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Article

A 24 h Change and Reactivity in Heart Rate Variability During Games May Predict Excessive Internet Gaming: Weak Top-Down Control among Young Students

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Abstract: Several studies have reported a relationship between autonomic dysfunction during tasks and Internet addiction. Changes within 24 h regarding heart rate variability (HRV) may be a more sensitive indicator than short-term observations. We evaluated the influence of excessive Internet usage on HRV using a 24 h electrocardiogram (ECG) and examined acute changes during computer game tasks. A total 13 high school students and 22 young adults were recruited, and divided into excessive Internet user and non-excessive user groups based on Internet addiction test scores. The ECG was recorded continuously for 24 h by a wearable sensor and during two computer games (the Iowa gambling task and each participant's preferred game) using a standard type ECG system. Multiple psychometric tests were also conducted. The excessive Internet user group exhibited clinically significant depressive symptoms, and higher self-reported scores for anxiety, impulsivity, autistic tendencies, and sleep problems than the non- excessive internet user group. There were weak differences within the 24 h high-frequency (HF) band power between two groups. During the Iowa gambling task, younger participants exhibited a reduced HF response, which may be related to weaker top- down self- regulatory mechanisms.

Keywords: excessive Internet gaming; heart rate variability; high frequency; impulsivity; young male adults

Introduction

Decreased HRV has been reported in various illnesses, including depression, psychotic disorders, and autism. For example, in autism, resting HRV is decreased, especially in relation to emotional control [1], and in schizophrenia and bipolar disorder, HRV has also been associated with severity of psychiatric symptoms [2].

Several studies have reported relationships between altered autonomic function and Internet addiction by examining heart rate variability (HRV) at rest or during a computer task [3–9] (Supplementary Table).

Heart rate variability reflects the balance between parasympathetic and sympathetic activity at the sinoatrial node, and the HRV spectrum can be divided into very-low, low (LF: 0.04-0.15 Hz), and high (HF: 0.15-0.40Hz) frequency bands that reflect different autonomic inputs. The HF component is considered to most strongly reflect vagus-mediated parasympathetic input [10]. However, the HF band is influenced by respiration and there is no broadly accepted method to remove this influence [11]. Alternatively, the ~~LF band is thought to reflect both sympathetic and parasympathetic~~

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~~activities~~ [12]. LF band spectrum is thought to be mix of sympathetic and vagal activity, baroreflex activity. They highlight a link between cardiac sympathetic nerve activity and baroreflex sensitivity. However, traditional time and frequency domain measures fail to account for important properties related to multiscale organization and nonequilibrium dynamic. So the non-linear analysis based on entropy is recently investigated [13,14].

The HRV spectrum is computed directly from the variation in R-R (inter beat) intervals through statistical computation, which is sensitive to the length of the recording. Owing to the use of different acquisition and analysis procedures, it may be difficult to compare results across studies. In order to address this problem guidelines have been proposed [15,16].

Despite the methodological heterogeneity, such studies tend to show a weak relationship between HRV and Internet gaming addiction (Supplementary Table). Specific HRV indices may reflect the capacity of individuals to modulate cognitive activity, emotion, and behavior in response to changing environmental demands [17]. According to the perspective of Porges [18,19] and Thayer [20] HRV is a biomarker of top down regulation. Therefore, abnormalities in the HRV spectrum may predict deficits in cognitive, emotional, and (or) behavior control that predispose to Internet addiction.

Young people and students are considered more vulnerable to problematic Internet use [21,22].

While many studies have examined 24 hour HRV to evaluate cardiovascular neural regulation among health care workers [23], shift workers [24] and patients with coronary artery disease [25], such measures have not been conducted in healthy young adults with problematic Internet uses. The HF component displays a circadian pattern with peak power between 11 PM and 5 AM [26]. This circadian rhythm was altered in coronary artery disease patients [25] and night-shift workers [24]. Thus, long-term HRV analysis may be a more reliable tool for assessing autonomic dysfunction, as well as its relationship to disorders such as Internet addiction than, measurements during specific tasks [27]. But, the short-term HRV analysis is easy to perform and convenient to control the confounding factors.

In this study, we evaluated the differences in the HRV spectrum over 24 h and during computer tasks in males with or without excessive Internet gaming (EIG) behaviors. In addition, we compared the HRV spectrum between young adults and high-school students to assess the potential differences in behavioral control with maturity.

Methods and Materials

Participants

All the participants were recruited through postings in the Hirosaki Universities' campus Internet. This study cohort consisted of male individuals aged 15-35 years and included high-school students (13) and young adults (22). The participants were classified into the EIG group and non-EIG group using Young's Internet Addiction Test (IAT) [28]. A monetary reward of approximately USD 40 was given to each participant for their time and effort. The author screened the participants using a standard clinical assessment battery consisting of a psychiatric evaluation, structured diagnostic interview (the Structured Clinical Interview for DSM – IV) [29], and a medical history review. The study protocol was approved by the Research Ethics Committees of Hirosaki Universities, and the participants provided full written informed consent for their participation in the study.

Measures

Autonomic measures

Electrocardiograms (ECGs) were recorded continuously for 24 h with a wearable sensor- type ECG (Imec, Leuven, Belgium) and during game play (Iowa gambling task and each participant's own game) using a standard- type ECG system. Electrophysiological signals were sampled at 256Hz from the wearable- type ECG and at 200Hz from the standard- type ECG, and saved for offline

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analysis. The R – peaks in the ECG waveform were detected using an automated detection algorithm and subsequently verified by visual inspection using Hyper Wave 2.1 (Kissei Comtec, Nagano, Japan). A power spectral analysis of the beat to beat R-R intervals time series was performed using MemCalc software (GMS, Nagano, Japan). For frequency domain analyses, the recording period was divided into small segments of continuous 5 minute periods. For each segment, corresponding data points per segment were transferred to power spectral density by the maximum entropy method[30].

Both LF power (0.04 - 0.15Hz) and HF power (0.15 - 0.40 Hz) were measured. Data from each band were transformed into natural logarithms, and LF / HF ratios were calculated. The HRV values for the initial rest period and the two games were averaged. For the 24 h ECG analysis, we defined the HF difference as the maximum HF (60 min) / minimum HF (60 min) (Fig. 1). The 24 hour mean values for HF, LF, and LF/HF were averaged over 24 hours.

We also calculated average standard deviation of normal to normal inter-beat interval (SDNN) and square root of the mean of squared differences between successive beat intervals (RMSSD). SDNN is considered to reflect both sympathetic and parasympathetic activities, and RMSSD has relevance to parasympathetic functioning [31].

Questionnaires

The IAT developed by Young et al. [28] consists of 20 items, and each item is scaled by five points. The total IAT score ranges from 20 to 100, and a total score over 40 signifies problems caused by Internet use. Clinical psychiatric ratings were assessed using the Beck Depression Inventory [32,33], State Trait Anxiety Inventory [34,35], and Autism Spectrum Quotient [36,37]. ~~and Insomnia Severity Index [37, 38]. The Barratt Impulsiveness Scale Version 11 (BIS - 11)[39, 40] was also administered, with a higher total score indicating greater impulsiveness.~~

Procedures

The participants were instructed not to smoke, drink alcohol or consume caffeinated beverages the night before data collection. In order to record the ECG, three disposable Ag/AgCl electrodes were placed on the participant's chest.

After a rest period of at least 5 min, the participants played two games in succession, namely the Iowa gambling task (IGT) and one of their own choice played daily, with a 4 min rest between each game session. A computer version of the IGT [38] was used. The subjects were instructed to select 100 cards arranged in four decks with the intention of gaining simulated monetary rewards. Each card had a monetary value that was revealed only after selection, and could either be a gain or a loss. The aim of the task was to optimize net gains across several trials. Two decks had higher rewards (gains) but also higher risks (losses) and could result in monetary losses over time, while the other two decks had lower rewards and even lower risks, making them advantageous in the long term. The IGT is a clinically sensitive tool to evaluate problems in impulse control and emotion regulation. The subjects used a mouse to select cards from one of the four decks and the amounts won or lost per trial as well as the total cumulative earnings were recorded. After the participants finished the games, a wearable sensor- type ECG was attached to their anterior chest wall for 24 h recordings.

Statistical analysis

The normality of the data distribution was assessed using the Shapiro-Wilk test. The comparison between the EIG and non - EIG groups, and between the adult and high-school student groups conformed to the normal distribution using the T test. The Mann–Whitney U test was used if the comparison which didn't conform to the normal distribution

~~Student's t - tests were used to compare proportions and means between the EIG and non - EIG groups, and between the adult and high-school student groups.~~ The numbers of cards selected in each block of the IGT were compared by two- way repeated measures analysis of variance between the EIG and non- EIG groups, and between the adult and high-school student groups. All p- values

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were two- tailed, and $p < 0.05$ was defined as statistically significant. The statistical analysis was conducted using SPSS version 23.0 for Windows (SPSS, Chicago, IL, USA).

Results

Clinical characteristics of the subjects

EIG vs. non - EIG

The subjects with an EIG also exhibited clinically significant depressive symptoms, and significantly higher self-reported scale scores for anxiety, and autism tendency, ~~and sleep problem~~. However, only 24 hours averaged HF demonstrated significant group differences in terms of HRV indices (Table 2).

Table 1. Demographics, clinical variables of subjects and absolute values of HRV parameters in excessive Internet user and non – excessive user groups .

internet addiction test(IAT)	less than40(n=21)	more than 41(n=14)	p
age	21.3	20.1	0.549
BDI-II	5	12.8	0.002*†
STAI-I	40.1	52.4	0.002*
AQ(autism quotinent)	14.5	19.7	0.014*
IGT score	0.95	4.57	0.309†
IAT	30.7	53.1	0*
body mass index	21.6	20.9	0.507
preHF	5.57	5.67	0.811†
HF IGT/pre	1.05	1.04	0.6
HF game/pre	5.67	5.74	0.82
average HF	536.3	881.7	0.023*†
HF difference	14.7	13.2	0.387
average LF	1072.2	1268.8	0.117
average LF/HF	4.43	3.34	0.191†
SDNN	304.5	295.7	0.381†
RMSSD	295.7	177.6	0.558†

BDI-II; Beck depression inventory, STAI; state and trait of anxiety; IGT; Iowa gambling scale, HF; high frequency, LF; low frequency, SDNN; standard deviation of N-N intervals, RMSDD; root-mean-squared differences N-N intervals; * ; $p<0.05$ †; Mann-Whitney tes.t

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Table 2. Demographics, clinical variables of subjects and absolute values of HRV parameters in adult and high school student groups.

	adult(n=22)	young(n=13)	p
age	15.8	23.8	0*
BDI-II	7.5	9.1	0.428†
STAI-I	45.7	45.2	0.895
AQ(autism quotinent)	17.2	15.3	0.402
IGT score	7.36	−7.38	0.03*
IAT	39.2	40.5	0.786
body mass index	22.6	18.7	0*†
preHF	5.63	5.57	0.821
HF IGT/pre	1.07	1.01	0.000*†
HF game/pre	5.71	5.67	0.878
average HF	711.1	595.2	0.984M
HF difference	13.4	17.8	0.866†
average LF	1123.6	1193.3	0.602
average LF/HF	4.07	3.89	0.813
SDNN	333.6	328.5	0.381†
RMSSD	242.7	198.2	0.694†

BDI-II; Beck depression inventory, STAI; state and trait of anxiety, IGT; Iowa gambling scale, HF; high frequency, LF; low frequency, SDNN; standard deviation of N-N intervals, RMSDD; root-mean-squared differences N-N intervals ＊; $p<0.05$ †; Mann-Whitney test.

Figure 1.

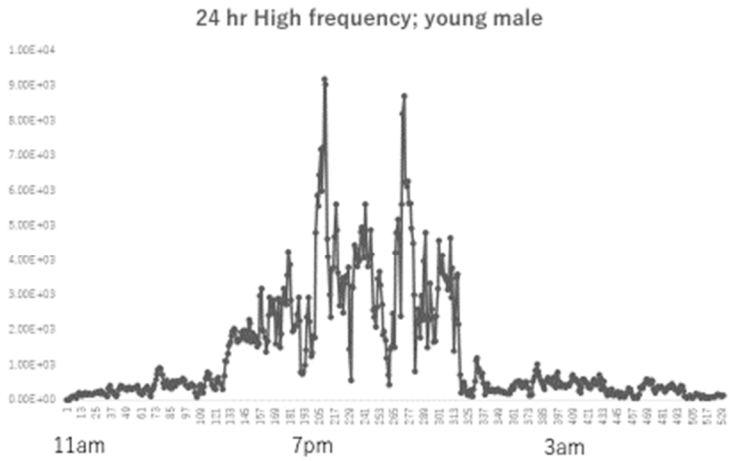

Figure 1. Time course of the heart rate variability (HRV) high- frequency (HF) power band in a young adult male.

High-school student vs. young adult.

The 24 h HF power displayed no difference, but the adult group exhibited greater HF power during the IGT while the high-school student group exhibited reduced HF power compared to the

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baseline. There were no differences in clinical symptoms between age groups except for the IGT score and body mass index (Table 3).

Effects of EIG and age on IGT scores

In the EIG vs. non-EIG comparison, there was no significant group x block interaction ($F = 0.474$, $df = 4$, $p = 0.755$), or main effect of the group ($F = 0.429$, $df = 1$, $p = 0.517$) on the IGT score, but there was a significant main effect of the block ($F = 6.372$, $df = 4$, $p = 0.00$) (Fig. 2).

Figure 2.

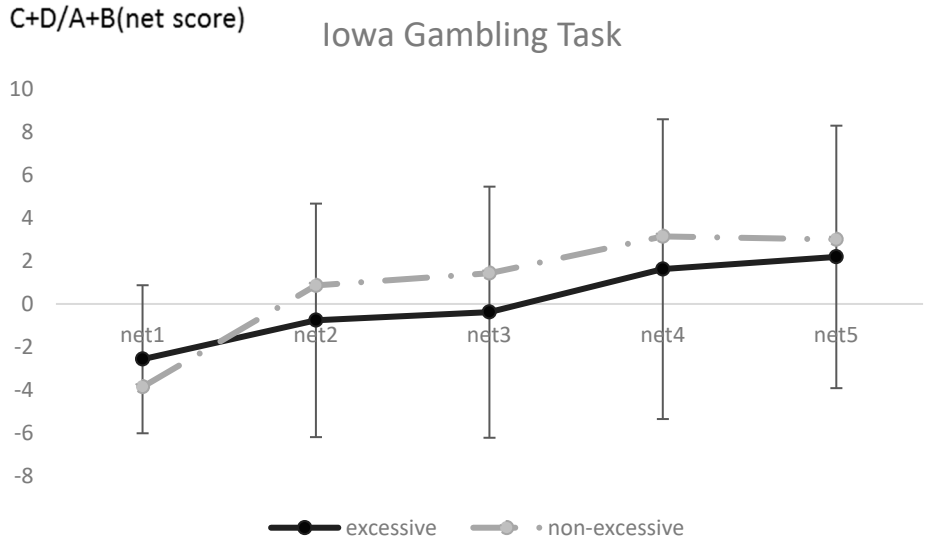

Figure 2. Performance on each block of the Iowa gambling task (IGT) for non-excessive Internet gaming (non-EIG) user and excessive Internet gaming (EIG) user groups. Each net score (1- 5) represents the results of 20 sequential card selections. Net score was calculated by subtracting the number of disadvantageous deck selections (losses) from the number of advantageous card selections (gains).

In the age group comparison, there was also no significant group x block interaction ($F = 1.853$, $df = 4$, $p = 0.122$), but there was a main effect of the group ($F = 5.168$, $df = 1$, $p = 0.030$) and a significant main effect of the block ($F = 4.425$, $df = 4$, $p = 0.002$) (Fig. 3).

Figure 3.

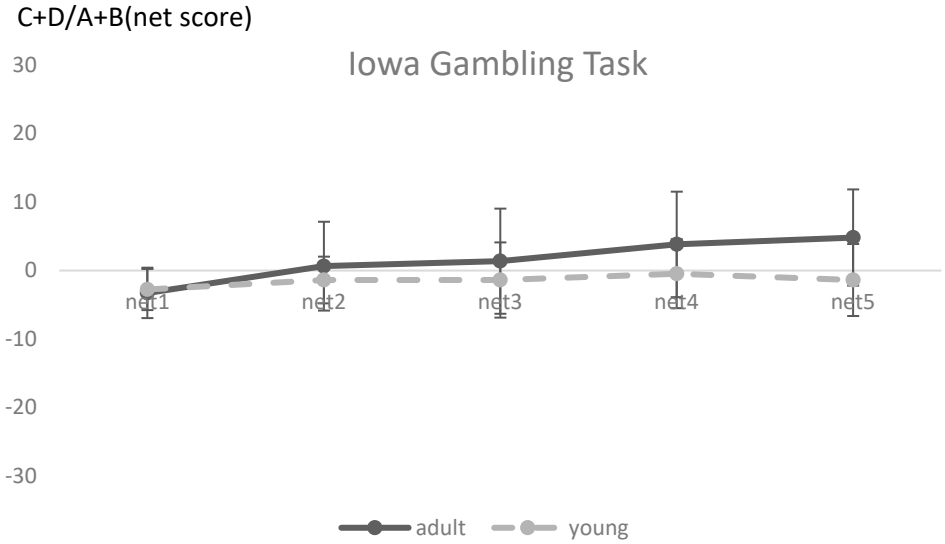

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Figure 3. Performance on each Iowa gambling task block for high school students and adults.

Discussion

To the best of our knowledge, this is the first study to examine autonomic changes in young males with and without excessive Internet gaming behaviors using 24 h HRV monitoring. While there was no difference in the HRV band power change (min-max) between the EIG and non –EIG groups, we found a significant difference in the daily average of HF. On the other hand, there was no significant difference in HF during IGT or when the subject was playing games that he played every day.

The results of the previous reports on HF at rest showed that HF decreased when depression [39] or Internet dependence were strong [3–9], which was the opposite of the present results. The subjects in this study did not demonstrate the severity of Internet addiction observed in previous studies [3–9]. The present study was conducted on healthy subjects classified by IAT, and the low level of severity was considered to be a reason for which no significant differences were found except for HF. HRV is related to frontal lobe function, and moderate game use is reported to have a positive effect on it [40].

According to Tateno et al. [41], an IAT cut- off point of 40 is not appropriate to evaluate Internet addiction, while 50 may be ideal.

In addition, the 24 hour measurement was insufficient, including sleep and various daily activities. Strictly speaking, it is necessary to conduct more detailed studies on the differences in the amount of exercise, sleep stage, etc., by using accelerometers and PSG together.

The clinical usefulness of Heart rate variability is not yet well understood, whether short-time or 24-hour measurements are better. For example, in myocardial infarction Lu et al. [42] demonstrated that SDNN of a 5-min ECG recording could predict the mortality of patients with myocardial infarction, but was inferior to long- term HRV indices. In contrast, Bigger et al. [43] compared the power spectrum of short ECG recordings with 24 h long-term HRV, and concluded that both HRV analyses were excellent predictors of mortality in patients with myocardial infarction.

There was a significant difference in the depressive state, anxiety, impulsivity, autistic tendency, and sleep problems between both groups; thus, at the early stage of excessive Internet gaming, psychometric testing appears superior to HRV monitoring for evaluating the psychological factors contributing to this aberrant behavior. Using multimodal biosignals such as EEG and galvanic skin response [44], as well as other kinds of tests such as an individual minute test, which evaluates time perception, will improve the detection of Internet gaming addiction [45]. In the past, gaming, social tasks and watching films have been used to evaluate heart rate variability reactivity (Table 1), but there was not significant result compared to the baseline heart rate variability [2].

Hong et al. [7] also observed significant reductions in HF power during periods of high attention and during the last 5 min of the task. It is possible that the time course of the game may influence HRV. However, we did not find time course changes between both groups in terms of HF during the IGT.

When the overall results were classified by age, there were significant differences in the IGT scores and responses to IGT between the high-school students and the adults. In other words, the IGT scores were significantly higher in adults than in high-school students, and the responses to HF were greater in adults than in high school students. This is consistent with the authors of [46], who found that adolescents have a poor decision-making process and lower IGT results. It is also consistent with the results found in [47] according to which the better the IGT results, the more autonomic activity is activated. In Table 3, there was a significant difference in BMI between both groups, but Antelmi et al. [48] found no significant difference in terms of HRV between the normal, overweight, and obese groups of men and women.

Therefore, it is reasonable to limit the time and content of Internet use for high school students who are in the process of maturing their decision-making process, as has been conventionally established.

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According to a recent review, there is a small but significant relationship between HRV and top-down self- regulation, and this relationship is thought to be stronger in older individuals [17]. The observed differences in terms of HRV in our study between age groups suggest such a relationship.

This study has several limitations. First, excessive Internet use was less severe than in previous studies, so relationships between HRV indices and EIG are still possible. Second, we did not monitor respiratory changes during game playing, and differences in respiratory response could influence the HF band of the HRV spectrum. However, a recent study found no significant group difference in respiration during a gaming task [4]. Third, we did not consider specific details of the participants' Internet use such as excessive social networking and online shopping, gambling, or pornography use.

In conclusion, the 24 hour average HF of the wearable sensor demonstrated a significant difference between the EIG and non -EIG groups. Contrary to previous results, however, the averaged HF was higher in the EIG group, which was more likely to be depressed and to have pre-Internet tendencies. This result was an evaluation of net-dependent tendencies in healthy subjects, and it is possible that a moderate use of the net may have resulted in functional improvement.

Younger participants also tended to exhibit a decreased HF response during the IGT, which may be related to weakness in top down self regulatory mechanisms compared to older individuals.

In this study, we performed long-time measurement for 24 hours and short-time loading for a few minutes, and found significant differences only in the long-time frequency analysis. In the future, in addition to the parameters to be compared in the analysis method, it is necessary to solve such problems as what kind of load is likely to cause differences in short time, and whether the long time measurement should be divided into resting and sleeping periods.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author contributions: Y.O. designed the study, collected and analyzed the data, and wrote the draft. M.K. and K.N. contributed to data collection, and M.O. contributed to HRV data analysis. M.K. and M.O. provided critical revision of the manuscript and important intellectual content.

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Institutional Review Board Statement: This study was conducted according to the guidelines of the Declaration of Helsinki, and was approved by the Research Ethics Committee of the University of Hirosaki (protocol code: 2021-122).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available upon request.

Conflicts of Interest: The authors declare no conflict of interest.

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Author Year	Study desin	Comparison	Indices	ECG position, recording time	age	no	Diagnostic Criteria	task	Major finding
Hong 2018	Case	21 IGD	SDNN, RMSDD, TP,	Seated, 5 min	22yo	48 male	IAT> 50	battle game	lowerSDNN, RMSSD, TP
	control	27 Control	LF,HF,LF/HF	ECG					(not significant)
Moretta 2018	Case	24 PIU	SDNN, RMSSD	3 min ECG	23yo	9 male	IAT > 50	social stress test	lower SDNN, RMSSD
	control	21 Control	LF, HF			4 male			
Chang 2015	Case	22 PIU	SDNN, RMSDD, LF,HF,	Seated, 5 min	22–23yo	44 male	IAT> 50	battle game	lower SDNN, RMSSD, HF,
	control	22 Control	LF/HF, En	ECG					and higher LF/HF in internet addictio
Lee 2018	Case	23 IGD	SDNN, RMSSD	Seated, 10min	23.1yo	41male	IAT > 50	battle game	no significant difference of baseline I
	control	18 Control	pNN50, LF, HF	ECG					
Lee 2021	Case	33 IGD	SDNN, RMSSD, LF, HF	Seated 5 min	22.6yo	62 male	IAT > 50	battle game	lower HF
	control	29 control		ECG					
								film	
Hsieh 2016	Case	19 Internet addiction	Peak to trough amplitude	Seated, 3 min	21.97yo	12 male	CIAS > 63	positive & negative	lower RSA values in PIU group
	control	15 Control	of the heart rate	ECG		11 male			
								time estimation	
Krivonogova 2022	Case	49 Healthy students	SDNN, RMSDD, TP	Seated , 5 min	16–17yo	49(32girls)	CIAS	individual minute test	lower HF, LF
	control		HF, LF	ECG			cluster analysis		

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IGD, Internet gaming disorder; PIU, problematic Internet us
;SDNN, standard deviation of normal to normal RR intervals;
; HF, high frequency power; LF, low-frequemcy power; LF/
; IAT, Internet Addiction Test; CIAS, Chen internet addicitic
; RSA=HF/(HF+LF), respiratory sinus arrhythmia