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Short Communication

Toward a Digital Dependency Analysis: Prior Research and Challenges in Generating Privacy-Protected Smartphone Logs

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Introduction

This research presents a novel approach to understanding digital dependency through the development and implementation of a smartphone behavior log data generation model. Particularly amid the COVID-19 pandemic and growing concerns about digital addiction, this study introduces a quantitative framework for analyzing digital behavior patterns and their impact on mental health. The study employs a comprehensive data-generating model that integrates behavioral indicators such as application usage patterns, temporal distribution of smartphone interactions, environmental factors, and psychological indicators. Our implementation demonstrated significant correlations between smartphone usage patterns and mental health indicators. During the pandemic period, smartphone dependence indicators showed marked increases, especially in social media and gaming applications, with varying effects across occupational groups.

Research Background and Problem Statement

Digital addiction, particularly gaming disorder as recognized by WHO in the latest version of ICD-11 (2022), represents a significant public health challenge. According to [1], the prevalence of problematic smartphone use among young people has been rising rapidly, with reported negative impacts on mental health and academic performance. This trend notably accelerated during the COVID-19 pandemic, as confirmed by *Montag, et al.,* (2021)'s [2] study showing significant increases in both internet use and problematic internet use. The WHO's diagnostic criteria for gaming disorder identify key indicators including impaired control, increasing priority given to gaming over other activities, and continuation despite negative consequences. These criteria enable standardization of diagnosis while providing a unified framework for research approaches. As demonstrated by *Elhai, et al.,* (2017)'s [3] systematic review, digital addiction shows strong correlations with anxiety disorders and deterioration in real-life interpersonal relationships.

Diagnostic Framework and Clinical Understanding

The WHO's diagnostic criteria for gaming disorder have established a foundational framework for understanding digital addiction more broadly. These criteria encompass three key dimensions:

1) Impaired control over gaming behavior

2) Increasing prioritization of gaming over other life activities

3) Continuation or escalation of gaming despite negative consequences

This framework has proven valuable not only for clinical diagnosis but also for structuring research approaches. The systematic review conducted by *Elhai, et al.,* (2017) [3] revealed robust correlations between digital addiction patterns and various psychological conditions, particularly anxiety disorders. Their work also highlighted the significant impact of digital dependency on real-life interpersonal relationships, demonstrating the far-reaching implications of this phenomenon.

Contemporary Challenges in Digital Dependency Research

The current landscape of digital dependency research faces several critical challenges. First, the rapid evolution of digital technologies and usage patterns requires continuous adaptation of research methodologies. Second, the need to protect user privacy while collecting meaningful behavioral data presents significant technical and ethical challenges. Third, the complex interplay between environmental factors, individual characteristics, and digital

behavior patterns demands sophisticated analytical approaches. Our research addresses these challenges through the development of a novel data generation model that maintains privacy while capturing the multifaceted nature of digital dependency. The model incorporates various behavioral indicators, including:

- Temporal patterns of application usage
- Contextual factors affecting user behavior
- Psychological indicators and their correlations with usage patterns
- Environmental influences, particularly those related to the COVID-19 pandemic

The integration of these elements, while maintaining robust privacy protections, represents a significant advancement in digital dependency research methodology.

Methodology and Data Processing

Our research methodology represents a significant advancement in digital dependency analysis through its innovative combination of quantitative behavioral tracking and privacy protection measures. The foundation of our approach lies in the development of a sophisticated data generation model that enables detailed analysis of smartphone usage patterns while maintaining robust privacy safeguards.

Data Generation Model Architecture

The core of our methodology centers on a comprehensive data generation model that captures the multifaceted nature of smartphone usage. We have developed a state-based classification system that categorizes usage patterns into four distinct states: active engagement, background processing, idle status, and sleep mode. This classification enables detailed behavioral analysis while maintaining user anonymity through aggregated pattern recognition rather than individual tracking. The model incorporates temporal variation analysis, recognizing that usage patterns fluctuate significantly across different times of day and days of the week. This temporal dimension is crucial for understanding the rhythms of digital dependency and identifying potential intervention points. By implementing probabilistic state transitions, our model captures the natural flow of user behavior while preserving privacy through statistical abstraction.

Privacy Protection Framework

Our privacy protection framework employs multiple layers of security measures while maintaining the analytical utility of the data. The primary components include: The anonymization process begins at the data collection stage, implementing sophisticated transformation algorithms that convert raw behavioral data into privacy-preserved formats. This transformation maintains statistical relationships while eliminating personally identifiable information. Our approach draws upon advanced cryptographic techniques to ensure that even aggregate data cannot be reverse-engineered to identify individuals.

We have developed specific protocols for handling sensitive temporal data, ensuring that longitudinal analysis can proceed without compromising user privacy. This includes the implementation of dynamic anonymization thresholds that adjust based on data density and sensitivity levels.

Analysis Framework Implementation

(Figure 1,2,3) The analytical framework we developed integrates multiple data streams while maintaining privacy safeguards at each processing stage. This framework enables: The examination of usage patterns across various temporal scales, from hourly variations to long-term trends Analysis of correlations between usage patterns and psychological indicators Investigation of environmental impacts on digital behavior Assessment of occupation-specific usage patterns and risk factors.

Figure 1: Correlation Between Mental Health Indicators.

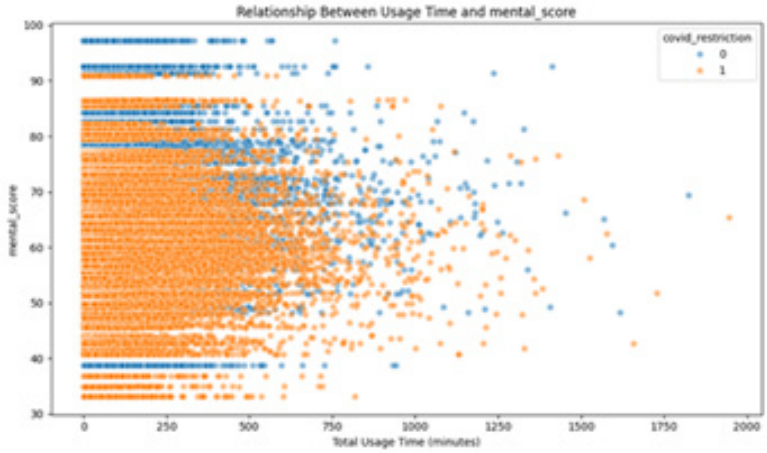

Figure 2: Relationship Between Usage Time and mental score.

Figure 3: Relationship Between Usage Time and loneliness score.

Results and Analysis

Our comprehensive analysis revealed several significant findings regarding the relationship between smartphone usage patterns and mental health indicators. The results demonstrate complex interactions between digital behavior and psychological well-being, with important implications for intervention strategies.

Correlation Analysis of Mental Health Indicators

The correlation matrix analysis (Figure 1) revealed intricate relationships between mental health scores, loneliness indicators, and digital addiction metrics. Particularly noteworthy is the identification of weak but consistent positive correlations between loneliness scores and digital addiction measures (game addiction: r=0.25, smartphone addiction: r=0.18). These correlations suggest that while digital behavior and psychological well-being are related, the relationship is more nuanced than previously theorized.

Temporal Analysis and Usage Patterns

Our analysis of usage patterns revealed critical thresholds that may indicate increased risk for digital dependency. Most significantly, users exceeding 750 minutes of daily usage demonstrated markedly lower mental health scores, particularly during periods of COVID-19 restrictions. This finding suggests a potential ceiling effect in digital engagement, beyond which negative psychological impacts become more pronounced. The relationship between usage time and loneliness scores (Figure 3) displayed an interesting pattern of increased dispersion at higher usage levels. This pattern suggests that excessive digital engagement may lead to divergent psychological outcomes, potentially influenced by individual differences and environmental factors.

Discussion

The findings from our research present several important implications for both theoretical understanding and practical applications in digital dependency intervention. The identification of specific usage thresholds provides concrete markers for intervention planning, while the complex relationship patterns between usage and mental health indicators suggest the need for nuanced, personalized intervention approaches. Our research contributes to the theoretical understanding of digital dependency in several ways. First, the identification of specific usage thresholds advances our understanding of when digital engagement transitions from beneficial to potentially harmful. Second, the complex correlations

observed between different addiction indicators and mental health metrics suggest that digital dependency operates through multiple, interacting pathways rather than simple cause-effect relationships. The practical implications of our findings extend to various stakeholders involved in digital wellness promotion. For healthcare providers, our results offer specific metrics for risk assessment and intervention planning. For developers of digital wellness tools, our findings suggest optimal points for intervention notifications and usage limitations. For educational institutions and employers, our results provide guidance for developing digital wellness policies that balance productivity with well-being [4-23].

Conclusion

This research establishes a robust framework for studying digital dependency while maintaining strong privacy protections. Our findings contribute significantly to both the theoretical understanding and practical applications in digital addiction research. The identification of specific usage thresholds and correlation patterns provides concrete guidance for intervention strategies, while our privacy-preserving methodology offers a template for future research in this sensitive domain.

Future research directions should focus on:

1) Further refinement of prediction models for early intervention

2) Development of more sophisticated privacy-preserving analysis techniques

3) Integration of real-time monitoring capabilities with privacy protection

4) Expansion of the framework to accommodate emerging forms of digital interaction

These developments will be crucial in addressing the growing challenges of digital dependency in an increasingly connected world, while maintaining the highest standards of privacy protection and research ethics.

Acknowledgement

None.

Conflict of Interest

None.

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