The Effect of Violent and Nonviolent Video Games on Heart Rate Variability, Sleep, and Emotions in Adolescents With Different Violent Gaming Habits

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Objective: To study cardiac, sleep-related, and emotional reactions to playing violent (VG) versus nonviolent video games (NVG) in adolescents with different gaming habits. **Methods:** Thirty boys (aged 13–16 years, standard deviation = 0.9), half of them low-exposed (≤1 h/d) and half high-exposed (≥3 h/d) to violent games, played a VG/NVG for 2 hours during two different evenings in their homes. Heart rate (HR) and HR variability were registered from before start until next morning. A questionnaire about emotional reactions was administered after gaming sessions and a sleep diary on the following mornings. **Results:** During sleep, there were significant interaction effects between group and gaming condition for HR (means [standard errors] for low-exposed: NVG 63.8 [2.2] and VG 67.7 [2.4]; for high-exposed: NVG 65.5 [1.9] and VG 62.7 [1.9]; $F(1,28) = 9.22$, $p = .005$). There was also a significant interaction for sleep quality (low-exposed: NVG 4.3 [0.2] and VG 3.7 [0.3]); high-exposed: NVG 4.4 [0.2] and VG 4.4 [0.2]; $F(1,28) = 3.51$, $p = .036$, one sided), and sadness after playing (low-exposed: NVG 1.0 [0.0] and VG 1.4 [0.2]; high-exposed: NVG 1.2 [0.1] and VG 1.1 [0.1]; ($F(1,27) = 6.29$, $p = .009$, one sided). **Conclusions:** Different combinations of the extent of (low versus high) previous VG and experimental exposure to a VG or an NVG are associated with different reaction patterns—physiologically, emotionally, and sleep related. Desensitizing effects or selection bias stand out as possible explanations. **Key words:** children, heart rate variability, emotion, sleep quality, violent video game, desensitization.

HR = heart rate; **HRV** = heart rate variability; **HF** = high frequency; **LF** = low frequency; **VLF** = very low frequency; **LF/HF** = low-frequency/high-frequency ratio; **VG** = violent video game; **NVG** = nonviolent video game; **SCAS** = The Swedish Core Affect Scales; **SQ** = sleep quality index; **SNS** = sympathetic nervous system; **ANS** = autonomic nervous system; **PSNS** = parasympathetic nervous system.

INTRODUCTION

Playing violent video games (VG) can induce aggressive behavior (1) and increase antagonistic emotions such as anger (2–4). Playing video games, in general, has been related to shorter sleep duration, elevated reported tiredness (5), and a prolonged sleep onset (6–8). Furthermore, physiological outcomes such as galvanic skin response (9), blood pressure (10), and heart rate (HR) (9,11,12) may be influenced by violent gaming, displaying signs of arousal. In a previous study, we have also demonstrated significant changes in HR variability (HRV) in response to playing video games (13).

The heart responds to central regulatory systems, and HR parameters can be used as "probes" reflecting these systems, the most basic measure being the HR as beats per minute. HRV also reflects the autonomic regulation of the heart, and its magnitude and timing are considered an important marker of emotional responses (14). HRV can be analyzed in two principally different ways: in the time domain or in the frequency domain. The time domain means using HR "as it is," that is, HR as a mean for a certain period and its standard deviation used as a measure of the HRV. Frequency domain analyses transform HR data into different frequency patterns. The regulating systems of the heart differ in time between activation and inhibition (i.e., cycle time). These cycle times can be extracted into different frequency bands, which have been found to correspond to different autonomic regulatory systems.

Frequency domain HRV analyses commonly involve three primary intervals: the high-frequency (HF) band (0.15–0.40 Hz) with the shortest cycle time of approximately 2.5 to 6.7 seconds that is vagally mediated, with breathing rate as the main contributing factor (15). The low-frequency (LF) band (0.04–0.15 Hz) corresponds to a cycle time of 6.7 to 25.0 seconds, has traditionally been used as a marker of sympathetic nervous system (SNS) activity, and is associated with blood pressure regulation (15). However, the LF component is now recognized to reflect both sympathetic and parasympathetic activity. A ratio of LF/HF is used as an index of the sympathovagal balance. An alternative perspective on the LF and HF bands is that the HF band reflects signals by a myelinated and in an evolutionary sense young branch of the vagal nerve, whereas the LF reflects an unmyelinated and older branch of the vagal nerve (16). The significance of the very low frequency (VLF) band (0.003–0.04 Hz), the slowest cycle of more than 25 seconds, is not fully understood and may partly reflect the parasympathetic outflow (17).

In our previous experimental study with teenage boys, VG induced a higher HF and LF activity during the night after playing but not during the play (13), whereas HR was not influenced.

The aim of the present study was to investigate if reaction patterns differed between teenage boys with high exposure to VG (≥3 h/d) and those with low exposure (≤1 h/d), during and after playing a VG and a nonviolent video game (NVG). We hypothesized that HR parameters (HR and HRV) would differ between the groups and that the low-exposed gamers would report more negative emotions (sadness, anxiety, anger, dissatisfaction) and lower sleep quality in relation to the violent game than the high-exposed gamers.

PARTICIPANTS AND METHODS

Study Groups and Design

Boys were recruited consecutively from schools in a metropolitan area. As in a previous study, it was hard to recruit high-frequency gamers of these ages, and as many as 11 schools—corresponding to approximately 500 boys—had to

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be approached before this group was fully recruited. Half of the boys ($n = 15$) were thus used to play violent computer/video games at least 3 hours daily ("high-exposed"), and the other half ($n = 15$) used to play 1 hour or less daily ("low-exposed"). The experimental setting has been described previously (13). In short, the boys were invited to play video games in their homes on two different occasions (violent game/nonviolent game) with counterbalanced order. The experiments started on weekday evenings and ended the next morning. The games were played between 8 and 10 PM, and the boys were instructed not to make any breaks while playing. Questionnaires were filled in before and after playing, as well as the next morning after sleep. Both study participants and parents provided informed consent, and the study was approved by the Regional Ethical Review Board in Stockholm. Data were collected from April 2009 until January 2010.

Exposure: Video Games

By the help of experienced adult gamers, two games were selected following preformulated criteria, modified by us (13) after Anderson (18). In the violent game—Manhunt—the scene is an abandoned hostile area with criminals trying to kill the main character (the player). His only chance to survive is to kill everyone he meets by beating and kicking. Simple weapons such as plastic bags and baseball bats stolen from the people he kills are available. The nonviolent game—Animaniacs—takes place in different movie genre environments. The aim is to find all the stolen Edgar statuettes and rescue the forthcoming Edgar gala. Both characters and surroundings are in cartoon style. To avoid any visual differences between the games, colors, contrast, and brightness were adjusted beforehand in the laboratory, and similar adjustments were used for each television screen in the participants' home. The boys played without coplayers or anybody observing them. Microsoft XBOX consoles had been connected by the research assistant to the participant's home television set in the late afternoon. The participants were instructed to use a comfortable volume and were offered headphones.

Physiological Outcome Measures

HR and HRV were measured using a combined HR and torso movement sensor (Actiheart; Cambridge Neurotechnology Ltd, Papworth, UK). This sensor, a small portable rechargeable unit, was applied on the chest where it registered (and stored) the interbeat intervals measured from the R-wave maximum of a beat to the R-wave maximum of the next, with a sampling frequency of 128 Hz. The registration went on from before start of playing until the next morning. The R-R intervals of the entire registration was exported (without any editing) from the Actiheart device into a software used for further calculations. This software has been described in detail previously (19). In brief, a linear interpolating algorithm is used to reduce the impact of ectopic beats on the calculations. Five-minute periods with more than 4% ectopic beats are identified by the software and omitted from further analyses. Consecutive 5-minute segments are resampled at 2 Hz, producing a linear trend that is subtracted from the array of data before the spectral analysis. From the R-R intervals, five measures were calculated: HR from the time domain; the power of the different frequency bands; LF, HF, and VLF expressed in milliseconds squared; and the ratio of LF/HF. The torso movement (vertical acceleration measurement) was recorded as a control variable.

Both HR and HRV parameters were calculated by the software for 5-minute intervals. R-R intervals of more than 2000 milliseconds cannot be detected by the Actiheart device, and 5-minute intervals with R-R intervals of 2000 milliseconds or longer was considered signal loss (electrode or cable failure) and omitted. The remaining periods were aggregated into longer phases, "playing" and "sleep," and averages for these periods were calculated. The period of playing was basically identified by self-reports, but points of time were validated by the absence of gross motor activity as indicated by the movement sensor of the Actiheart. Start of sleep was defined according to a similar combination of self-report and movement validation. With the aim of collecting information on equally long periods in all participants, end of sleep was defined as 4 hours from start of sleep because this was the shortest period of complete HRV measurement.

Questionnaires

On the first occasion before playing, questions about gaming habits were filled in (a first part of a control questionnaire—see later). The participants also filled in an adapted Swedish Core Affect Scales (SCAS) questionnaire (20) reflecting general reactions when playing violent games in general. After each gaming session, the participants filled in the SCAS questionnaire again, with the reference to the emotional reactions to the game in focus. They also filled in another part of the control questionnaire (see later). In the morning to follow, a sleep diary was filled in (21).

The SCAS questionnaire (20) was modified to the age of the participants and to the subject matter referring to emotional reactions; sad, angry, glad, worried, nervous, dispirited, calm, tense, irritated, hastened, satisfied, stressed, and refreshed answered on a four-graded scale with response alternatives from "not at all" to "very much." Ten of the items could be reduced into two components (later used as indices) using principal component analysis. The principal component analysis was based on the SCAS filled in prior playing on the first occasion. The two indices, labeled anxiety and emotionality, accounted for 53% of the variance, and the former included worried, nervous, calm (reversed), tense, hastened, and stressed and had a Cronbach α value of .76. The emotionality component included angry, glad, irritated, and satisfied and had a Cronbach α of .68. The three remaining items, sad, dispirited, and refreshed, did not load on the two components and were analyzed separately. The questionnaire also included an open question about any particular reactions from playing the current game.

In the sleep diary (21), the initial questions concerned bedtime, sleep latency, wake-up time, and rising time. The following questions concerned alertness at bedtime and rising time to be answered on a nine-grade scale with labels on every second step from "very alert" to "very sleepy, struggling against sleep, hard to keep awake" (Karolinska Sleepiness Scale (22)). Subsequent questions referred to the number of awakening (0−>5), time spent awake (from "no time" to "more than an hour"), perceived stress, premature awakening, and sleep depth, with a 5-step scale with response alternatives from "not at all" to "very much." The questionnaire also included multiple-choice questions about disturbances during sleep, the cause of awakening in the morning, if any dream may have influenced the sleep, and, finally, an open question about any particular incidents during night. Furthermore, questions about difficulties falling asleep, sleep quality (phrased "how was your sleep?"), and sleep calmness constituted a sleep quality index (SQ). Questions about slept throughout, ease of awakening, and perceived rest were used as an awakening index. The items later used in the two indices were graded in a five-step scale, with response alternatives from "not at all" to "very much."

The first part of the control questionnaire concerned violent gaming habits filled in before playing on the first occasion: hours of playing violent games per week, first experience of a violent game, and names of games most frequently played during the last month.

The other part of the control questionnaire concerned the experimental gaming in focus filled in on both occasions after gaming: distance (centimeters) from television screen, audio volume (no/low/middle high/high level), previous experiences of the game in focus (yes/no), if the game was difficult to play (yes/no), if it was fun to play (yes/no), and report of any deviations from the instructions (in own words).

Statistical Analysis

Logarithm transformations were applied in all HRV, emotion, affect and sleep data analyses to normalize the distribution of data (with the exception of numbers of awakening that was square root transformed because of many zero reports). Group and condition comparisons were performed using a two-way between-group analysis of variance for each outcome measure, with group (low-exposed and high-exposed gamers) as a between-group variable and condition (NVG and VG) as a within-group variable. Because the hypothesis was that the violent game would have a more adverse affect on emotions and be more disturbing to the sleep compared with the nonviolent game, one-tailed significance levels were applied in the calculations of the variables related to emotion and sleep. All statistical analyses were made using the statistical package SPSS for Windows (IBM SPSS Statistics version 19; Chicago, IL).

RESULTS

There were no differences between the groups or gaming conditions concerning torso movement during playing or during

TABLE 1. Means (SE) of Heart Rate and Heart Rate Variability Variables During 2 Hours of Playing a Violent (VG) and a Nonviolent (NVG) Game

	≤1 h		≥3 h		Group		Condition		Group × Condition	
	VG	NVG	VG	NVG	*F* ratio	*p*	*F* ratio	*p*	*F* ratio	*p*
HR	82.1 (2.9)	77.1 (2.6)	76.5 (2.2)	76.2 (2.2)	0.92	.35	4.43	.044	3.45	.074
HF	1219.8 (399.9)	1603.6 (628.9)	1647.2 (525.2)	1594.4 (535.9)	1.01	.32	0.02	.88	1.70	.20
LF	1395.9 (289.5)	1711.3 (447.0)	1809.1 (327.6)	1644.4 (270.0)	1.17	.29	0.24	.63	2.91	.099
VLF	2825.6 (634.1)	2406.7 (501.4)	2600.0 (481.3)	2177.3 (243.1)	0.25	.62	1.68	.21	0.06	.80
LF/HF	2.4 (0.5)	2.4 (0.5)	1.9 (0.27)	2.1 (0.4)	0.53	.56	0.01	.93	0.23	.64

SE = standard error; HR = heart rate; HF = high frequency; LF = low frequency; VLF = very low frequency; LF/HF = low frequency/high frequency.
F ratios and *p* values (based on log-transformed data) of group (low-exposed [n = 15] versus high-exposed [n = 15] gamers), condition (VG versus NVG), and group × condition interaction (df = 1,28; $F_{\mathrm{crit}}(1,28) = 4.20$ at $\alpha = .05$).

sleep. Neither were there any differences between the groups or gaming conditions concerning distance, audio volume, previous experience of the games, or whether the games were perceived as difficult/fun to play ($p > .05$).

Physiological Outcomes

No 5-minute intervals with more than 4% ectopic beats were identified by the software. During the 2 hours of playing (Table 1), there were no significant interaction effects between group and gaming condition, or differences between the two groups for HR or any of the HRV parameters. There was a significant main effect of game for HR (η^2 = 0.137), but for none of the other HRV parameters. During sleep (Table 2), there was a significant interaction effect between group and gaming condition for HR (η^2 = 0.255), with higher HR in the violent condition compared with the nonviolent condition within the low-exposed group (p = .018) and a reversed direction in the high-exposed group. Individual HR-data during playing and sleep in both groups and for both conditions are visualized in Figure 1. There were no significant interaction effects or differences during sleep between the two groups or gaming conditions neither for HF nor LF. The LF/HF ratio displayed a significant interaction with the same direction (η^2 = 0.134). In VLF, there was also a significant interaction effect (η^2 = 0.209), but with reversed direction, with a significant difference between the gaming conditions within the low-exposed group (p = .014).

Questionnaire Outcomes

For emotion variables, there was a significant interaction effect of group and gaming condition for perceived sadness (η^2 = 0.189), with higher levels after playing the violent game compared with the nonviolent game within the low-exposed group (p = .028, one sided) and reversed direction in the high-exposed group (Table 3). The high-exposed gamers felt significantly more refreshed after both games compared with the low-exposed gamers (η^2 = 0.112). The violent game elicited more anxiety (index) after playing compared with the nonviolent game to both groups (η^2 = 0.332).

For sleep variables, there were two significant interaction effects of group and gaming condition, indicating lower sleep quality among low-exposed gamers after the violent game compared with the nonviolent game and an opposite pattern among the high-exposed gamers (Table 4):

- Alertness at bedtime (η^2 = 0.153), with a significant difference within the low-exposed group between the two gaming conditions (p = .023, one sided) and a significant difference within the nonviolent condition between the groups (p = .041, one sided)
- SQ (η^2 = 0.111), with a significant difference within the low-exposed gamers group between the gaming conditions (p = .025,

TABLE 2. Means (SE) of Heart Rate and Heart Rate Variability Variables During Sleep After Playing a Violent (VG) and a Nonviolent (NVG) Game

	≤1 h		≥3 h		Group		Condition		Group × Condition	
	VG	NVG	VG	NVG	*F* ratio	*p*	*F* ratio	*p*	*F* ratio	*p*
HR	67.7 (2.4)	63.8 (2.2)	62.7 (1.9)	65.5 (1.9)	0.36	.56	0.20	.66	9.56	.004
HF	2326.7 (453.2)	2624.9 (546.4)	4172.0 (1027.9)	3608.3 (909.6)	1.07	.31	0.16	.69	2.30	.14
LF	2589.0 (463.0)	2738.0 (598.8)	3659.2 (566.9)	3294.8 (547.8)	1.64	.21	0.75	.39	1.68	.21
VLF	3899.5 (569.1)	4528.1 (776.5)	5081.1 (459.5)	4526.7 (409.8)	1.61	.22	0.03	.86	7.40	.011
LF/HF	1.4 (0.1)	1.3 (0.2)	1.3 (0.2)	1.5 (0.2)	0.04	.85	0.07	.79	4.32	.047

SE = standard error; HR = heart rate; HF = high frequency; LF = low frequency; VLF = very low frequency; LF/HF = low frequency/high frequency.
F ratios and *p* values (based on log-transformed data) of group (low-exposed [n = 15] versus high-exposed [n = 15] gamers), condition (VG versus NVG), and group × condition interaction (df = 1,28; $F_{\mathrm{crit}}(1,28) = 4.20$ at $\alpha = .05$).

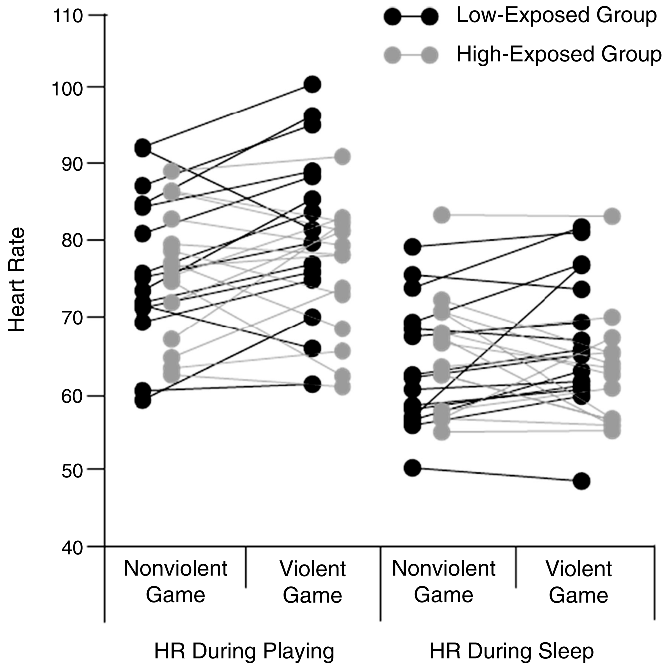

Figure 1. Plots of heart rate (HR) during playing and sleep in the low- and high-exposed groups after playing a violent and a nonviolent game.

one sided) and a significant difference within the violent condition between the groups ($p = .020$, one sided).

For another three aspects, there were significant differences between the groups, regardless of game type:

- The high-exposed gamers reported shorter sleep latency compared with the low-exposed gamers.
- The high-exposed gamers felt significantly more alert at rising time than the low-exposed gamers.
- In awakening index, the high-exposed gamers scored significantly higher than the low-exposed gamers.

The violent game elicited significantly higher stress at bedtime than the nonviolent game in both groups ($\eta^2 = 0.173$).

DISCUSSION

In this experimental study, we investigated whether boys aged 13 to 15 years with different habits of playing violent games had different response patterns to VG and NVG concerning physiological outcomes (HR, HRV), emotional reactions, and sleep quality. Low-exposed gamers had higher HR and LF/HF ratio during sleep after the violent game compared with the nonviolent game, whereas high-exposed gamers showed an opposite tendency. In our preceding study involving another study group—of the same ages, predominantly with low previous exposure to violent games—violent (as compared with nonviolent gaming) was associated with increased HF and LF activity during the night to follow after gaming, whereas HR was unaffected. In the study now presented, violent gaming was associated with increased HR during playing. Both types of violence-related psychophysiological outcomes probably reflect increased sympathetic activation, which is discussed in detail later in relation to the main outcomes of this study.

Low-exposed gamers reported more sadness after the violent game compared with the nonviolent game, with a different pattern among the high-exposed gamers. SQ and also alertness at bedtime were more negatively influenced after the violent game in low-exposed compared with high-exposed gamers.

The HR is regulated by the two parts of the autonomic nervous system (ANS), the SNS that is activated by psychological or physical stress and increases HR, and the antagonistic parasympathetic nervous system (PSNS), which decreases HR. The HR results could thus be interpreted as an expression of an imbalance of the ANS toward sympathetic activation. Seemingly contradictory to these findings, a previous study from our group with a similar design showed no change in HR but increased HF and LF during the night after violent gaming—compared with nonviolent gaming—in boys of the same ages as in the present study. Previously, it has been claimed—although with some uncertainty—that LF, to a substantial degree, reflects sympathetic activity (15). However, Porges (16) has suggested that LF—just as HF—reflects vagal activity (see later). Taking off from this claim, the seemingly contradictory results in our two studies are possible to interpret as two different expressions of sympathetic activation. In our previous study, more pronounced sympathetic activity (not directly expressed in any of the HRV parameters) during the night after the violent (versus nonviolent) game may have been counterbalanced by increased vagal activity (expressed by increased HF and LF), with no change in HR as a consequence. In the present study, the underlying stronger

TABLE 3. Means (SE) of Emotion Variables After Playing a Violent (VG) and a Nonviolent (NVG) Game

	≤1 h		≥3 h		Group		Condition		Group × Condition	
	VG	NVG	VG	NVG	*F* ratio	*p*	*F* ratio	*p*	*F* ratio	*p*
Sad	1.4 (0.2)	1.0 (0.0)	1.1 (0.1)	1.2 (0.1)	0.04	.42	1.01	.16	6.29	.009
Dispirited	1.9 (0.3)	1.5 (0.2)	1.9 (0.3)	1.9 (0.3)	0.20	.33	1.03	.16	1.03	.16
Refreshed	1.3 (0.1)	1.3 (0.2)	1.7 (0.3)	1.6 (0.2)	3.41	.038	0.14	.36	0.01	.47
Anxiety (index)	2.0 (0.2)	1.4 (0.1)	1.6 (0.2)	1.3 (0.1)	2.32	.07	13.44	.001	1.87	.092
Emotionality (index)	1.8 (0.1)	1.9 (0.1)	1.8 (0.1)	1.9 (0.1)	0.10	.38	0.85	.18	0.07	.40

SE = standard error.

F ratios and *p* values (based on log-transformed data) of group (low-exposed [$n = 15$] versus high-exposed [$n = 15$] gamers), condition (VG versus NVG), and group × condition interaction ($df = 1,27$, one-sided test; $F_{\text{crit}}(1,27) = 2.90$ at $\alpha = .10$).

TABLE 4. Means (SE) of Sleep Variables After Playing a Violent (VG) and a Nonviolent (NVG) Game

	≤1 h		≥3 h			Group		Condition		Group x Condition	
	VG	NVG	VG	NVG	*df*	*F* ratio	*p*	*F* ratio	*p*	*F* ratio	*p*
Bedtime, hours PM (min)	10:35 (9)	10:47 (14)	10:29 (7)	10:30 (6)	1,28	0.77	.19	1.19	.14	0.71	.20
Sleep latency, min	37.6 (10.1)	29.1 (4.8)	19.3 (4.0)	22.4 (5.4)	1,28	3.10	.045	0.03	.43	0.39	.27
Wake-up time AM, hours PM (min)	7:11 (9)	7:11 (12)	6:56 (7)	7:00 (6)	1,28	1.60	.11	0.07	.40	0.04	.42
Rising time AM, hours PM (min)	7:24 (8)	7:18 (12)	7:06 (7)	7:07 (6)	1,28	1.53	.11	0.22	.32	0.35	.28
Sleeping time, h	7.97 (0.2)	7.93 (0.3)	8.13 (0.2)	8.11 (0.2)	1,28	0.41	.52	.022	.88	0.02	.96
Alertness bedtime	3.7 (0.5)	5.3 (0.6)	4.7 (0.7)	4.0 (0.4)	1,24	0.21	.33	1.15	.15	4.35	.024
Alertness rising time	3.1 (0.4)	2.8 (0.4)	4.9 (0.7)	4.3 (0.6)	1,28	3.52	.036	1.39	.12	0.02	.45
Stress bedtime	1.5 (0.3)	1.2 (0.1)	1.5 (0.2)	1.1 (0.1)	1,28	0.002	.48	5.87	.011	0.25	.31
Premature awakening	1.3 (0.3	1.1 (0.1)	1.4 (0.3)	1.2 (0.1)	1,28	0.26	.31	0.76	.20	0.06	.41
No. awakening	1.4 (0.5)	0.5 (0.2)	0.6 (0.3)	0.9 (0.3)	1,28	0.34	.28	0.27	.31	2.33	.069
Time spend awake, min	8.8 (3.8)	5.3 (2.0)	6.2 (3.6)	7.8 (3.6)	1,27	0.004	.47	0.05	.42	0.54	.23
Sleep depth	3.6 (0.2)	3.3 (0.2)	3.1 (0.4)	3.3 (0.3)	1,27	2.08	.081	0.01	.46	1.40	.12
Sleep quality (index)	3.7 (0.3)	4.3 (0.2)	4.4 (0.2)	4.4 (0.2)	1,28	2.70	.056	2.54	.061	3.51	.036
WAKE (index)	3.2 (0.3)	2.9 (0.2)	3.7 (0.3)	3.5 (0.2)	1,28	3.38	.039	0.45	.26	0.13	.36

SE = standard error. WAKE = awakening index.
F ratios and *p* values of group (low-exposed [n = 15] versus high-exposed [n = 15] gamers), condition (VG versus NVG), and group × condition interaction (df = 1,27, one-sided test; $F_{\text{crit}}(1,28) = 2.89$, $F_{\text{crit}}(1,27) = 2.90$, and $F_{\text{crit}}(1,24) = 2.93$ at $\alpha = .10$).

sympathetic activation in the low-exposed gamers during sleep after the violent game seems to have been expressed as an increased HR, which has not been counterbalanced by a firm vagal activation—as indicated by the absence of significant changes in both HF and LF. The reason for these different patterns related to increased sympathetic activity may be understood in different ways. First, it should be reminded that the design, research questions, and study groups were similar but not identical. Second, as Porges points out, HRV data tend not to be statistically stationary (16). Third, the impact of the violent game may have changed over time with a gradual adaptation in this age group to more dramatic and severe characteristics of violent games and/ or a more advanced technology.

According to the polyvagal theory (16,23), the decelerating input from the PSNS to the heart is conducted in two different ways by the two branches of the vagus nerve. The phylogenetically younger myelinated vagus branch, reflected by the HF band, has a calming function by hindering sympathetic influences. It is found only in mammals and is related to more advanced processes like communication. The unmyelinated vagus branch, reflected in the LF band, is older and related to more primitive functions like the freezing response to threat. The balance between the two PSNS branches is reflected in the LF/HF ratio. One may thus speculate that a higher LF/HF ratio—reflecting a shift of balance between the two vagal branches—indicates a stronger activation of a more primitive system, which, in turn, may be seen as a result of exposure to a more demanding stressor. Such an interpretation would fit well with the higher ratios in the violent condition for low-exposed gamers and lower ratios for high-exposed gamers.

In the VLF, the direction of the interaction effect pattern was reversed to HR, with a significantly lower VLF after the violent game for the low-exposed gamers and an opposite tendency for the high-exposed gamers. However, VLF is not yet completely understood as a physiological representation, and it has even been questioned if it reflects any specific physiological process (15).

Interestingly, the physiological effects occurred during sleep but not during playing. The same delayed reaction also occurred in our first study, with the strongest results during the sleep after the exposure (13). It is well known that perceived stress during the evening may affect the sleep adversely (24). Moreover, stress-related shifts in the autonomic balance occur quite slowly, as demonstrated in an experimental study on mental stress where sympathetic activation (as expressed by peripheral vasoconstriction) remained elevated during 45 minutes of recovery (25). Notably, our findings demonstrate not only the inertia of the ANS but also that the physiological processes may be detectable hours after the exposure to the stressor. We do not know whether this indicates that sleep is a very sensitive indicator of stress or if similar ANS reactions would have been evoked if the games had been played in the morning.

Sleep is a quiescent state that permits physiological recording with a minimum of environmental interference. Earlier studies have shown that gaming in general can generate prolonged sleep onset (8) and fatigue caused by shorter time in bed (5). The current study also takes into account how game habits and game content are associated with sleep. According to Åkerstedt and coworkers (21), good sleep quality is a matter of time to fall asleep and subjective feeling of good or poor sleep. The interaction effects of group and game were significant for the same aspects (alert at bedtime and the SQ), thereby supporting the hypothesis of lower sleep quality after the violent game in the low-exposed group.

One of the benefits of playing VG is to experience emotions (26). Furthermore, research on violent games is usually focused on aggressive emotions (e.g., Anderson and Dill (27) and Bushman and Anderson (28)). In this study, we also examined other emotions. The high-exposed group reported higher levels of feeling refreshed after playing than did the low-exposed group on both occasions. The low-exposed gamers reported more sadness than did high-exposed gamers during the violent as compared with the nonviolent condition. Both groups reported more emotions related to the anxiety index after violent than after nonviolent gaming, especially the low-exposed group. The results suggest that violent games may induce more adverse emotions in gamers with low experience than in gamers with high experience of violent gaming. However, our design does not allow for separating effects related to the hostile setting from the effects of violent actions in the violent game. To summarize, we have found several differences between the study groups with more (presumed) sympathetic activation, signs of impaired sleep and sadness, in the low-exposed group than in the high-exposed group when playing a VG as compared with an NVG. The violent game seems to have elicited more stress at bedtime in both groups, and it also seems as if the violent game in general caused some kind of exhaustion. However, the exhaustion did not seem to be of the kind that normally promotes good sleep but, rather, as a stressful factor that can impair sleep quality (29), especially for low-exposed gamers. The interaction of groups and game may be an effect of desensitizing of the high-exposed players. Alternatively—or complementarily—our results may reflect selection bias. The extent of previous violent gaming may be associated with personality traits like aggressiveness (30). Similarly, prior psychological trauma may attract people to violent and intense experiences like violent games (31). Circumstances of these kinds may affect the ANS as well as on sleep and emotional reactions. We have no background data to discharge such bias, but our data on group comparisons offer some guidance. Thus, there were no differences between groups for HR- and HRV-related outcomes. Because the cardiac system is a valid reflection of personal differences like personality (32), our results, to some degree, limit the strength of the hypothesis that selection bias may have confounded these results. However, the high-exposed group reported stronger feelings of being refreshed and also some indications of a better sleep, which calls for some caution when interpreting these data.

Findings of physiological desensitizing have been reported previously. For instance, Carnagey et al. (9) demonstrated that previous violent gaming was associated with less arousal (measured by galvanic skin response and HR) by real-life violence compared with nonviolent gaming, even after controlling for trait aggressiveness. Bartholow et al. (33) studied electroencephalographic reactions and found that the event-related brain potential showed lower amplitude in the P300 component (associated with activation of the aversive motivational system) for ”chronic” violent gamers when exposed to violent images. It should also be noted that the process of desensitization is a documented powerful therapeutic technique in regulating emotions, feelings, and behaviors (34). To further shed light on the two potential mechanisms of desensitization and selection bias, future studies should collect more data about background characteristics of the participants.

Limitations

The experiment was performed in the homes after instructions but not under direct supervision, implying limited control of compliance, although the HRV device provides information about motor activity. This ruled out the possibility to correlate HRV activity with specific sequences of the games and with changing qualities (such as complexity and characteristics of violence) of the game over time. For the same reason, it was impossible to identify a baseline. Even if we regard our design as ecologically relevant—quite similar to everyday gaming without any adult observing or interfering—we welcome complementary laboratory and more strictly regulated and supervised experimental approaches for comparisons with our results.

The informed consent process may have introduced selection bias based on gaming habits. Some experienced gamers chose not to participate because they did not want to make a break in their own everyday favorite gaming, meaning that the most advanced gamers may have been poorly represented. Although we had ambitions to find games that were as similar as possible, with the exception of a component of violence, it should be acknowledged that this is probably an impossible task. Interviewing experienced gamers before selection and controlling for a number of aspects during playing were undertaken with the ambition of minimizing these problems. Still, for instance, the animation component may imply different reactions in itself. Such differences have been observed with differences in physiological reactions between realistic and cartoon-like games (11). Data on longer sleep periods than 4 hours may have brought up complementary information of interest, but because that was the shortest period of complete HRV measurement, we had to accept this limitation. In the present study, a number of analyses were performed, implying a certain risk of statistical Type I error. The key analyses were the interactions between type of game and group, yielding 28 F ratios, of which 7 were significant. Thus, 25% of the analyses were significant, which clearly exceeds the 5% that would be expected by chance alone. One-sided tests were applied for sleep and emotion-related data because we had a firm hypothesis about the direction of the associations, based on previous empirical findings (2–8).

An ethical dilemma was the choice of a violent game that was rated for 18 years and older, although the participants in this study did not have the proper age. Because many children play games that are not rated for their chronological age (35), the use of age proper games would have created another dilemma by not being ecologically valid.

Only 13- to 15-year-old boys were recruited in this study, and the results cannot be generalized to girls or to other ages. Gaming is more common in boys, and girls are less attracted by violent games (36). Sex-related differences concerning cardiovascular reactivity have been well established (37), and HRV reactions to gaming in girls may be quite different from what we observed in this study group of only boys.

To conclude, high versus low experience of violent gaming seems to be related to different physiological, emotional, and sleep-related processes at exposure to VG. These processes seem to proceed concurrently across various systems. Still, we do not know if they are related to behavior changes, which stand out as a question of interest for future research just as more deep-going analyses to chisel out the mechanisms underlying the different patterns.

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REFERENCES

1. Anderson CA, Shibuya A, Ihori N, Swing EL, Bushman BJ, Sakamoto A, Rothstein HR, Saleem M. Violent video game effects on aggression, empathy, and prosocial behavior in Eastern and Western countries. Psychol Bull 2010;136:151–73.
2. Panee CD, Ballard ME. High versus low aggressive priming during video-game training: Effects on violent action during game play, hostility, heart rate, and blood pressure. J Appl Soc Psychol 2002;32:2458–74.
3. Williams KD. The effects of frustration, violence, and trait hostility after playing a video game. Mass Commun Soc 2009;12:291–310.
4. Barlett CP, Harris RJ, Baldassaro R. Longer you play, the more hostile you feel: examination of first person shooter video games and aggression during video game play. Aggress Behav 2007;33:486–97.
5. van Den Bulck J. Television viewing, computer game playing, and Internet use and self-reported time to bed and time out of bed in secondary school children. Sleep 2004;27:101–4.
6. Alexandru G, Michikazu S, Shimako H, Xiaoli C, Hitomi K, Takashi Y, Robert WR, Sadanobu K. Epidemiological aspects of self-reported sleep onset latency in Japanese junior high school children. J Sleep Res 2006;15: 266–75.
7. Dworak M, Schierl T, Bruns T, Strüder HK. Impact of singular excessive computer game and television exposure on sleep patterns and memory performance of school-aged children. Pediatrics 2007;120:978–85.
8. Weaver E, Gradisar M, Dohnt H, Lovato N, Douglas P. The effect of presleep video-game playing on adolescent sleep. J Clin Sleep Med 2010; 6:184–9.
9. Carnagey NL, Anderson CA, Bushman BJ. The effect of video game violence on physiological desensitization to real-life violence. J Exp Soc Psychol 2007;43:489–96.
10. Baldaro B, Tuozzi G, Codispoti M, Montebarocci O, Barbagli F, Trombini E, Rossi N. Aggressive and non-violent videogames: short-term psychological and cardiovascular effects on habitual players. Stress Health 2004; 20:203–8.
11. Barlett CP, Rodeheffer C. Effects of realism on extended violent and nonviolent video game play on aggressive thoughts, feelings, and physiological arousal. Aggress Behav 2009;35,213–24.
12. Fleming M, Rickwood D. Effects of violent versus nonviolent video games on childrens' arousal, aggressive mood and positive mood. J Appl Soc Psychol 2001;31:2047–71.
13. Ivarsson M, Anderson M, Akerstedt T, Lindblad F. Playing a violent television game affects heart rate variability. Acta Paediatr 2009;98:166–72.
14. Appelhans BM, Luecken LJ. Heart rate variability as an index of regulated emotional responding. Rev Gen Psychol 2006;10:229–40.
15. Task Force. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 1996;93:1043–65.
16. Porges SW. The polyvagal perspective. Biol Psychol 2007;74:116–43.
17. Taylor JA, Carr DL, Myers CW, Eckberg DL. Mechanisms underlying very-low-frequencyRR-interval oscillations in humans. Circulation 1998;98: 547–55.
18. Anderson CA. An update on the effects of playing violent video games. J Adolesc 2004;27:113–22.
19. Storck N, Ericson M, Lindblad L, Jensen-Urstad M. Automatic computerized analysis of heart rate variability with digital filtering of ectopic beats. Clin Physiol 2001;21:15–24.
20. Västfjäll D, Friman M, Gärling T, Kleiner M. A Swedish mood measure derived from the affect circumplex. Scand J Psychol 2002;43:19–31.
21. Åkerstedt T, Hume K, Minors D, Waterhouse J. The subjective meaning of good sleep, an intraindividual approach using the Karolinska Sleep Diary. Percept Mot Skills 1994;79:287–96.
22. Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci 1990;52:29–37.
23. Porges SW. The polyvagal theory: phylogenetic substrates of a social nervous system. Int J Psychophysiol 2001;42:123–46.
24. Åkerstedt T, Kecklund G, Axelsson J. Impaired sleep after bedtime stress and worries. Biol Psychol 2007;76:170–3.
25. Steptoe A, Willemsen G, Kunz-Ebrecht SR, Owen N. Socioeconomic status and hemodynamic recovery from mental stress. Psychophysiology 2003;40:184–91.
26. Jansz J. The emotional appeal of violent video games for adolescent males. Commun Theory 2005;15:219–41.
27. Anderson CA, Dill KE. Video games and aggressive thoughts, feelings, and behavior in the laboratory and life. J Pers Soc Psychol 2000;78: 772–90.
28. Bushman BJ, Anderson CA. Violent video games and hostile expectations: a test of the general aggression model. Pers Soc Psychol Bull 2002;28: 1679–86.
29. Urponen H, Vuori I, Hasan J, Partinen M. Self-evaluations of factors promoting and disturbing sleep: an epidemiological survey in Finland. Soc Sci Med 1988;26:443–50.
30. Scarpa A, Raine A. Psychophysiology of anger and violent behavior. Psychiatr Clin North Am 1997;20:375–94.
31. Al-Krenawi A, Graham J, Kanat-Maymon Y. Analysis of trauma exposure, symptomatology and functioning in Jewish Israeli and Palestinian adolescents. Br J Psychiatry 2009;195:427–32.
32. Sirois BC, Burg M. Negative emotion and coronary heart disease: a review. Behav Modif 2003;27:83–102.
33. Bartholow BD, Bushman BJ, Sestir MA. Chronic violent video game exposure and desensitization to violence: behavioral and event-related brain potential data. J Exp Soc Psychol 2006;42:532–9.
34. Weersing VR, Weisz JR. Mechanisms of action in youth psychotherapy. J Child Psychol Psychiatry 2002;43:3–29.
35. Rideout V, Foehr U, Roberts D. Generation M: Media in the Lives of 8–18 Year-Olds. Menlo Park, CA: Kaiser Family Foundation; 2010.
36. Olson CK, Kutner LA, Warner DE, Almerigi JB, Baer L, Nicholi AM, Beresin EV. Factors correlated with violent video game use by adolescent boys and girls. J Adolesc Health 2007;41:77–83.
37. Kudielka BM, Buske-Kirschbaum A, Hellhammer DH, Kirschbaum C. Differential heart rate reactivity and recovery after psychosocial stress (TSST) in healthy children, younger adults, and elderly adults: the impact of age and gender. Int J Behav Med 2004;11:116–21.