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Application of gamified mobile health to enhance postoperative rehabilitation compliance in total joint arthroplasty patients

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***Abstract*---**Background: Adherence to home-based rehabilitation protocols after Total Joint Arthroplasty (TJA) is a critical determinant of optimal functional recovery. However, patients frequently demonstrate poor compliance due to lack of motivation and boredom. Gamification strategies incorporated into mobile health (mHealth) applications offer an innovative approach to boost patient engagement. Aim: This study aimed to evaluate the effectiveness of gamified mobile health application in enhancing postoperative rehabilitation compliance in total joint arthroplasty patients. Methods: A quasi-experimental study was conducted using a convenient sample of 80 patients undergoing total joint arthroplasty patients from the orthopedic department and outpatient physical therapy at Sohag University Hospitals. Participants were allocated into two equal groups (40 patients in the experimental group and 40 patients in the control group). The experimental group utilized a customized mHealth embedded with gamification elements (progress tracking, rewards, and interactive badges) for home rehabilitation, while the control group received standard paper-based home exercise instructions. Baseline

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(pre-test) clinical measurements, including: Demographic and Clinical Data Questionnaire, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Visual Analog Scale (VAS) for Pain Intensity, Rehabilitation Adherence Tracking Log, and System Usability Scale (SUS) were conducted and compared between both groups at 6 weeks and 3 months postoperatively. Results: Statistical analysis revealed that while both groups showed post-intervention improvements compared to baseline, the experimental group utilizing the gamified app demonstrated a statistically significantly higher rehabilitation compliance rate ($P < 0.05$). Furthermore, the experimental group exhibited superior post-test improvements in joint range of motion (ROM) and overall physical function, alongside a significantly faster reduction in pain scores compared to the control group. Conclusion: The application of a gamified mHealth app significantly enhances postoperative compliance and clinical outcomes in TJA patients compared to traditional methods. This two-group pre- and post-test evidence supports the integration of interactive mobile technology into remote orthopedic rehabilitation pathways to maximize recovery.

***Keywords*---**Gamification, Mobile Health, Postoperative Rehabilitation Compliance, Total Joint Arthroplasty.

Introduction

Total Joint Arthroplasty (TJA), encompassing Total Knee Arthroplasty (TKA) and Total Hip Arthroplasty (THA), remains one of the most effective and high-volume orthopedic interventions globally to address end-stage joint degeneration **(Mont & Issa, 2014).** The primary clinical objectives of TJA are to alleviate severe chronic joint pain, correct structural deformities, and restore mechanical functional mobility in patients suffering from advanced osteoarthritis. While modern advancements in minimally invasive surgical techniques, prosthetic biomaterials, and intraoperative anesthesia have significantly reduced acute perioperative complications, the ultimate success of the surgery depends heavily on the subsequent recovery period. Postoperative physical recovery is an active, time-sensitive physiological process that relies on systematic physical stimulus to facilitate tissue remodeling and muscle strengthening. Consequently, the long-term clinical outcome of an otherwise flawless surgical procedure remains fundamentally reliant on the quality and consistency of the patient's postoperative rehabilitation program (**Learmonth et al., 2007)**.

Postoperative rehabilitation protocols are specifically designed to restore physiological joint range of motion (ROM), improve quadriceps and hip abductor muscle strength, and re-establish normative gait patterns **(Artz et al., 2015).** Immediately following hospital discharge, patients are expected to perform structured physical therapy exercises multiple times a day for several consecutive weeks. These early movements prevent arthrofibrosis, mitigate joint stiffness, and reduce the risk of deep vein thrombosis through mechanical circulatory assistance. However, a significant paradigm shift has occurred in modern healthcare systems, marked by a transition toward fast-track surgical pathways and shortened hospital stays to maximize institutional efficiency **(Kehlet & Thienpont, 2013).**

While home-based rehabilitation provides substantial economic benefits by reducing healthcare costs and improving hospital bed turnover, it shifts the primary responsibility of recovery directly onto the patient and their caregivers **(Büttner et al., 2020).** Ample clinical evidence demonstrates that adherence to home-based exercise protocols is a critical determinant of optimal functional recovery **(Menon et al., 2020).** Patients who closely follow their prescribed physical therapy regimens achieve superior functional recovery scores, faster pain reduction, and a significantly lower incidence of long-term mobility limitations **(Gränicher et al., 2022).** Conversely, non-compliance or suboptimal adherence to the prescribed exercises severely undermines surgical outcomes, often resulting in permanent joint stiffness, persistent chronic pain, and an increased risk of revision surgery **(Jack et al., 2010).**

Despite the clear benefits of physical therapy, poor compliance remains a pervasive and challenging issue in orthopedic care. Longitudinal studies report that a high percentage of patients fail to complete their home exercise protocols as prescribed due to a lack of professional oversight. This widespread non-compliance stems from a combination of physiological and psychological barriers. Physiologically, patients frequently experience significant pain and physical discomfort during the initial weeks after surgery, leading to a fear of movement or kinesiophobia **(Al-Amiry et al., 2022).** Psychologically, the repetitive and isolated nature of performing the same physical routines daily at home leads to severe boredom, isolation, and a rapid decline in intrinsic motivation. Traditional methods of home-based guidance, such as distributing static paper booklets or simple illustration sheets at the time of discharge, fail to provide the dynamic feedback or ongoing support required to maintain engagement over time (**Argent et al., 2018).**

To bridge this gap in remote orthopedic care, mobile health (mHealth) applications have emerged as a scalable and clinically viable technological solution **(Marcolino et al., 2018)**. Mobile health tools allow clinicians to deliver structured rehabilitation guidance remotely, providing patients with video demonstrations of exercises and automated scheduling reminders. By converting static paper protocols into interactive, media-rich platforms, mHealth apps help overcome the ambiguity and confusion often associated with home exercises (**Safari et al., 2020).** However, early iterations of standard, non-interactive medical applications faced similar limitations to traditional methods; while they provided clear instructions, they lacked the behavioral mechanisms needed to sustain long-term user engagement and overcome boredom **(Free et al., 2013).**

To address the motivational limitations of standard digital interventions, contemporary healthcare developers are increasingly incorporating gamification strategies into mHealth designs **(Johnson et al., 2016).** Gamification involves utilizing game-design elements, behavioral mechanics, and interactive features within non-game medical contexts to foster meaningful user behavior change (**Cugelman et al., 2013).** Rather than making a game out of the condition itself, gamification focuses on structuring the recovery pathway around engaging milestones **(Sardi et al., 2017).** Common elements include interactive progress tracking, virtual points, rewards, and unlockable digital badges. These components leverage proven behavioral psychological frameworks, transforming a painful and monotonous physical routine into a structured, rewarding series of tasks that promote intrinsic and extrinsic motivation **(Ryan & Deci, 2020).**

From a psychological perspective, gamified mHealth applications function by providing continuous positive reinforcement and real-time visual feedback **(Cugelman, 2013).** When a patient completes a scheduled exercise routine, the application records the activity and updates a visual progress tracking bar **(Kari et al., 2016).** Reaching specific recovery milestones rewards the user with virtual points or unlockable badges, which acknowledge their hard work and dedication. This immediate feedback loop triggers a psychological sense of competence and achievement, aligned with Self-Determination Theory. By shifting the patient's focus from the immediate physical discomfort of the exercise toward achieving a clear virtual target, gamification effectively mitigates boredom and counteracts the fear of movement **(Johnson et al., 2016).**

While the conceptual framework supporting gamification in healthcare is strong, empirical research evaluating its direct clinical impact on major orthopedic populations remains limited. Most existing research on orthopedic mHealth apps focuses on basic telemedicine communication or remote vital sign monitoring, without deeply exploring behavioral engagement mechanics **(Dionisi et al., 2021).** There is a clear gap in the current literature regarding how structured gamification elements directly affect objective adherence rates and validated clinical outcomes—such as joint function and pain intensity in TJA patients during the critical first three months post-discharge **(Santiago et al., 2022).** Investigating these factors through a structured, multi-group comparative design is necessary to confirm the practical utility of interactive digital therapeutics in standard orthopedic care pathways.

Significant of the study:
This study directly addresses this research gap by evaluating the effectiveness of a gamified mobile health application in enhancing postoperative rehabilitation compliance in total joint arthroplasty patients. By comparing a gamified digital intervention to standard paper-based protocols, this research seeks to determine whether interactive technology can improve patient compliance and accelerate functional recovery. The primary hypotheses are that patients utilizing the gamified app will demonstrate significantly higher exercise compliance rates, superior improvements in joint range of motion, enhanced overall physical function, and a faster reduction in pain levels compared to those receiving traditional paper instructions.

Aim:
This study aimed to evaluate the effectiveness of gamified mobile health application in enhancing postoperative rehabilitation compliance in total joint arthroplasty patients.

Research Hypotheses:

- **Hypothesis 1:**
  Patients undergoing Total Joint Arthroplasty who utilize the gamified mobile health application (experimental group) will demonstrate a statistically significantly higher postoperative rehabilitation compliance rate at 6 weeks and 3 months compared to those who receive standard paper-based home exercise instructions (control group).
- **Hypothesis 2:**
  Patients in the experimental group will exhibit statistically significantly superior improvements in joint range of motion (ROM) and overall physical functional mobility (measured via lower WOMAC index scores) at 6 weeks and 3 months postoperatively compared to their baseline scores and the post-test scores of the control group.
- **Hypothesis 3:**
  Patients in the experimental group will demonstrate a statistically significantly faster and more substantial reduction in postoperative pain intensity scores (measured via the Visual Analog Scale at 6 weeks and 3 months compared to their baseline scores and the post-test scores of the control group.

Subjects and Method:

Research Design

A two-group pre-test/post-test quasi-experimental design was employed to evaluate the effectiveness of a gamified mobile health application in enhancing postoperative rehabilitation compliance and clinical outcomes among patients undergoing Total Joint Arthroplasty. This design allowed for the comparison of a digital therapeutic intervention against conventional care while tracking longitudinal changes over specific clinical intervals.

Setting

The study was conducted within the orthopedic surgery wards and the outpatient physical therapy departments at Sohag University Hospitals. While the recruitment, baseline assessments, and initial technical training occurred in the institutional hospital setting, the primary physical rehabilitation intervention took place remotely within the patients' home environments following hospital discharge.

Sample:

A convenience sampling method was used to recruit a total of 80 patients undergoing primary unilateral Total Joint Arthroplasty.

- Inclusion Criteria: Age ≥ 18 years; scheduled for primary unilateral Total Joint Arthroplasty; ownership and independent operation of a smartphone (iOS or Android); and intact cognitive and communication capacities.
- Exclusion Criteria: Revision joint arthroplasty; presence of severe neurological or cardiovascular comorbidities that contraindicate standard home exercise; or major post-surgical complications during the acute inpatient stay.

The 80 recruited participants were allocated into two equal cohorts: the Experimental Group (n = 40) and the Control Group (n = 40).

Data collection tools:

1. Demographic and Clinical Data Questionnaire: To gather baseline characteristics of the participants to ensure homogeneity and comparability between the experimental and control groups at the pre-test stage. It was consisted of two parts:

1. Demographic Variables: Age, biological sex, Body Mass Index (BMI), educational level, and prior experience with smartphones/mobile apps.
2. Clinical Variables: Primary diagnosis, type of surgery, surgical side (unilateral or bilateral), medical comorbidities, and length of hospital stay.

2. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)

- The global gold standard for assessing joint pain, stiffness, and physical functional limitations in patients undergoing total joint arthroplasty **(Bellamy et al., 1988).**
- Content and Structure: A 24-item self-reported questionnaire utilizing a 5-point Likert scale (0 = None to 4 = Extreme):
    1. Pain (5 items): Evaluates pain during walking, stair climbing, sitting, lying in bed, and standing upright.
    2. Stiffness (2 items): Assesses severity of morning stiffness and stiffness occurring later in the day after resting.
    3. Physical Function (17 items): Measures difficulty performing activities of daily living (e.g., descending stairs, rising from sitting, bending, putting on socks, and shopping).
- Collected as a pre-test at discharge, and as a post-test at 6 weeks and 3 months postoperatively. (Lower scores indicate better functional recovery).

3. Visual Analog Scale (VAS) for Pain Intensity (Hawker et al., 2011).

- Objective: To measure subjective postoperative pain levels during rest and physical movement.
- Content and Structure:
    - A 100-millimeter (or 10-centimeter) horizontal line.
    - The left anchor (0 mm) represents "No Pain."
    - The right anchor (100 mm) represents "Worst Possible Pain."
- Patients mark a point on the line corresponding to their current pain level. Collected at pre-test (baseline) and post-test intervals (6 weeks and 3 months) to evaluate the rate of pain reduction between the groups.

4. Rehabilitation Adherence Tracking Log (Allam et al., 2015; Chao et al., 2015).

- To quantify patient compliance with the prescribed home-based exercise protocols. Because the study measures the impact of the app, adherence is tracked differently for each group:
- Content and Structure:
    - Experimental Group (mHealth App): Adherence is objectively captured via automated built-in app analytics. Monitored metrics include daily login frequencies, time spent on exercise screens, the percentage of completed daily routines, and gamified milestones reached.
    - Control Group (Traditional): Adherence is tracked using a paper-based daily logbook. Patients manually check off completed physical therapy sessions and record the date and duration.
- Statistical Calculation: Final compliance is expressed as an overall percentage rate calculated via the formula:

- Adherence Rate (%), Number of completed\ sessions, Total number of prescribed sessions, right times 100)

5. System Usability Scale (SUS)

(Administered to the Experimental Group Only)

- To assess the usability, technical feasibility, and patient satisfaction regarding the interactive features of the gamified mHealth app **(Brooke, 1996).**
- Content and Structure: A 10-item standard industrial questionnaire using a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). It alternates between positive and negative statements (e.g., "I found the app very easy to use" and "I found the app unnecessarily complex").
- Administration: Administered once as a post-test at the final 3-month follow-up. Final calculated scores range from 0 to 100, where a score above 68 indicates acceptable usability.

Tool Validity

To ensure the scientific rigor of the data collection process, the research instruments underwent thorough validation pathways. For the structural Demographic and Clinical Data Questionnaire, face and content validity were established by submitting the preliminary draft to a panel of five independent experts in the fields of orthopedic surgery, nursing, and physical therapy. The experts evaluated each item for clarity, clinical relevance, and alignment with the study objectives, and no modifications were made based on their consensus. Regarding the secondary clinical tools, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and the Visual Analog Scale (VAS) are already universally validated, gold-standard instruments widely recognized in orthopedic literature for capturing joint function and pain intensity.

Tool Reliability

The reliability and internal consistency of the multi-item assessment tools were evaluated to ensure stable and replicable measurements. Internal consistency was statistically assessed using Cronbach's alpha (α) coefficients calculated from the patient data. The standardized Arabic version of the WOMAC index demonstrated an excellent overall reliability coefficient of $\alpha = 0.91$, with its subscales ranging between 0.84 and 0.89, indicating high internal consistency. The System Usability Scale (SUS), administered to the experimental group to evaluate the gamified mHealth application's technical feasibility, yielded a strong Cronbach's alpha of $\alpha = 0.85$. For the objective metrics, the Rehabilitation Adherence Tracking Log built into the application was tested across multiple operating systems (iOS and Android) prior to deployment, ensuring stable data logging and reliable technical synchronization with the central database.

Pilot Study

A pilot study was conducted on a separate cohort representing 10% of the total calculated sample size (8 patients) who underwent Total Joint Arthroplasty (TJA). The primary objectives of this pilot phase were to test the logistical feasibility of the recruitment process, evaluate the operational performance of the customized mHealth application under real-world home conditions, and estimate the time required for patients to complete the questionnaires. The pilot study confirmed that the 30-minute in-hospital training session was sufficient for elderly patients to navigate the gamified interface comfortably. Minor technical adjustments, such as increasing the font size and modifying the push-notification delivery times, were implemented based on feedback from the pilot participants. Because no major structural modifications were made to the core clinical assessment scales, and to maintain statistical integrity, the 8 patients involved in the pilot study were strictly excluded from the final sample of 80 patients.

Ethical Considerations

The study was conducted in strict compliance with the ethical principles outlined in the Declaration of Helsinki. Formal ethical approval was obtained from the **Research Ethics Committee** of the participating university and hospital before starting any data collection. Official administrative permissions were also secured from the heads of the orthopedic and outpatient physical therapy departments. All potential participants were provided with a comprehensive disclosure form explaining the study's purpose, the nature of the gamified digital intervention, their right to voluntary participation, and their freedom to withdraw from the study at any time without any negative impact on their standard medical care. Written informed consent was obtained from each eligible patient prior to enrollment. To protect patient privacy and confidentiality, all collected data were coded numerically, anonymized on the digital application interface using pseudonyms, and stored securely on a password-protected research server accessible only to the primary investigators.

Procedure:

1. Ethical Considerations and Patient Recruitment

Prior to data collection, official administrative approvals were secured from the hospital's institutional review board and faculty of nursing. Potential participants undergoing Total Joint Arthroplasty (TJA) were screened sequentially using a convenience sampling method in the orthopedic department during their preoperative or immediate postoperative phase. Patients who met the inclusion criteria (e.g., age ≥ 18 years, undergoing primary unilateral TKA or THA, owning and operating a smartphone, and possessing stable cognitive capacity) were invited to participate. All eligible patients received a detailed briefing on the study's purpose, risks, and benefits, and signed a written informed consent form before any data was gathered.

2. Baseline Assessment and Allocation (Pre-test Stage)

Upon enrollment and prior to hospital discharge, all 80 patients underwent a comprehensive baseline evaluation (Pre-test) managed by the research team. At this stage, data were collected using the Demographic and Clinical Data Questionnaire, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Visual Analog Scale (VAS) for Pain Intensity. Following the baseline assessment, participants were allocated into two equal cohorts: the Experimental Group (n = 40) and the Control Group (n = 40).

3. Hospital-Based Preparation and Training (Setting Stage)

- For the Control Group: Patients received standard, paper-based home exercise instructions. A physical therapist reviewed the printed illustrations, explained the required frequency, duration, and sets for each postoperative exercise, and provided a paper-based diary to manually record daily compliance.

- For the Experimental Group: Before discharge, patients were registered on the customized gamified mHealth application. The researchers installed the app on the patient's smartphone and conducted a structured 30-minute interactive training session. The patient was taught how to log into the application, view the assigned orthopedic physical therapy video clips, interpret the gamified reward system, and troubleshoot basic application features.

4. Home-Based Remote Intervention Period

The active intervention spanned a total duration of 3 months post-discharge, with both groups adhering to identical physical therapy exercise protocols but engaging via completely different delivery mechanisms:

- Standard Care (Control Group Pathway): Patients executed their physical therapy routines independently at home by following the paper booklet. No digital interactions, notifications, or remote tracking metrics were provided. They recorded their completed sessions manually on the paper tracking log.
- Gamified mHealth Care (Experimental Group Pathway): Patients completed their physical rehabilitation routines guided entirely by the interactive application. The digital application protocol utilized explicit behavioral gamification mechanisms, detailed as follows:
    1. Progress Tracking: Visual, interactive progress bars filled up incrementally as the patient completed each daily exercise session, providing immediate visual confirmation of physical performance.
    2. Rewards and Virtual Points: Completing an entire daily session awarded the patient specific numerical points. Consecutive daily tracking triggered "streak bonuses" to reward consistent behavioral adherence over time.
    3. Interactive Badges: Achieving structural medical milestones (e.g., completing the first full week of recovery, or completing 50 total individual exercise cycles) unlocked digital milestone badges celebrating patient achievement.
    4. Reminders: Automated push notifications were delivered twice daily to prompt exercise engagement and overcome patient forgetfulness or boredom.

Gamification Framework Elements (The PBL Triad & Behavioral Design)

The application's behavioral design is rooted in the Self-Determination Theory (SDT) and the Octalysis Gamification Framework, focusing on the core drives of *Development & Accomplishment* and *Ownership*. By implementing the PBL Triad (Points, Badges, and Leaderboards), the app transforms repetitive, often painful postoperative physical exercises into a structured series of rewarding milestones, driving intrinsic and extrinsic compliance.

1. Experience Points (XP) and Reward System

Points serve as the foundational feedback loop within the application, providing immediate positive reinforcement following exercise execution.

- Base Points: Patients earn 100 XP upon completing a full, prescribed daily physical therapy session.
- Granular Feedback: If a patient is unable to finish a full routine due to pain, points are distributed proportionally based on completed sets (e.g., 25 XP per set) to prevent discouragement.

- Streak Bonuses (Behavioral Consistency): To foster long-term behavioral habits, the app incorporates a multiplier system. Completing exercises for 3, 5, and 7 consecutive days awards bonus multipliers (e.g., a 50% XP streak bonus), incentivizing patients to log in and exercise daily.

2. Milestone-Driven Digital Badges

Badges act as visual tokens of achievement, satisfying the patient's psychological need for competence and recognition during their 3-month recovery journey. The badges are progressive and divided into three core categories:

- Adherence & Consistency Badges: Unlocked through long-term participation (e.g., *"Week 1 Warrior"* for completing the first 7 days, or *"Dedication Master"* for reaching 30 days of continuous compliance).
- Functional Milestones: Aligned with clinical recovery protocols (e.g., *"Flexibility Champion"* unlocked when the patient logs a specific target joint range of motion [ROM] improvement, or *"Pain Defier"* when completing routines despite baseline discomfort).
- Onboarding Badges: Granted immediately upon completing the in-hospital training session (*"First Steps"*) to stimulate early digital engagement.

3. Privacy-Protected Leaderboards & Progress Tracking

Social comparison theory dictates that observing peers can boost motivation; however, in a clinical orthopedic population, competitive leaderboards must be handled with care to prevent kinesiophobia or demotivation.

- Anonymous Peer Comparison: Patients are placed into randomized, anonymous cohorts of 5 to 10 peers who underwent Total Joint Arthroplasty (TJA) around the same time. Names are replaced with avatars or pseudonyms (e.g., *"User_40"*) to maintain strict patient confidentiality.
- Metrics of Comparison: The leaderboard ranks users based on total accumulated compliance points (XP) and streak longevity, rather than physiological capabilities or speed. This ensures that elderly or slower-recovering patients are evaluated purely on their effort and adherence.
- User-Controlled Opt-Out: Patients can opt out of the leaderboard at any time, reverting to a private progress-tracking mode where they compete only against their previous week's baseline scores.

  5. Post-test Evaluations and Follow-up Intervals

  Follow-up evaluations were conducted uniformly for all participants in both groups at two primary clinical intervals: 6 weeks and 3 months postoperatively.

- Adherence Tracking: At each interval, rehabilitation compliance rates were extracted automatically from the app analytics for the experimental group and collected from the paper diaries for the control group.
- Clinical Outcomes: The WOMAC and VAS indices were re-administered blindly by clinical evaluators to track joint recovery and pain changes.
- Usability Feedback: At the final 3-month mark, patients in the experimental group also completed the System Usability Scale (SUS) to evaluate their technical satisfaction and the practical viability of the digital app interface.

Statistical Analysis

Data analysis was performed using IBM SPSS Statistics software (Version 28.0). Descriptive statistics, including frequencies and percentages, were utilized to summarize categorical demographic and clinical variables, while means and standard deviations (SD) were calculated for continuous variables (such as age, BMI, VAS, and WOMAC scores). The normality of data distribution was verified using the Shapiro-Wilk test. Baseline homogeneity between the experimental and control groups was evaluated using the Chi-square test for categorical characteristics and the Independent-samples t-test for continuous demographic and clinical parameters. To test the primary research hypotheses, an Independent-samples t-test was employed to compare the mean rehabilitation adherence rates between both groups at the 6-week and 3-month follow-up intervals. To evaluate changes over time and determine the interactive effects of the gamified mHealth intervention on clinical outcomes, a Two-Way Repeated Measures Analysis of Variance (ANOVA) was conducted. This model assessed the within-subject factor of time (baseline vs. 6 weeks vs. 3 months) and the between-subject factor of the intervention group (experimental vs. control) for both pain intensity (VAS) and physical function (WOMAC) scores. For all statistical tests, the level of significance was set a priori at a *p*-value of less than 0.05 ($p < 0.05$).

Results:

Table 1: Homogeneity of Demographic and Clinical Characteristics Between Both Groups (N = 80)

Characteristics	Experimental Group (n = 40)	Control Group (n = 40)	Test of Significance	*p*-value
Age (Years) (Mean ± SD)	61.2 ± 5.4	62.1 ± 4.8	$t = 0.787$	0.434
BMI (kg/m²) (Mean ± SD)	28.4 ± 3.1	28.9 ± 2.7	$t = 0.769$	0.444
Gender [n (%)] - Male - Female	 18 (45.0%) 22 (55.0%)	 16 (40.0%) 24 (60.0%)	$x^2 = 0.205$	0.651
Type of Surgery [n (%)] - Total Knee (TKA) - Total Hip (THA)	 25 (62.5%) 15 (37.5%)	 23 (57.5%) 17 (42.5%)	$x^2 = 0.208$	0.648
Baseline VAS Score (Mean ± SD)	7.8 ± 1.1	7.6 ± 1.2	$t = 0.776$	0.440
Baseline WOMAC Score (Mean ± SD)	68.4 ± 8.5	67.9 ± 9.1	$t = 0.254$	0.800

Note: Significance level set at p < 0.05. x² = Chi-square test; t = Independent t-test.

As illustrated in **Table 1,** a total of 80 participants were successfully randomized into either the Experimental Group (n = 40) or the Control Group (n = 40). To evaluate the homogeneity of the two cohorts at baseline, independent sample t-tests were conducted for continuous variables, while Chi-square (x^2) tests were utilized for categorical data.

The statistical analysis revealed no significant differences between the groups regarding demographic profiles. The mean age was 61.2 ± 5.4 years for the experimental group and 62.1 ± 4.8 years for the control group ($t = 0.787$, $p = 0.434$). Body Mass Index (BMI) was also well-matched at 28.4 ± 3.1 kg/m² versus 28.9 ± 2.7 kg/m², respectively ($t = 0.769$, $p = 0.444$). Similarly, sex distribution ($x^2 = 0.205$, $p = 0.651$) and the specific type of orthopedic surgery performed—Total Knee Arthroplasty (TKA) versus Total Hip Arthroplasty (THA)—showed no statistically significant variation ($x^2 = 0.208$, $p = 0.648$).

Furthermore, baseline clinical outcome measures demonstrated excellent comparability between the two arms. No significant differences were observed in initial pain severity via the Visual Analog Scale (VAS), with scores of 7.8 ± 1.1 in the experimental group and 7.6 ± 1.2 in the control group ($t = 0.776$, $p = 0.440$). Baseline joint function, assessed using the WOMAC score, was also equivalent between the cohorts (68.4 ± 8.5 vs. 67.9 ± 9.1; $t = 0.254$, $p = 0.800$).

Table 1 also, demonstrates the baseline homogeneity of demographic and clinical characteristics between the experimental and control groups. Statistical analysis revealed no statistically significant differences between both cohorts regarding age, BMI, gender distribution, or the specific type of arthroplasty (TKA vs. THA), with all *p*-values exceeding the 0.05 threshold. Furthermore, baseline pre-test measurements for pain intensity (VAS) and physical function (WOMAC) confirmed that both groups were statistically equivalent at the time of hospital discharge, establishing a robust foundation for longitudinal comparison.

Table 2: Comparison of Rehabilitation Adherence Rates Between Both Groups Over Time

Follow-up Intervals	Experimental Group (n = 40) (Mean ± SD %)	Control Group (n = 40) (Mean ± SD %)	Independent *t*-test	*p*-value
At 6 Weeks	88.5% ± 6.2%	68.2% ± 11.4%	$t = 9.872$	< 0.001**
At 3 Months	82.4% ± 7.8%	51.6% ± 14.3%	$t = 12.015$	< 0.001**

*Note: **Highly statistically significant (p < 0.001).*

Table 2 outlines the statistical comparison of home-based rehabilitation adherence rates between the two groups. The findings indicate that the experimental group, which utilized the gamified mHealth app, demonstrated significantly higher compliance rates compared to the control group across all intervals. At 6 weeks postoperatively, the experimental group achieved a mean adherence rate of 88.5% compared to 68.2% in the control group. This behavioral gap widened dramatically at 3 months, where the app users sustained high adherence (82.4%), whereas the control group's compliance dropped significantly to 51.6%.

Table 3: Longitudinal Changes in Clinical Outcomes (VAS and WOMAC) Across Tracking Intervals

Clinical Tool / Interval	Experimental Group (n = 40) (Mean ± SD)	Control Group (n = 40) (Mean ± SD)	Repeated Measures ANOVA (Interaction Effect: Group × Time)	*p*-value
Pain Intensity (VAS Score)				
- Baseline (Pre-test)	7.8 ± 1.1	7.6 ± 1.2		
- Post-test: 6 Weeks	3.2 ± 0.9	4.8 ± 1.1	*F* = 24.615	< 0.001**
- Post-test: 3 Months	1.4 ± 0.5	3.1 ± 0.8		
Physical Function (WOMAC)				
- Baseline (Pre-test)	68.4 ± 8.5	67.9 ± 9.1		
- Post-test: 6 Weeks	32.1 ± 5.4	45.6 ± 7.2	*F* = 31.842	< 0.001**
- Post-test: 3 Months	18.2 ± 3.1	33.4 ± 5.9		

*Note: Lower scores indicate improvement (less pain, better function). **Highly significant interaction effect (p < 0.001).*

Table 3 details the longitudinal changes and interactive effects of the intervention on pain intensity and physical function scores. The Two-Way Repeated Measures ANOVA revealed a highly statistically significant Group × Time interaction effect for both metrics ($p < 0.001$). Although both groups demonstrated gradual clinical improvements compared to baseline, the experimental cohort experienced a significantly faster and deeper reduction in pain scores at 6 weeks (3.2) and 3 months (1.4) than the control group. Similarly, the experimental group achieved superior functional recovery, with post-test WOMAC scores dropping to a mean of 18.2 at 3 months, compared to 33.4 in the conventional care group, validating the secondary research hypotheses.

Table 4: Stratified Levels of Rehabilitation Adherence at 3-Months Postoperatively (N = 80)

Adherence Levels (Based on Tracking Log %)	Experimental Group (n = 40) n (%)	Control Group (n = 40) n (%)	Chi-Square (x^2)	*p*-value
High Adherence (≥ 80%)	28 (70.0%)	9 (22.5%)		

Adherence Levels (Based on Tracking Log %)	**Experimental Group (n = 40) n (%)**	**Control Group (n = 40) n (%)**	**Chi-Square (x^2)**	***p*-value**
Moderate Adherence (50% - 79%)	10 (25.0%)	15 (37.5%)	x^2 = 19.421	< 0.001**
Low Adherence (< 50%)	2 (5.0%)	16 (40.0%)		

*Note: x^2 = Chi-square test. ** indicates a highly statistically significant difference at $p < 0.001$.*

The empirical categorization illustrated in Tables 4 details the structural behavioral split driven by the delivery mechanisms at the conclusion of the 3-month trial. Chi-square analysis **(Table 4)** revealed a highly significant difference in adherence levels between cohorts ($x^2 = 19.421$, $p < 0.001$). A dominant majority of patients utilizing the gamified mHealth application (70.0%) maintained a High Adherence level, whereas only 5.0% fell into low compliance. Conversely, the control group exhibited a substantial motivational decline, with 40.0% of the paper-instructed cohort demonstrating Low Adherence.

Table 5: System Usability Scale (SUS) Descriptive Levels for the Gamified mHealth App (n = 40)

(Administered exclusively to the experimental group to profile technical feasibility)

SUS Score Interval	**Usability Grade / Level**	**Frequency (n)**	**Percentage (%)**
85 - 100	Excellent / Highly Acceptable	22	55.0%
68 - 84	Good / Acceptable	14	35.0%
< 68	Poor / Unacceptable	4	10.0%
Total		40	100.0%

The empirical categorization illustrated in Tables 5 details the structural behavioral split driven by the delivery mechanisms at the conclusion of the 3-month trial. Chi-square analysis. Regarding user-interface feasibility **(Table 5)**, 90.0% of the intervention group rated the software as "Good to Excellent" (SUS score ≥ 68), proving that the embedded gamified mechanics provided an accessible user experience without digital friction for orthopedic patients.

Table 6: Distribution of Patients According to Pain Intensity Levels (VAS) Across Tracking Intervals (N=80)

Pain Severity Levels (VAS Score Range)	**Baseline (Pre-test) Exp (n=40) | Ctrl (n=40)**	**Post-test: 6 Weeks Exp (n=40) | Ctrl (n=40)**	**Post-test: 3 Months Exp (n=40) | Ctrl (n=40)**
Severe Pain (Score: 7 - 10)	36 (90.0%) | 35 (87.5%)	0 (0.0%) | 5 (12.5%)	0 (0.0%) | 0 (0.0%)
Moderate Pain (Score: 4 - 6)	4 (10.0%) | 5 (12.5%)	11 (27.5%) | 29 (72.5%)	0 (0.0%) | 14 (35.0%)

Pain Severity Levels (VAS Score Range)	Baseline (Pre-test) Exp (n=40) | Ctrl (n=40)	Post-test: 6 Weeks Exp (n=40) | Ctrl (n=40)	Post-test: 3 Months Exp (n=40) | Ctrl (n=40)
Mild / No Pain (Score: 0 - 3)	0 (0.0%) | 0 (0.0%)	29 (72.5%) | 6 (15.0%)	40 (100%) | 26 (65.0%)
Chi-Square (x^2) Test	x^2 = 0.125, p = 0.724	= 27.214, p < 0.001**	= 17.037, p < 0.001**

*Note: Exp = Experimental Group; Ctrl = Control Group. ** Indicates highly statistically significant differences between groups.*

Table 6 describes the longitudinal categorical shifts in pain intensity levels between the two cohorts. At the baseline pre-test stage, the vast majority of participants in both groups experienced severe pain (90.0% in the experimental group vs. 87.5% in the control group), confirming no statistically significant difference prior to the intervention (p = 0.724). However, highly significant statistical divergences emerged at the 6-week post-test interval (p < 0.001), where 72.5% of the gamified app users successfully transitioned into the mild/no pain category, compared to a meager 15.0% in the control group. By the 3-month mark, 100% of the experimental group achieved complete baseline resolution into the mild/no pain cluster, whereas 35.0% of the conventional care cohort continued to suffer from lingering moderate pain, validating the acceleration of clinical recovery via digital gamified adherence.

Table 7: Pearson's Inter-Correlation Matrix Between Adherence Rates, Technical Usability, and Postoperative Clinical Outcomes at 3 Months

Study Variables	1. Adherence Rate	2. SUS Score	3. Post-test Pain (VAS)	4. Post-test Function (WOMAC)
1. Adherence Rate (%)	1			
2. SUS Usability Score	.542**	1		
3. Post-test Pain (VAS)	-.684**	-.412*	1	
4. Post-test Function (WOMAC)	-.745**	-.489**	.712**	1

Note: () Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). Lower clinical scores (VAS/WOMAC) signify superior clinical recovery.*

The Pearson correlation matrix **(Table 7)** shows strong, statistically significant cross-variable connections across behavioral, systemic, and clinical dimensions. A strong and statistically significant negative correlation was established between rehabilitation adherence rates and post-test pain intensity (r = -0.684, p < 0.01), as well as overall joint dysfunction scores (r = -0.745, p < 0.01). Within the context of orthopedic scoring protocols, these negative coefficients show a strong clinical benefit: higher exercise compliance tracked through the mHealth application leads to lower postoperative joint pain and greater physical recovery (lower WOMAC scores). Additionally, a significant positive correlation was identified between application usability and compliance ($r = 0.542$, $p < 0.01$), demonstrating that intuitive and engaging interface designs directly improve user adherence.

Discussion

The primary objective of this quasi-experimental study was to investigate the effectiveness of a gamified mobile health (mHealth) application in enhancing postoperative home-based rehabilitation compliance, improving functional outcomes, and mitigating pain among Total Joint Arthroplasty (TJA) patients. The empirical findings confirmed all three primary hypotheses, demonstrating that integrating game-design mechanics into digital orthopedic recovery pathways yields highly significant behavioral and clinical benefits over traditional paper-based home exercise instructions.

The statistical results revealed a stark and expanding behavioral divergence between the two cohorts. While both groups started their recovery with relatively acceptable compliance, the experimental group maintained a high adherence rate at 3 months postoperatively, whereas the control group's compliance collapsed significantly. This major find proves that traditional, static methods fail to maintain long-term patient engagement once the initial motivation of post-discharge recovery fades. Traditional paper booklets do not offer interactive feedback, leaving patients isolated and prone to abandoning their routines due to monotony.

In contrast, the gamified mHealth app successfully counteracted this behavioral decline. By incorporating the PBL triad (Points, Badges, and Leaderboards), the digital interface converted painful and repetitive physical exercises into a rewarding series of short-term milestones. The immediate receipt of 100 XP upon exercise completion and the accumulation of streak bonuses provided continuous positive reinforcement. This mechanism directly satisfies the psychological needs of competence and autonomy defined by Self-Determination Theory.

These adherence findings are highly consistent with recent multi-center evidence by **Santiago et al.** (**2022**), who documented that interactive mobile systems utilizing gamification achieved long-term compliance rates exceeding 80% in major joint replacement populations. Similarly, our results align with **Dionisi et al. (2021),** who reported that automated behavioral cues and progress tracking are vital digital therapeutic tools to sustain remote physical therapy habits.

However, our findings contrast with the earlier research of **Alzakri et al. (2022). T**hey argued that home-based compliance drops within the first two months regardless of the delivery medium used. This disagreement stems from a crucial design difference evaluated standard, non-gamified medical apps that merely delivered passive video instructions. This reinforces our conclusion that digital health tools must include interactive behavioral incentives, rather than just digital text or video, to truly drive patient compliance.

The behavioral success of the gamified mHealth intervention translated directly into superior clinical outcomes. The Two-Way Repeated Measures ANOVA revealed a highly significant Group × Time interaction effect ($p < 0.001$) for both pain intensity and physical function scores. At the 3-month mark, the experimental group reached an exceptional functional recovery level, with mean WOMAC scores dropping to 18.2, compared to 33.4 in the control group. Concurrently, pain intensity among app users decreased to a minimal mean VAS score of 1.4, whereas the control group continued to experience moderate residual pain (VAS = 3.1).

This clinical superiority is directly linked to the higher exercise volume and consistency maintained by the experimental cohort. Early, regular movement is essential to stimulate mechanical blood flow, improve muscle strength, and prevent arthrofibrosis. By executing their exercises precisely as prescribed, patients in the experimental group achieved optimal joint remodeling and faster reduction in localized swelling.

Furthermore, the interactive app design explicitly addresses the psychological barrier of kinesiophobia (fear of movement). By focusing the patient's immediate attention on unlocking digital milestone badges (e.g., *"Flexibility Champion"*) or climbing the anonymous compliance leaderboard, the application lessened their focus on immediate physical discomfort. This cognitive distraction mechanism breaks the classic postoperative "pain-avoidance-inactivity" cycle that commonly delays recovery in unmonitored home settings.

Our clinical outcome findings are in complete agreement with the landmark study by **Menon et al. (2020),** which proved that strict adherence to remote home-based physical therapy leads to significant improvements in joint range of motion (ROM) and physical function. Our results also align with the clinical consensus published by **Westby et al. (2014)**, which emphasizes that structured, high-frequency rehabilitation routines are necessary to achieve optimal joint recovery and prevent long-term functional limitations.

Conversely, our findings contrast with the clinical trials of **Patel & Thind, (2020**). Their study found no significant differences in 3-month WOMAC functional recovery scores between patients using a digital platform and those using traditional paper methods. This clinical contradiction can be explained by examining the features of the software platform they used. The digital system served only as a basic telemedicine communication tool for sending vital signs, completely lacking any interactive progress bars, rewards, or gamified mechanics to motivate daily exercise compliance. This difference highlights that remote digital platforms can only improve clinical outcomes if they include effective behavioral design features that keep patients actively engaged in their physical rehabilitation.

The stratification of patient data into distinct proficiency levels and the subsequent inferential correlation analysis provide deep behavioral insights into why the gamified mobile health application succeeded where traditional orthopedic care models fail. By looking past simple group averages to analyze individual patient behaviors, these findings provide clear evidence of how digital behavioral design can reshape home-based rehabilitation after Total Joint Arthroplasty.

The behavioral division emphasized the role of the gamified application in preventing the drop in compliance that usually occurs during unsupervised home-based recovery. Finding that less than three quarters of the experimental group maintained a High Adherence level (exercising ≥ 80% of their prescribed sessions) during the 3-month period confirms that the application provides sustained behavioral motivation. Conversely, the fact that two fifths of the control group fell into the Low Adherence level (< 50% compliance) highlights the vulnerability of unsupervised patients when relying solely on static paper booklets. Paper booklets lack dynamic feedback loops, interactive incentives, and behavioral prompts, meaning traditional home exercise protocols often fail to help patients build lasting behavioral habits (Tran et al., 2022).

Furthermore, the high compliance rates achieved by the experimental group are directly supported by the software usability results. The finding that most of the intervention group rated the gamified application as "Good" or "Excellent" (System Usability Scale [SUS] ≥ 68) addresses a common concern in orthopedic digital health: the worry that elderly patients might struggle with digital interfaces. By combining clear visual paths with clear gamified rewards (such as points and digital badges), the software design minimized technical friction.

These stratified findings are highly consistent with recent research by **Santiago et al. (2022),** who reported that orthopedic mobile systems using gamification frameworks helped over three quarters of patients maintain high adherence during remote home care. Similarly, our results align with the usability models evaluated by **Kari et al., (2016**), which showed that health applications focusing on clear progression systems significantly lower technology anxiety and increase sustained user interaction.

However, our findings contrast with those of **Li et al. (2021**), who found that elderly orthopedic cohorts reported high technology frustration and drop-out rates when using mobile monitoring software. This difference in findings highlight a key design distinction: the application relied on complex manual input and text-heavy compliance tracking, lacking any interactive gamified elements to encourage participation and simplify the user experience.

The categorical breakdown of pain intensity levels over time clearly illustrates the direct clinical benefits of sustained exercise adherence driven by the gamified mHealth application. The data shows that while both groups experienced identical severe pain profiles directly after hospital discharge, their paths to pain resolution diverged significantly. The experimental group achieved a much faster transition away from moderate and severe pain categories within the first 6 weeks compared to the control group. This clinical acceleration is directly linked to the consistent, high-frequency physical movements performed by the app users. In major joint surgery, early and consistent home physical therapy promotes biological joint lubrication, reduces localized soft-tissue swelling, and **decreases** joint stiffness, which collectively lower the overall perception of pain **(Wainwright & Kehlet, 2019).**

Furthermore, the fast elimination of moderate-to-severe pain in the experimental group addresses a critical clinical challenge in orthopedic recovery: the psychological cycle of fear-avoidance, or kinesiophobia. Traditional paper booklets often fail because when a patient experiences acute pain during an unmonitored home exercise session, they frequently stop exercising out of fear of causing structural damage to the joint **(Al-Amiry et al., 2025**).

The gamified app successfully broke this negative feedback loop. By utilizing cognitive-behavioral distraction methods—such as shifting the patient's immediate focus toward earning experience points (XP) or unlocking the *"Pain Defier"* milestone badge—the app decreased their focus on immediate physical discomfort. This psychological shift allowed patients to complete their prescribed movement sets, leading to faster tissue adaptation and accelerated pain relief over time.

The inferential relationships provided a clear physiological and behavioral explanation for the success of the digital intervention. The strong, statistically significant negative correlation between rehabilitation adherence rates and post-test joint dysfunction and pain intensity directly validates the study's core therapeutic logic: higher compliance with digital home protocols leads to superior physical recovery.

From a physiological perspective, this strong correlation shows that the consistent exercise habits maintained by app users provided the regular mechanical movement needed to accelerate tissue healing, reduce joint stiffness, and restore muscle strength around the new joint.

Additionally, the significant positive correlation between technical usability and adherence rates empirically demonstrates that software design directly influences user behavior. When a digital health interface is intuitive and easy to navigate, patients interact with it more frequently, which directly increases their adherence to the physical rehabilitation exercises.

These correlation findings are in complete agreement with recent digital therapeutic research by **Dionisi et al. (2021**), which found a strong direct correlation between automated mobile app usage logs and objective functional mobility scores in post-arthroplasty patients. Our results also support the remote rehabilitation guidelines published by **Westby et al. (2014),** which state that systematic, high-frequency exercise habits are the single most reliable predictor of long-term joint health and successful recovery.

Conversely, our findings contrast with the clinical trials of **Patel & Thind, (2020)**, who reported no meaningful statistical correlation between patient interaction with a remote monitoring application and final functional recovery scores. This difference in findings can be explained by looking at the specific features of the software platform used in their study. The digital platform served only as a basic communication tool for checking clinical vital signs, without providing any active exercise guidance or gamified motivation.

Because it lacked features to keep patients engaged with their physical therapy, simply logging into the app did not lead to increased physical exercise or improved recovery. This reinforces our primary conclusion: for an mHealth platform to truly improve orthopedic recovery, it must go beyond simple data collection and include interactive, behavioral design elements like gamification to keep patients actively engaged in their physical rehabilitation.

Limitations of the Study

Despite the significant clinical and behavioral findings, several limitations must be acknowledged when interpreting the results of this study. First, the use of a convenience sampling method at a single medical center restricts the random representation of the participants, which may limit the generalizability of the findings to the broader population of Total Joint Arthroplasty (TJA) patients in different healthcare sectors. Second, the study relied partly on a quasi-experimental design rather than a true randomized controlled trial (RCT); although baseline homogeneity was established, the lack of complete randomization might introduce potential selection bias. Third, while the rehabilitation adherence of the experimental group was monitored through objective app analytics, the control group's adherence relied entirely on self-reported paper diaries, which are naturally susceptible to recall bias or over-reporting by patients. Lastly, the evaluation period was limited to a short-term 3-month follow-up postoperatively; therefore, the long-term sustainability of gamified mHealth apps and their impact on late prosthetic complications or joint survival rates remain unassessed.

Conclusion

Based on the findings of the current study, This study provided strong empirical evidence supporting the application of gamified mobile health (mHealth) applications to optimize remote orthopedic recovery pathways. The integration of specific behavioral gamification mechanics such as experience points (XP), milestone-driven digital badges, and privacy-protected leaderboards—significantly enhances postoperative rehabilitation compliance among TJA patients during the critical first three months following hospital discharge. By effectively transforming a repetitive, painful, and monotonous home-based exercise routine into a structured and rewarding series of tasks, this digital therapeutic intervention successfully counteracts patient boredom and motivational decline. Ultimately, the marked increase in exercise compliance translates directly into superior clinical outcomes, demonstrated by faster pain reduction and superior functional joint recovery compared to traditional paper-based instruction methods.

Recommendations:

- Healthcare organizations should transition from traditional static paper booklets to interactive, media-rich mHealth platforms as a standard component of discharge planning for orthopedic major surgeries.
- Orthopedic surgeons and physical therapists should be equipped with centralized digital dashboards synchronized with the patients' apps to monitor exercise compliance in real-time, allowing for early clinical screening and timely remote adjustment of exercises.

- Structured, in-hospital educational sessions (similar to the 30-minute training protocol utilized in this study) should be standard practice before discharge to ensure technical literacy and reduce digital anxiety, especially among elderly patients.
- Future research should extend the tracking and follow-up intervals to 12 months or longer to assess the long-term durability of digital behavioral interventions and their impact on overall quality of life.
- Investigators should replicate this study utilizing multi-center, true randomized controlled trial designs with larger, randomly selected samples to enhance the generalizability of the findings.
- Research should explore the clinical efficacy of "personalized gamification," where the app's rewards, notifications, and competitive elements automatically adapt to the user's specific age, psychological profile, and daily pain levels rather than using a one-size-fits-all model.

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