study quality, ranging from robust RCTs to smaller pilot studies with higher bias risks, poses challenges for meta-level synthesis [63, 64]. Additionally, the operationalization of 'engagement' varied significantly across studies—ranging from sensor wear-time to app login frequency—meaning that the aggregated engagement comparisons must be interpreted cautiously as macro-level trends rather than precise equivalents.

E. Practical Implications

1) Clinical and Public Health

Digital interventions offer scalable, cost-effective tools for preventing inactivity-linked conditions such as cardiovascular disease and diabetes. The integration of mobile PTs into chronic care pathways has demonstrated clinically meaningful improvements in metabolic outcomes [65-67]. For patients with type 2 diabetes, app-based tracking combined with tailored reminders significantly improves adherence to lifestyle recommendations [68-70]. Crucially, hybrid interventions provide clinicians with objective data streams, enhancing decision-making and remote monitoring capabilities [71, 72].

2) Workplace Wellness

In the occupational sector, interventions targeting office workers have successfully reduced prolonged sitting through micro-break prompts [73, 74]. Employers are encouraged to adopt hybrid solutions (wearables + apps) to not only improve employee health but also enhance productivity and reduce healthcare costs [75, 76].

3) Demographic Tailoring

Policymakers must recognize that older adults and women respond better to multi-modal support than to apps alone [77-79]. As global access to smartphones expands, tailoring content to specific cultural and socioeconomic contexts will be critical for maximizing equity and public health impact [80, 81].

F. Future Research Directions

1) Addressing Long-Term Adherence

Future trials must evaluate durability over periods exceeding 12 months using objective sensor-based endpoints. Research should focus on adaptive engagement strategies, such as gamification and data-driven personalization, which have shown promise in counteracting engagement erosion [82, 83].

2) Comparative and Multimodal Studies

There is a pressing need for more head-to-head comparative effectiveness studies contrasting app-only, wearable-only, and hybrid interventions across harmonized protocols [84-86]. Research into multimodal sensing should also evaluate the trade-offs between measurement accuracy and user burden [87, 88].

3) Engineering Optimizations

Technical constraints, particularly battery life, remain a critical barrier to continuous engagement in hybrid systems [89]. Emerging research [90] highlights the necessity of AI-driven energy efficiency optimizations, such as adaptive sampling and predictive user behavior modeling. Implementing such techniques is essential to reduce power consumption without compromising data quality, thereby addressing a primary technical cause of user attrition [89-91].

4) Equity and Policy

Future work must broaden recruitment to underrepresented groups, including lower socioeconomic strata and shift workers, ensuring that interventions are culturally tailored [92-94]. In workplace settings, research should integrate organizational-level policies with pragmatic designs that capture productivity and musculoskeletal outcomes to accelerate policy adoption [94-97]. Lastly, improving reporting standards through preregistration and robust intention-to-treat analyses is vital for enhancing the reproducibility of future research.

V. CONCLUSION

This systematic review underscores a critical paradigm shift required in the design of digital health interventions. Although standalone smartphone applications provide an accessible entry point for initial behavioral modification, this synthesis clearly indicates that they suffer from severe engagement erosion and a distinct rebound in sedentary behavior over time. The fundamental limitation lies in the cognitive burden placed on users for manual data entry and self-reporting.

The primary implication of this study is that future digital health architectures must transition toward 'hybrid-by-design' frameworks. By integrating the engaging interfaces of mobile applications with the objective passive data collection capabilities of wearable sensors, hybrid systems successfully mitigate the friction of self-monitoring. This technological synergy not only ensures more reliable continuous feedback loops but also yields more methodologically robust data for clinical evaluation. To fully realize the public health potential of these persuasive technologies, engineering efforts must now prioritize AI-driven energy optimizations to support continuous multi-sensor tracking, alongside the development of inclusive, low-cost wearable integration to reach diverse and underrepresented populations.

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