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ORIGINAL RESEARCH

Altered Heart Rate Variability During Mobile Game Playing and Watching Self-Mobile Gaming in Individuals with Problematic Mobile Game Use: Implications for Cardiac Health

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Introduction: The surge in mobile gaming, fueled by smartphone and internet accessibility, lacks a comprehensive understanding of physiological changes during gameplay.

Methods: This study, involving 93 participants (average age 21.75 years), categorized them into Problematic Mobile Gaming (PMG) and non-problematic Mobile Gaming (nPMG) groups based on Problematic Mobile Gaming Questionnaire (PMGQ) scores. The PMGQ is a 12-item scale developed in Taiwan to assess symptoms of problematic mobile gaming. The research delved into heart rate variability (HRV) alterations during real-time mobile gaming and self-gaming video viewing.

Results: Results showed that the PMG group significantly presents a lower root mean square of successive differences (RMSSD), and High Frequency (lnHF) than does the nPMG group ($F=4.73$, $p=0.03$; $F=10.65$, $p=0.002$, respectively) at the baseline. In addition, the PMG group significantly displayed elevated HF and low-frequency to high-frequency (LF/HF) in the mobile-gaming ($F=7.59$, $p=0.007$; $F=9.31$, $p=0.003$) condition as well as in the watching self-gaming videos ($F=9.75$, $p=0.002$; $F=9.02$, $p=0.003$) than did the nPMG.

Conclusion: The study suggests targeted interventions to mitigate autonomic arousal, offering a potential avenue to address adverse effects associated with problematic mobile gaming behavior. The PMG group displayed increased craving scores after real-time mobile gaming and watching self-gaming video excerpts, unlike the nPMG group. Elevated LF/HF ratios in frequent gaming cases heightened autonomic arousal, presenting challenges in relaxation after mobile gaming. These findings contribute to a nuanced understanding of the complex interplay between mobile gaming activities, physiological responses, and potential intervention strategies.

Keywords: addictive behaviors, video games, internet addiction, autonomic nervous system, craving, heart rate variability, self-regulation

Introduction

With the widespread adoption of smartphones, gaming has shifted to mobile devices. People use smartphones for gaming to relax and cope with negative emotions, potentially leading to problematic usage.[1] Mobile game addiction may be associated with Internet Gaming Disorder (IGD). IGD was introduced as a research diagnosis in DSM-5 (2013)[2,3] and

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later as a formal diagnosis in ICD-11 (2018).[4] Mobile gaming addiction involves prolonged and recurrent mobile game use, resulting in adverse physical and psychological effects, including social anxiety, depression, loneliness, insomnia, eye strain, impaired self-control, headaches, and academic underperformance.[1,5–7]

In Taiwan, internet cafés were once highly popular among young adults for playing online games, especially with friends.[8] However, media outlets have depicted online gaming as hazardous, publishing accounts of sudden deaths after excessive play in internet cafés.[9–11] Consequently, the impact of long-term gaming on cardiovascular function has drawn attention.[12] An "internet-addiction hypothesis of autonomic activity" has been proposed and suggested that dysregulation of the autonomic nervous system (ANS) is related to internet addiction and characterized by shifts towards sympathetic dominance and decreased parasympathetic activity.[13]

Correlation Between Gaming and Heart Rate Variability

Heart rate variability (HRV) gauges autonomic nervous system (ANS) functioning,[14] revealing variations in individuals with and without Internet Gaming Disorder (IGD) during resting states, suggesting potential ANS imbalances, especially in sympathetic nervous system (SNS) activity even in the presence of gaming stimuli.[15] The severity of IGD correlates with reduced HRV in the high-frequency (HF) range. During gaming, IGD individuals display diminished HF HRV and root mean square of successive differences (RMSSD), while the non-IGD group maintains stable HRV.[16,17] These findings imply heightened SNS activity and diminished parasympathetic nervous system (PNS) activity in IGD individuals during gaming,[18,19] as confirmed by Hsieh and Hsiao (2016).[20] However, comprehending the clinical implications and advantages of increased HRV during and after gaming requires further investigation. Although existing studies suggest temporary HRV elevation during gaming, the lasting clinical impact on gamers remains uncertain.[13]

Correlation Between Craving and Gaming Experiences

Individuals with Internet Gaming Disorder (IGD) often experience cravings, and powerful motivational desires implicated in addictive behavior development and maintenance.[21,22] Such cravings can arise when encountering negative emotions[23] and game-related cues, stimulating cravings among those with IGD.[24,25] Similar patterns have been observed in alcohol use disorder, where reduced resting heart rate variability (HRV), particularly in the high-frequency (HF) range, is linked to craving and relapse.[26,27] Additionally, lower HRV, particularly in the HF range, has been associated with increased food cravings.[28,29] This interconnection between cravings, emotional regulation, and HRV in addiction suggests that interventions targeting HRV enhancement and emotional regulation may aid in addiction management. Higher HRV is associated with better emotional control, potentially reducing cravings. This understanding highlights the potential for interventions to address cravings and promote healthier emotional regulation in the context of addiction.[23,30,31]

Previous research has explored the connection between craving and heart rate variability (HRV) in IGD. One study found that the standard deviation of normal-to-normal intervals (SDNN) decreased during gaming, but self-reported craving scores failed to distinguish effectively between individuals with IGD and those without. This study did not, however, delve into the links between craving and ANS system metrics.[32] The rise of social media platforms like YouTube, Instagram, and TikTok has provided opportunities to witness the gaming experiences of others. This exposure may trigger cue-related cravings, leading to desires to continue playing or watching games despite negative consequences like fatigue, sleep deprivation or neglect of other responsibilities.

The current study investigated relationships between problematic mobile gaming (PMG), HRV, and craving to gain insight into physiological underpinnings. Specifically, we hypothesized that individuals with PMG would demonstrate increased cue-related cravings. Further, we hypothesized that craving would link to diminished HRV among individuals with PMG.

Methods

This study was approved by the Institutional Review Board (IRB) at Tsaotun Psychiatric Center (No. 111014) and China-Medical University Hospital (CMUH109-REC2-123). Before initiating the study, all participants needed to provide signed consent. For individuals under 20 years old, a parent's consent was also required alongside their own. Participants were given the choice to leave the study at any time.

Participants

Ninety-three participants, recruited through digital platform advertisements (from July 2022 to December 2022), provided informed consent for their involvement in the study. A power analysis using G*power 3.1[33] determined that a minimum of 66 participants was required for statistical significance in a mixed-model ANOVA test, with an assumed medium effect size (d = 0.5) and a power of 0.8. Participants, averaging 21.75 years, included 37 males and 56 females. Based on the Problematic Mobile Gaming Questionnaire (PMGQ) thresholds, 33 were classified with problematic mobile gaming (PMG; 14 males, 19 females), and 60 as non-problematic mobile gaming (nPMG; 23 males, 37 females). Within the PMG group, 45.5% met IGD-10 criteria, indicating a relative risk of Internet Gaming Disorder. Exclusive criteria involved neurological or mental disorders, substance use, tobacco, and conditions affecting heart rate variability (HRV). Demographic details are available in Table 1.

Table 1 Demographic Information of the Participants

Variables	**nPMG (N = 60)**	**PMG (N = 33)**		**χ^2/F (p)**	
		PMG^{-IGD} (N=18)	**PMG^{+IGD} (N=15)**	**nPMG vs PMG**	**PMG^{-IGD} vs vs PMG^{+IGD}**
Age (M ± SD)	21.77 ± 2.72	21.56 ± 2.85	21.93± 3.03	0.004	0.37 (0.72)
Gender (N, %)				0.36	0.20 (0.65)
Male	23 (38.3%)	7 (38.9%)	7 (46.7%)	-	
Female	37 (61.7%)	11 (61.1%)	8 (53.3%)	-	
PMGQ (M ± SD)	21.27 ± 4.91	33.89 ± 3.43	33.73 ± 3.56	84.02***	0.02 (0.90)
T1-Baseline					
SDNN	53.49 (21.46)	46.30 (22.15)	47.85 (14.00)	2.13 (0.15)	0.05 (0.82)
RMSSD	42.06 (23.14)	31.13 (19.88)	32.34 (20.45)	4.73 (0.03)	0.03 (0.87)
lnLF	5.29 (0.90)	5.27 (1.03)	5.33 (0.89)	0.01 (0.85)	0.04 (0.85)
lnHF	5.40 (1.06)	4.64 (1.12)	4.67 (1.04)	10.65 (0.002)	0.01 (0.93)
LF/HF	1.91 (5.56)	2.15 (1.25)	3.75 (5.20)	0.81 (0.37)	1.60 (0.22)
CMGSb	5.27 (5.00)	11.50 (3.43)	11.20 (4.02)	37.84 (<.00001)	0.05 (0.82)
T2-Mobile gaming					
SDNN	53.25 (19.49)	48.79 (20.33)	46.67 (20.49)	1.61 (0.21)	0.09 (0.77)
RMSSD	44.56 (23.48)	34.14 (23.40)	32.40 (21.93)	5.01 (0.028)	0.05 (0.83)
lnLF	5.31 (0.81)	5.27 (1.03)	5.33 (0.59)	0.43 (0.52)	1.78 (0.19)
lnHF	5.21 (1.00)	4.68 (1.21)	4.44 (1.20)	7.59 (0.007)	0.33 (0.57)
LF/HF	1.49 (1.19)	2.37 (1.39)	2.29 (1.52)	9.31 (0.003)	0.03 (0.88)
T3-Post mobile gaming					
SDNN	56.10 (19.78)	47.64 (21.71)	53.63 (20.47)	1.71 (0.19)	0.65 (0.43)
RMSSD	42.26 (21.79)	29.12 (15.41)	28.98 (15.84)	9.50 (0.003)	0.001 (0.98)
lnLF	5.34 (0.93)	5.30 (1.00)	5.58 (0.95)	0.19 (0.66)	0.71 (0.41)
lnHF	5.45 (0.96)	4.71 (1.03)	4.41 (0.95)	17.38 (<.00001)	0.71 (0.41)
LF/HF	1.34 (1.55)	2.19 (1.45)	4.47 (3.04)	19.72 (<.00001)	7.98 (0.008)[a]
CMGSpg	9.20 (4.97)	16.39 (4.57)	17.80 (4.21)	57.21 (<.0001)	0.84 (0.37)
T4- (Relax)					
SDNN	59.12 (21.71)	59.02 (33.09)	58.90 (25.38)	0.001 (0.98)	0.00 (0.99)
RMSSD	42.45 (19.30)	33.95 (21.79)	33.04 (16.91)	4.53 (0.04)	0.02 (0.90)
lnLF	5.54 (0.93)	5.59 (0.98)	5.65 (0.87)	0.15 (0.70)	0.03 (0.86)
lnHF	5.47 (0.87)	4.68 (1.02)	4.78 (0.95)	14.33 (<.0001)	0.09 (0.77)
LF/HF	1.59 (1.76)	2.76 (1.43)	2.91 (1.81)	11.12 (0.001)	0.07 (0.79)
CMGSr	4.00 (4.29)	13.61 (4.83)	13.13 (4.85)	56.05 (<.00001)	0.08 (0.78)

(Continued)

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Table 1 (Continued).

Variables	nPMG (N = 60)	PMG (N = 33)		χ^2/F (p)	
		PMG^{-IGD} (N=18)	PMG^{+IGD} (N=15)	nPMG vs PMG	PMG^{-IGD} vs vs PMG^{+IGD}
T5-Watching gaming video)					
SDNN	59.57 (21.53)	60.46 (32.76)	54.03 (20.64)	0.15 (0.70)	0.43 (0.52)
RMSSD	46.64 (23.93)	42.23 (33.50)	34.11 (23.04)	2.09 (0.15)	0.63 (0.43)
lnLF	5.63 (0.78)	5.74 (0.84)	5.37 (0.59)	0.15 (0.70)	2.05 (0.16)
lnHF	5.40 (0.91)	4.85 (1.21)	4.61 (0.96)	9.75 (0.002)	0.38 (0.54)
LF/HF	1.71 (1.66)	2.94 (1.90)	2.67 (1.63)	9.02 (0.003)	0.20 (0.66)
T6-Post watching gaming video					
SDNN	60.82 (17.65)	59.34 (24.15)	64.80 (22.95)	0.05 (0.82)	0.44 (0.51)
RMSSD	43.92 (18.96)	32.60 (19.72)	37.15 (20.47)	4.89 (0.029)	0.42 (0.52)
lnLF	5.46 (0.91)	5.62 (0.86)	5.95 (0.75)	2.68 (0.11)	1.41 (0.25)
lnHF	5.42 (0.85)	4.69 (0.82)	4.87 (0.88)	12.42 (0.001)	0.38 (0.55)
LF/HF	1.68 (2.15)	2.91 (1.65)	3.47 (1.86)	11.43 (0.001)	0.83 (0.37)
CMGSpw	7.57 (5.70)	15.61 (4.30)	16.67 (6.64)	56.05 (<.0001)	0.49 (0.49)

Note: [a]significant difference in PMG sub-groups (PMG^{-IGD} vs PMG^{+IGD}); ***p < 0.0001.
Abbreviations: PMG, Problematic mobile gaming; nPMG, non-problematic mobile gaming; CMGS, Craving for mobile gaming score; SDNN, Standard deviation of NN interval; RMSSD, Root mean square of successive differences of normal NN intervals; LF, Low-frequency power; HF, High-frequency power; LF/HF, Low Frequency/High Frequency.

Measurements

Problematic Mobile Gaming Questionnaire (PMGQ)

The PMGQ, developed by Pan, Chiu, and Lin (2019)[34] in Taiwan, was constructed based on the Smartphone Addiction Inventory (SPAI) created by Liu, Lin, Pan, and Lin (2016).[35] to assess symptoms of problematic mobile gaming. This 12-item scale assesses "compulsion", "tolerance", and "withdrawal" using a 4-point Likert scale (1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, and 4=strongly agree) based on experiences in the past 3 months. A PMG is defined by a score exceeding 30 points.[34,35] The Cronbach's alpha was 0.92 for this study.

Ten-Item Internet Gaming Disorder Test (IGDT-10)

The IGDT-10 scale (Chiu et al, 2018) assesses Internet Gaming Disorder (IGD) based on DSM-5 criteria (American Psychiatric Association, 2013). It includes 10 items, with participants rating the frequency of IGD-related behaviors on a 3-point scale (0=never, 1=sometimes, and 2=often). Items 9 and 10 were combined as one criterion. A score range of 0–18 was employed, with higher scores indicating more severe IGD. A threshold of 5 was used to define IGD. The IGD-10 demonstrated strong internal consistency, with a Cronbach's α of 0.87 in the present study.

Craving for Internet Gaming Scale (CIGS)

The CIGS, devised by Savci and Griffiths (2019),[36] is a modification of the alcohol craving scale by Flannery, Volpicelli, and Pettinati (1999). A Chinese adaptation, composed of 5 items rated along a 7-point Likert scale, was used here and adapted to assess craving for mobile gaming (CMGS). The Cronbach's alpha was 0.94 for this study.

Instruments

Electrocardiograms (ECGs) were obtained using a BioGraph Infiniti 6.0 system. ECG electrodes were positioned on participants bilaterally, beneath the midclavicular line, and at the fifth intercostal space on the left side (below the heart). Heart rate was measured in beats per minute, and subsequently, the CardioPro Infiniti HRV Analysis Module was utilized for ANS analysis. This software enabled the correction of inter-beat interval data, which were then converted into an HRV index.[37,38]

Procedure

Each participant was required to fixate on the monitor while resting. ECG sensors were attached and tested to ensure that stable signals were obtained for 5 minutes while participants were in a relaxed sitting position for baseline HRV assessments. Each participant then selected their regular/favorite game and engaged in real-time gaming for 10 minutes. Next, each participant relaxed for 5 minutes and then watched their self-mobile gaming video excerpt for 10 minutes. During each experimental phase, HRV signals were measured. The experimental protocol is shown in Figure 1.

HRV Analysis

Three ECG channels were connected to participants' chests for EEG signal acquisition. Data underwent rigorous processing to eliminate unwanted noise caused by movement, breathing, and muscle electrical activity. These steps included a third-order Butterworth high-pass filtering (0.1 Hz cutoff), a sixth-order Butterworth notch filter, and a third-order Butterworth low-pass filtering with (cutoff at 15 Hz).[39] The ECG signals were recorded at a 200 Hz sampling rate, and R-R intervals were automatically detected using the Pan and Tompkins method.[40] HRV parameters were then derived from time and frequency domains using HRV analysis software.[41] The time-domain analysis measured the time between R-R intervals, employing SDNN (reflecting overall HRV) and RMSSD (reflecting short-term heart rate changes and parasympathetic activity).[42] For frequency-domain analyses, a 20% filter removed ectopic beats, and data were interpolated at 4 Hz.[43] The frequency-domain parameters were transformed with an autoregressive model. The LF domain (0.04–0.15 Hz) reflects parasympathetic and sympathetic nerve activity, and the HF domain (0.15–0.4 Hz) primarily represents parasympathetic activity.[44] The frequency-domain HRV parameters with skewed distributions were logarithmically transformed.[45] The LF/HF ratio was used as an index of sympathovagal balance.[46]

Statistical Analysis

Chi-square tests compared categorical data between groups while One-way analyses of variance (ANOVAs) compared demographic and HRV parameters differences between groups. Repeated measures ANOVAs compared group differences across various phases, including baseline, real-time gaming, post-gaming relaxation, self-gaming video watching, and post-watching relaxation. HRV parameters (RMSSD, SDNN, lnLF, lnHF, and LF/HF) and craving score changes were examined for significant group and phase interactions. Post-hoc comparisons identified specific phase differences. Bonferroni corrections were applied for multiple comparisons ($p<0.003$). The analysis characterized HRV patterns during mobile gaming and self-gaming video watching in PMG and nPMG participants. Pearson correlation explored links between craving score changes and HRV parameters. Statistical Package for Social Sciences version 23.0 (SPSS Inc., Chicago, IL, USA) conducted all analyses.

Results

Demographic Data

Approximately one-third (35.5%) of our participants had PMG, and of these, 45.45% met the criteria as IGD. The demographic data between groups are shown in Table 1. No between-group differences regarding age, sex, or educational level were observed. All HRV parameters analyzed by mixed-model ANOVA revealed a significant main effect of group and condition with no significant interaction. A main effect of period was statistically significant for the SDNN-HRV ($F [5, 87] = 17.40$, $p <0.0001$, partial eta-squared = 0.160), the RMSSD ($F [5, 87] = 5.75$,

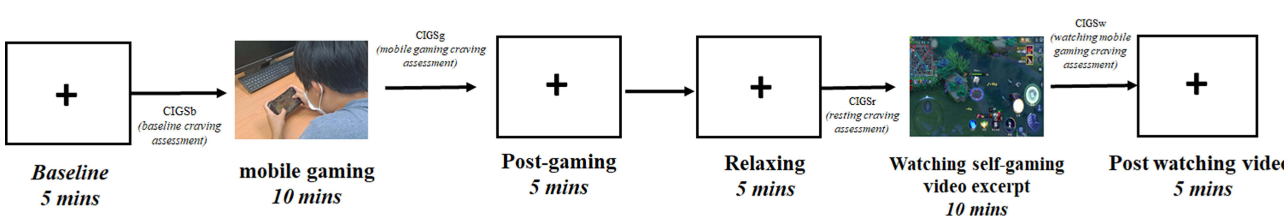

Figure 1 Experimental protocol.

p <0.00001, partial eta-squared = 0.06), and lnHF (F [5,87] = 2.32, p=0.04, partial eta-squared = 0.025). In addition, independent t-tests revealed significant differences between the two groups in the lnHF-HRV and LF/HF-HRV after real-mobile gaming and watching self-gaming videos (p <. 0016). Moreover, the PMG group displayed elevated craving scores compared to the nPMG group after real-time gaming and after watching self-mobile gaming videos, including baseline (ps < 0.001) (Table 1).

Correlation Between Craving Change Scores and HRV Parameters Across Different Conditions

CMGSg (Craving for mobile gaming score at the mobile gaming condition) significantly positively correlated to LF/HF_g ratio (r=0.43, p < 0.0001), and negatively correlated to both $RMSSD_g$ (r=−.31, p =0.003) and $lnHF_g$ (r=−.34, p = 0.001) (see Figure 2A). A similar pattern was observed correlating between $CMGS_w$ (Craving for mobile gaming score at the watching self-mobile gameplay video condition) with HRV parameters during that viewing period ($r_{LF/HFw}$= 0.35, p = 0.001; r_{RMSSDw}=−.23, p =0.03, and r_{lnHFw}=−.38, p < 0.0001 respectively) (Figure 2C). Significant correlations were also found between craving scores and HRV parameters during the post-mobile-gaming condition ($r_{LF/HFpg}$ = 0.42, p < 0.0001; $r_{RMSSDpg}$=−.36, p < 0.0001, and r_{lnHFpg}=−.45, p < 0.0001, respectively) and post-watching-gaming-video-excerpt condition ($r_{LF/HFpw}$=0.29, p=0.005; and r_{lnHFpw}=−.32, p=0.002) (Figure 2B and D).

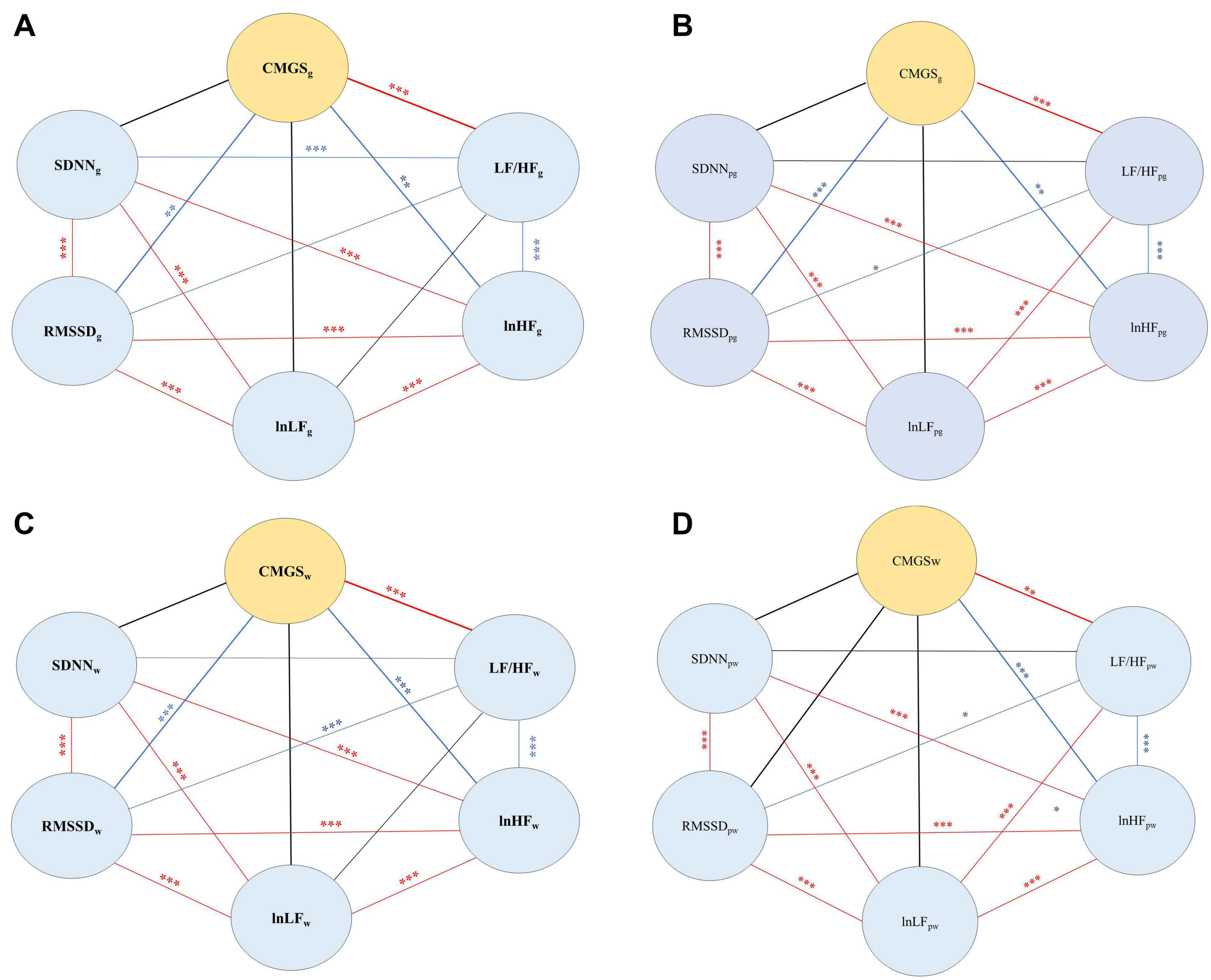

Figure 2 Correlations between craving scores and HRV parameters during each condition. (**A**) mobile gaming condition; (**B**) following the mobile gaming condition; (**C**) watching self-gaming video excerpts; (**D**) following the watching of self-gaming video excerpts.
Notes: *: p < 0.05; **p < 0.003 (Bonferroni correction); ***p < 0.0001.

Self-Regulation Among Groups Across Mobile Gaming Conditions

The results showed LF/HF significantly rose during real-time mobile gaming and self-mobile gaming video observation in both groups, followed by a subsequent decrease. Independent t-tests comparing HRV changes between conditions in the two groups revealed elevated LF/HF-HRV changes in the PMG group after gaming ($T=-2.53$, $p=0.01$), but no significant increase after watching self-mobile gaming video ($T=-.84$, $p=0.40$) compared to the nPMG group (Figure 3A). Moreover, when comparing PMG individuals who also met IGD criteria (PMG^{+IGD}), significant differences in LF/HF changes after real-time mobile gaming emerged ($T_{pgg} = -3.19$, $p=0.003$). The PMG^{+IGD} subgroup displayed the most pronounced LF/HF-HRV change during mobile gaming among all groups (Figure 3B). Interestingly, this change was absent after watching self-gaming video excerpts, instead revealing increased changes in lnLF-HRV ($T_{pwr}= -3.79$, $p=0.001$).

Discussion

Our study examined heart rate variability (HRV) fluctuations in young adults engaged in active mobile gaming and self-gaming video viewing. Participants with problematic mobile gaming (PMG) exhibited significant HRV parameter variations (SDNN, RMSSD, and lnHF) during both real-time mobile gaming and video watching. Within the PMG group, individuals with Internet Gaming Disorder (IGD) displayed distinct longitudinal LF/HF ratio shifts compared to those without IGD, indicative of unique HRV responses during gaming. The PMG^{+IGD} subgroup demonstrated elevated LF/HF ratios, indicating differing psychophysiological responses during gaming sessions. Subjective reports revealed consistent craving score increases after both real-time gaming and self-gaming video viewing in the PMG subgroup with IGD. A negative correlation between craving scores and lnHF HRV parameter changes suggested an impact of real-time mobile gaming on parasympathetic activity, highlighting cardiovascular responses during mobile gaming.[47–49] Notably, such a negative correlation was also observed after watching videos of mobile gaming experiences, the subjective craving was also induced while watching a self-mobile gameplay video. This implies that commercial advertisements for mobile games on TV may induce cardiovascular stress akin to the experience of playing a mobile game, and with a longer video and longitudinal game playing may impact more.

Previous studies have explored HRV in IGD individuals[16,18,19] emphasizing its relevance in the context of gaming. Our research specifically focused on the PMG group, revealing HRV alterations consistent with prior IGD findings, signifying heightened SNS activity and reduced PNS activity both at rest and in response to mobile gaming cues.[16,18–20]

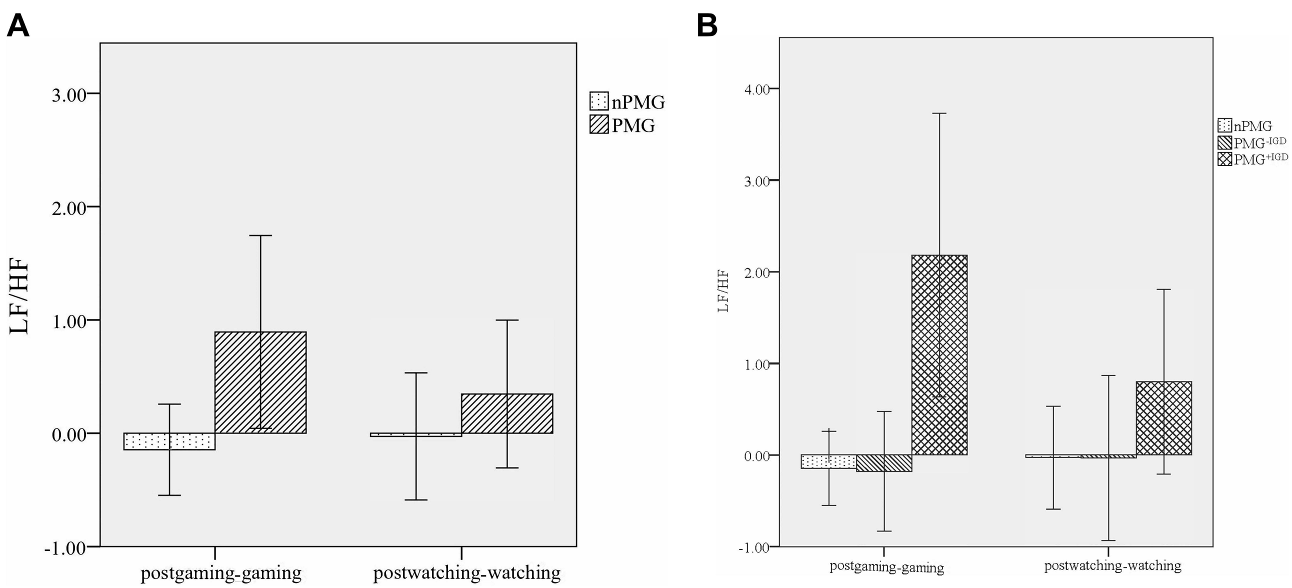

Figure 3 The changes in HRV parameters and LF/HF ratios between real-time gaming and watching gaming conditions among groups: (**A**) significant difference of LF/HF changes in the real-time gaming condition between nPMG and PMG group; (**B**) significant changes of LF/HF ratio in the real-time gaming condition between PMG^{-IGD} and PMG^{+IGD}.

Notably, we did not observe significant differences in SDNN, RMSSD, lnLF, and LF/HF between PMG and nPMG at baseline; a notable difference in lnHF was found between the PMG and nPMG, echoing previous findings in IGD.[19]

Furthermore, our study identified significant differences in RMSSD, lnHF, and LF/HF at rest, a departure from some prior IGD research.[15,50] Previous studies indicated that individuals without IGD tend to exhibit increased SNS activity during gaming, with a return to normal physiological states immediately after gaming.[51] In contrast, our PMG^{+IGD} displayed altered ANS functioning after following real-time mobile gaming.

Craving may sustain addictive behaviors, while studies have examined relationships between IGD and the ANS, there is limited research investigating relationships between gaming craving and the ANS. Regarding PMG and craving, while physiological signals associated with craving have been identified, research suggests that heart rate measurements are often not robust for detecting cravings. Moreover, the study found that video game materials do not effectively stimulate the cravings of individuals with PMG with a tendency as IGD. Researchers have emphasized the importance of HRV measurements to discern game cravings in individuals with IGD, facilitating an understanding of alterations in the ANS.[52] The results from our study suggest that there is a significant positive correlation between gaming craving and the LF/HF ratio, and a substantial negative correlation with RMSSD and lnHF measures. The findings suggest that gaming cravings may be reflected in ANS measures in individuals engaging in PMG.

In the context of time domains, the SDNN reflects overall HRV. On the other hand, the RMSSD reflects short-term HRV and is commonly employed to estimate PNS activity.[38,53] Among frequency domains, HF power has been linked to the regulation of the PNS and correlated with RMSSD. Conversely, LF power has been associated with SNS regulation. However, this interpretation has been disputed, as some researchers propose that LF represents the concurrent regulation of both the SNS and PNS. The LF/HF ratio reflects balance within the ANS and is frequently used as a measure of equilibrium between the SNS and PNS. A higher LF/HF ratio indicates a predominance of the SNS within the ANS, characterized by increased SNS activity and decreased PNS activity. Conversely, a lower LF/HF ratio suggests a dominance of the PNS within the ANS, with reduced SNS activity and increased PNS activity, typically observed when an individual is engaged in restful and relaxing behaviors.[38,46,53–56] Prolonged dominance of the SNS can potentially elevate the risk of mortality.[57,58]

Subgroup differences in LF/HF ratio change post-mobile gaming indicate distinct HRV responses in PMG, more specifically in the PMG met IGD similar to previous studies in IGD.[16] This suggests that individuals with more severe gaming problems may have elevated cardiac risk, potentially extending to gaming disorder.[59] Relative to the PMG^{-IGD} and nPMG groups, the PMG^{+IGD} exhibited significantly decreased LF/HF after playing a mobile game, suggesting a potential mechanism by which cardiac risk could extend into resting/relaxing states. Reduced HRV implies ANS imbalance, linked to various physiological and psychological disorders. Importantly, this imbalance has associations with cardiovascular disease and mortality.[58,60,61]

Previous studies have suggested potential connections between gaming and ANS function, posing risks like thromboembolisms due to prolonged sedentary periods and dehydration. Sudden blood pressure spikes during gaming could lead to hemorrhages, including strokes. Additionally, factors such as short-term and long-term sleep deprivation, extreme fatigue, and stress may disrupt autonomic functions, promoting heart rhythm irregularities.[10] Consequently, the potential links between maladaptive gaming and cardiovascular concerns should be closely monitored, especially in more vulnerable groups like older adults.

Limitations

There are some limitations in the current study. First, the sample size of the PMG^{+IGD} group was small, and not all variables affecting HRV could be controlled. The participants recruited in the current study were mostly young adults, implying that this population has easier and more accessible mobile phones for gaming. Although the PMGQ was developed to evaluate the problematic mobile gaming among adolescents, young adults may have more access to mobile gaming and need more attention. In addition, the categories and types of mobile games may alter the HRV parameters with different levels of stress reaction while playing different mobile games.[62,63] Second, participants were recruited from online platforms, which may have biased the participants' selection. Gamers who do not often use online platforms, such as Facebook or Instagram may miss the recruitment information. Third, the gender/sex distribution was unequal, implying the gender distribution among mobile gamers could be different. Women exhibited higher parasympathetic tone, whereas, in men, sympathetic dominance declined much later in life.[64] In addition, the preference for games has been reported differently between men and women. Moreover, gender-related differences in several typical CVDs have been reported.[65] The factor of gender and age may be considered as a factor for evaluating cardiac disease, and this could be considered a confounding factor in future studies. Future studies investigating larger samples of women and girls are needed, especially as cardiac risks may differ across sexes. Although all participants were instructed to choose and play their favorite mobile games, different games may have different physiological effects, and these should be investigated in future studies.

Conclusion

In sum, this study represents the first to explore associations between physiological information and problematic mobile gaming experiences. In addition, viewing videos related to gameplay may also induce relevant physiological responses as game-playing does. Moreover, we first identify the psychophysiological responses between the PMG and nPMG, and further demonstrate the similarly altered psychophysiological responses at real-time gaming and viewing gaming videos. This finding implied the potential induced physiological responses while watching gaming videos. Further, we first identified possible differences between PMG with and without IGD from a psychophysiological perspective, although the sample size was small to distinguish the difference between PMG with and without IGD from such psychophysiological markers. In addition, as the development of smartphone facilities embedded several types of applications (APP) and game genres, which may increase the risk of cardiac-related diseases. Moreover, game playing is applied for leisure time and stress relief,[66,67] as PMG has been linked to poor physical and mental well-being among teenagers and young adults,[68] future investigations may examine groups with co-occurring concerns. Such efforts might consider potential interventions, such as biofeedback training. Through biofeedback, individuals may learn to increase self-awareness, observe their physiological responses, and thus help reduce risks associated with PMG.

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Disclosure

Professor Marc N. Potenza has a pending patent application with Yale for Novartis; a consultant for Game Day Data; reports personal fees for consulting from Boehringer Ingelheim and Baria-Tek; advisory board for Opiant, outside the submitted work. The authors report no other conflicts of interest in this work.

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