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REVIEW

Sleep Science

Exposure to video games: effects on sleep and on post-sleep cognitive abilities. A sistematic review of experimental evidences

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ABSTRACT

The public opinion is ever more interested and worried about possible effects of exposure to VGs (video games) on human life and well-being. Scientific literature shows several evidences highlighting negative outcomes on behavioural, emotive, cognitive and physical health spheres. All these aspects are intrinsically linked to sleep quality and quantity and to date very few studies directly investigated the effects of videogame (VG) exposure on sleep and post-sleep cognitive status. The aim of the present systematic review is to examine the impact that the exposure to VGs can produce on sleep pattern and the consequent post-sleep cognitive abilities. To this extent, only studies directly investigating the effects of VGs on sleep features and post-sleep cognitive abilities have been selected and discussed. Data currently present in literature show the alteration of sleep pattern after exposure to VGs. The analysis indicated a reduction of Total Sleep Time (TST) and an increase of Sleep Onset Latency (SOL), modifications of the REM sleep and Slow Wave Sleep (SWS), and increased sleepiness and self-perceived fatigue. Moreover, post-sleep sustained attention and verbal memory also appear to be impaired. It can be concluded that playing VGs for long periods, particularly in the evening, is a significant, common and probable cause of sleep problems: evening exposure to VGs, in fact, can bring to insufficient and low quality sleep, with possible effects on cognition in the subsequent waking days. Potential methodological flaws and limitations of these studies have also been described and discussed. Because of the very limited number of available study on this topic further research is strongly needed.

Keywords: Adolescent; Video Games; Sleep; Disorders of Excessive Somnolence; Memory; Attention.

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INTRODUCTION

In the recent decades, video games (VGs) industry has expanded to the point of becoming one of the largest multimedia economic activities in the world. Thanks to their great availability and accessibility, VGs have become immediately and extremely popular among children, adolescents and adults. They appeared for the first time in the 1962 at M.I.T., when Steve Russell created *Spacewar!*, the very first VG of the history, with essential graphics and luminous dots moving on the display[1]. Then, mainly thanks to technological evolution, games ever more immersive and rich in details have been developed, contributing to the creation of new genres and types of VGs.

Such a great success of videogaming industry, together with the fact that it became one of the most popular recreational activities practiced by children and adolescents, fostered a strong public debate about the possible effects of VGs exposure on human well-being. Recent studies showed that in western industrialized countries many children and adolescents play VGs for a very long time during the day[2,3]. Several recent investigation have shown that children and adolescents live media-saturated lives: a percentage ranging from 83 to 97% has a home console for VG with which interact for several hours per day[4,5]. And this incidence is not limited to youngest: it has been reported that more than half of U.S. adults are interested in playing VGs[5] and it is believed that such percentages will reasonably increase over the years[6].

These data have conducted the researchers to question which are the effects of prolonged and continuous exposure. In 1983, U.S. Surgeon General hypothesized that VGs were one of the principal causes of family violence[7]. In the subsequent years, the debate moved and continued in the scientific community[8-10] showing often contrasting points of view.

Under the behavioral point of view, a good number of studies demonstrate that VG exposure can induce development of aggressive behaviors[11-13], associated with anger[14,15] and impulsivity[16]. Contrarily to these studies, some other authors refuted these results indicating the absence of a clear relationship between playing VG and addiction, and violent or aggressive behavior[17,18]. Some studies focused their attention to cognitive aspects, suggesting that prolonged exposure to VGs may have a detrimental impact on the attentional sphere[16,19,20], with possibility to evolve to a clinically relevant attentional deficit[21], with worsened scholastic performance[22,23] and memory deficiency[24]. In addition to these effects, a negative correlation between exposure to VGs and cognitive proactive control has also been reported[25]. On the other hand, several other studies highlighted a possible increase in cognitive performances as a consequence of exposure to VGs, reporting improvements in several brain abilities such as visuo-motor skills, when exposure is not excessive[26], information processing[27], executive functions[28-30], learning[31]. These studies have also been recently deeply reviewed and discussed in a theoretical framework of brain plasticity and on the opportunity to use this technology as a potential brain enhancer[32,33].

Additionally, some studies suggested an increase in depression and anxiety[34,35], a reduction of empathy[36] and an impairment of socially oriented behavior[37] as a consequence of VG playing. However recent studies have refuted such data showing no effect on social behaviour[38] and improvements in empathy[39]. Indeed Chen et al.[40] shown that interactive video games had a direct, positive impact on empathy and may be useful as part of innovative curricula to improve empathy among students. Another relevant aspect of prolonged videogaming (and, more in general, of media utilization) is related to physical activity and different kind of VG: people that play to classic VGs tend to show significant behavioural consequences as erroneous eating habits, BMI increase and increased risk of obesity in both males and females and independently by age[41,42]; on the contrary, people who play exergames tend to show some health benefits as the improvement of physical fitness, a significative weight loss, and an enhanced enjoyment[43,44]. In general, it would be taken into consideration that all these observations are relevant *caveats* when a systematic analysis of literature is done with respect to psychological, behavioral and physiological eggects of videogaming.

To all these considerations, some conflicting with each other, it should be added the one related to the fact that playing VGs is usually a nighttime activity[45]: due to work, study or social commitments, people tend to play during the first hours of night, sacrifying time to sleep[45,46] and exposing themselves to several negative cognitive consequences[47]. In spite of all these studies on behavioral, cognitive and emotional aspects, only a few investigations directly explored the effects of VG exposure on sleep in general and on behavioral aspects of sleep as quality, quantity, latency of sleep onset, nocturnal awakenings and so on.

To this aim, here we will review studies on the effects of exposure to VG on sleep, with particular attention to quantitative and qualitative self-reported aspects of sleep, physiological aspects of sleep after exposure to VG and related consequences on cognitive skills upon awakening. Limitations and future directions for research in this field will also be discussed.

METHODS

Systematic review strategies

A systematic review has been carried out, in order to summarize the available results of experimental studies. To identify eligible papers we performed a systematic literature search on PubMED, PsychINFO and PsychArticles databases. The research has been limited to papers written in English. We used the following search terms and logic: *"videogames OR video games OR video-games OR videogame OR video game OR video-game OR video-gaming OR video gaming OR videogaming AND sleep OR sleepiness"*, *"videogames OR video games OR video-games OR videogame OR video game OR video-game OR video-gaming OR video gaming OR videogaming AND sleep* and *"videogames OR video games OR video-games OR videogame OR video game OR video-game OR video-gaming OR video gaming OR videogaming AND sleep AND cognitive process"*.

In particular on PubMed was searched using term *"Video Games/adverse effects" [Mesh] OR "Video Games/classification"[Mesh] OR "Video Games/psychology"[Mesh]) AND "Sleep"[Mesh], "Video Games/adverse effects"[Mesh] OR "Video Games/classification"[Mesh] OR "Video Games/psychology"[Mesh]) AND "Sleep"[Mesh] AND "Attention"[Mesh], "Video Games/adverse effects"[Mesh] OR "Video Games/classification"[Mesh] OR "Video Games/psychology"[Mesh])" AND "Sleep"[Mesh] AND "Memory"[Mesh]* finally *"Video Games/adverse effects"[Mesh] OR "Video Games/classification"[Mesh] OR "Video Games/psychology"[Mesh]) AND "Sleep"[Mesh] AND "Cognition"[Mesh].*

No limit about year of publication has been set, and the final search is updated to July 2018.

All articles were recovered and selected on the basis of presence/absence of the search criteria (see below). To identify any articles that may have been missed during the literature search, also reference lists of candidate articles have been carefully checked. Following this procedure, we found 1824 publications and, after applying the selection criteria, the total number of relevant publications was reduced to 12 (see Results section). To document the literature search process, we used the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA): Figure 1 shows the process diagram followed to select the included studies.

Study Selection Criteria

To select only the relevant studies, both titles and abstracts of all citations identified by the literature search have been examined. To this extent, we included all studies that investigated the specific theme of exposition to VGs (console or computer game) and aspects of sleep in terms of quality and quantity, sleep onset latency (SOL), total sleep time (TST), subjective evaluation of daytime sleepiness, sleep components (NREM-REM cycles, sleep stages), slow-wave sleep (SWS) and other results regarding the level of fatigue and insomnia. Moreover, studies and investigations assessing cognitive skills (such as verbal and visuospatial memory, working memory, sustained attention) in people tested at the awakening after have played VG were also included. Furthermore, the literature review covered both experimental-provocative studies and qualitative-observational surveys.

All relevant studies have been divided on the basis of quantitative and qualitative self-reported aspects of sleep, of quantitative and qualitative physiological aspects of sleep, and on the basis of cognitive performance tested on the morning after the exposure to VG.

RESULTS

Studies selection

Following PRISMA procedure, a research on databases PubMED[Mesh], PsychINFO and PsychArticles was conducted and identified a total of 1824 articles. After having deleted all duplicate articles, we got a total number of 200 articles; 55 of these were rejected because they did not meet the evaluation criteria described above. The remaining 25 studies were analyzed integrally and only 12 were included in the systematic conclusive review as they fully satisfied inclusion criteria; of these 3 were literature reviews, dealing with effects of exposure to VGs on sleep and cognitive post-sleep abilities.

In the following sections, the selected studies will be reported and analyzed, grouping them on the basis of quantitative and qualitative aspects of self-reported sleep, quantitative and qualitative aspects of physiologically assessed sleep and of type of cognitive performance assessed upon awakening (after exposure to VG).

Qualitative and quantitative aspects of self-reported sleep

It is well known that the exposure to external stimuli before sleep can significantly influence consequent sleep: seven studies just analyzed self-perceived sleepiness after pre-sleep exposure to VG in teenagers.

In the first[46], thirteen male adolescent "evening types" participated in a counterbalanced, within-subjects design with experimental (active video-gaming to *Call of Duty 4*) and control (passive DVD watching of *March of the Penguins*) conditions. Their exposure to both experimental and control stimuli was limited to 50 minutes before the attempt to go to sleep; recording of two conditions were done in the laboratory at a distance of one week. Within the several outcomes recorded (see also the next section) daytime sleepiness was also assessed by means of Stanford Sleepiness Scale. Results (see Table 1) showed a slight but significant reduction in sleepiness assessment in VG condition with respect to control: this slightly significant effect was mainly due to the variability of data since the fact that after VG exposure, 7 participants reported a decrease in sleepiness, 2 reported an increase and 4 indicated no change with respect to DVD-control condition.

These results have been challenged by the study of Ivarsson et al.[48]. Here, the authors focused their attention mainly on the effects of different genres of VG (violent and non violent) on teenage boys that were selected on their previous history of exposure to VG. Also in this case, besides sleepiness/alertness and sleep quality indices, different outcomes were recorded (see following sections). Thirty participants (aged 13-16 years, SD=0.9), half of them low exposed (≤1 hours per day) and half high-exposed (≥3 hours per day) to violent games, played in a counterbalanced order to a violent VG and to a non violent VG for 2 hours (from 8 to 10 p.m.). The whole experiment took place at participants' home in two different weekdays. Results, summarized in Table 1, indicated a significantly increased level of alertness at bedtime within the low-exposed group between the two gaming conditions and within the nonviolent condition between the groups. Moreover a significant reduction of the quality of sleep among low-exposed gamers after having played the violent game compared with the nonviolent game, and an opposite pattern among the high-exposed gamers has been reported. Authors thus concluded that both sleep quality and alertness were more negatively influenced after the violent game in low-exposed compared with high-exposed gamers,

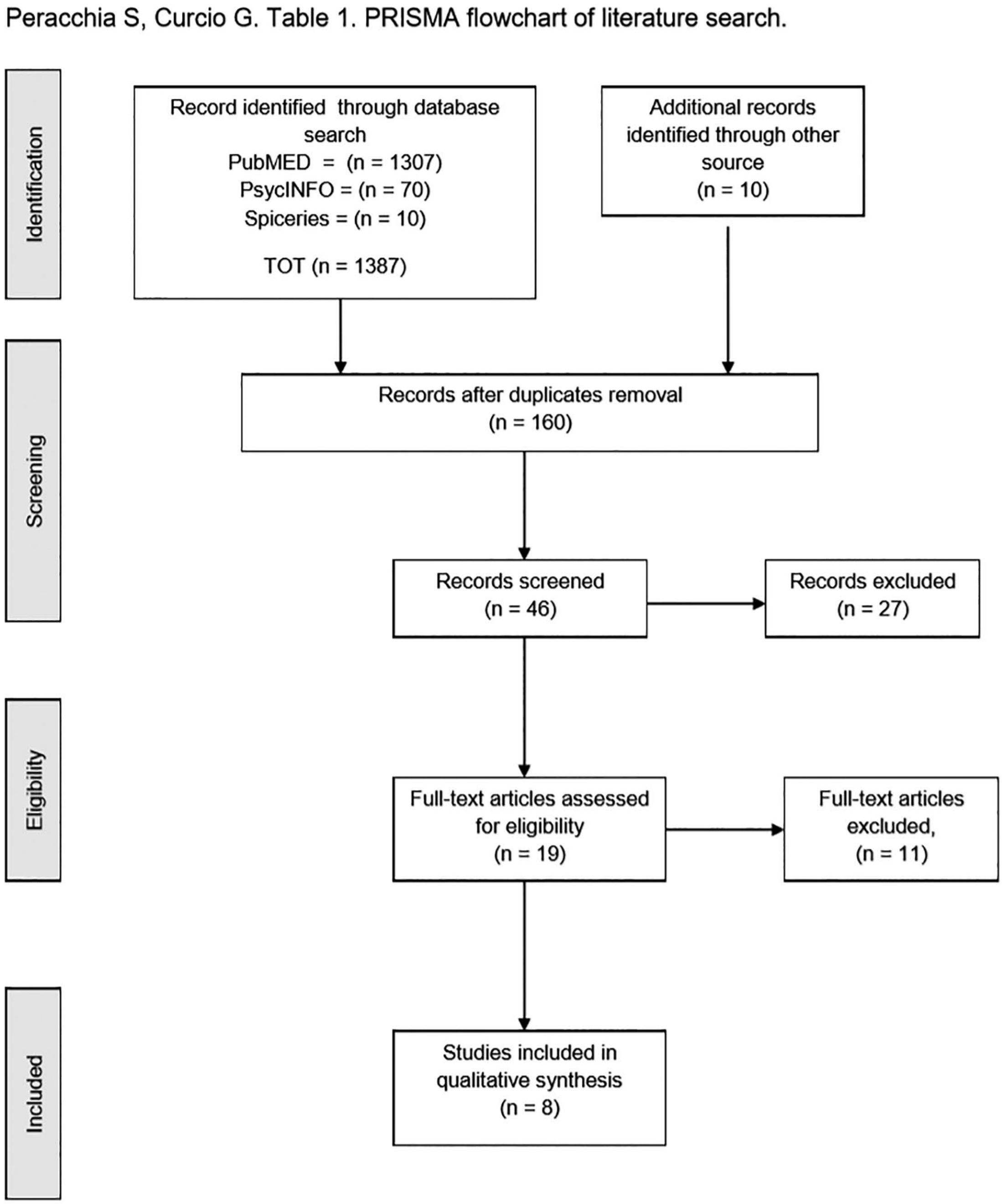

Figure 1. PRISMA flowchart of literature search.

hypothesizing that such different reaction patterns could be dependent by desensitizing effects in expert players[48].

A survey conducted in Belgium studied bedtime attitudes and entertainments media in the bedroom[49]. This survey was conducted on a sample of 2546 students of secondary school who have filled in a standardized self-administered questionnaire made "ad hoc" for this study. The questionnaire contained questions about media presence in bedrooms, volume of television viewing, computer game playing and Internet use, time to bed and time up on average weekdays and average weekend days, and questions regarding the level of tiredness in the morning, at school, after a day at school, and after the weekend. The results highlighted that the subjects with a gaming computer in their rooms went to bed significantly later on weekdays, spending significantly less time in bed. Also, teens who spent more time playing computer games went to bed later on weekdays and weekend days and got up later on weekend days: they spent less time in bed on weekdays and reported higher levels of tiredness.

Only one study, instead, did evaluate how the amount of time spent playing VG may influence sleep in adults[50]. A sample of 844 participants (56.2% women, aged 46.0±17.76 years)

Table 1. Outcomes and main results of reviewed studies. Peracchia S, Curcio G.

STUDY	SOL	TST	TIB	REM	nREM	SWS	SSt	SS	ST	SQ	VLF	HR	Temp	VM
Higuchi et al.[57]	+			-		=		-		-		+	+	
Dworak et al.[51]	+	=		=		-	+*							-
Ivarsson et al.[69]											+	+		
Weaver et al.[46]	+			=	=	=		-				=		
Brunetti et al.[53]		-												
Van den Bulck[49]			-***						+					
King et al.[52]	+	-		-						-				
Ivarsson et al.[48]								-				+**		
Wolfe et al.[47]														
Exelman & Van den Bulck[50]	+							+		-				
Twenge et al.54		-												
Arrona-Palacios[56]		-	-					+						

NOTE: (+) increase compared to the control group and/or baseline condition; (-) reduction compared to the control group and/or baseline condition; (=) no changes.
SOL: sleep onset latency; TST: total sleep time; TIB: time in bed; REM: rapid eye movement sleep; nREM: non rapid eye movement sleep; SWS: slow wave sleep; SSt: variations in sleep stages; SS: subjective sleepiness; ST: subjective tiredness; SQ: sleep quality; VLF: very low frequency; HR: heart rate; Temp: temperature; VM: verbal memory; VsM: visuospatial memory; WM: working memory; SA: sustained attention; Ins: insomnia; F: fatigue.
*: limitedly to stages 2 and 4
**: limitedly to violent videogames
***: both in weekdays and weekend days

filled in the Pittsburgh Sleep Quality Index, a scale on rise and wake time, the Fatigue Assessment Scale, the Bergen Insomnia Scale and a questionnaire about VG volume[50]. The study showed two main results: as a first, videogaming volume resulted significantly and negatively related to fatigue, insomnia, bedtime and rise time in adult sample, because the more people play VGs, the higher their complained levels of fatigue and insomnia, and the later reported their bedtime and rise time (see Table 1, dark gray section). Secondarily, these effects were greater (increased sleep onset latency and decreased sleep efficiency) when the time of videogaming exceeds 60 minutes per day, as also previously showed by other studies[51,52]. On the basis of these results, the authors concluded that VG activity become detrimental for the quality of sleep when the daily time dedicated to it exceed 1 hour, maybe due to screen exposure and arousal increase[50].

Recently a cross-sectional study was conducted on 1843 grade 5 students aged 10-12 years at inception in the greater Montreal (Canada) area[53]. Here the associations between screen (computer, videogame, TV) and nonscreen (talking on the phone, doing homework, reading) sedentary time, and sleep in adolescents was examined. Looking only at results about videogaming effects on sleep, it was reported that more than 2 hs per day of videogame use was associated with reduced sleep duration.

In a study by Twenge et al.[54] sought to determine whether the self-reported sleep duration of U.S. adolescents changed between 2009 and 2015 and to examine the new media screen time (related to other factors) might be responsible for changes in sleep. The results showed that between 2009 and 2015 16% to 17% more adolescents reported insufficient sleep and the number of adolescents getting insufficient sleep increased after 2011-2013. Use of video games define an increased odds of short sleep duration (increasing 44 minutes a day) and hours of video games use were positively correlated with failing to get 7 or more hours of sleep on most nights (constant across the years)[54]. The relation between self-perceived sleep and time spent on VG during nighttime before going to sleep tends to be different also in relation to different school shifts. Some works support that the school start time as an important social zeitgeber that synchronizes the circadian rhythms of adolescents[55]. However, the Arrona-Palacios study[56] demonstrates the opposite. A sample of 568 students (280 were boys and 288 girls, mean age 14.08±0.72 years), distributed into two school group (morning shift and afternoon shift), completed a battery of questionnaire for evaluating individual's habitual rise time and bed time, daytime sleepiness and use of VG[56]. Comparison of data obtained from morning shift and afternoon shift shown that adolescents from the afternoon shift showed a similar effect on the sleep-wake cycle, as with the adolescents from the morning shift when having a high exposure to VG during nighttime before going to sleep[56]. Adolescents from the afternoon shift reported a higher use of VG than adolescents from the morning shift consequently the afternoon shift, prolonged their bedtime and rise time even more than adolescents from the morning shift.

Qualitative and quantitative physiological aspects of sleep

In the very last years, a great body of research examined the extent, characteristics, and effects of VG play among children and adolescents. The existing literature showed the evidence that excessive VG play can displace healthier activities such as social, academic or athletic efforts, and also indicated that videogaming can influence sleep of players. Videogaming during nighttime, in fact, is able to delay sleep onset and interfere with sleep duration and efficiency. Thus, together with a displacing of sleep time, also effects on sleep architecture can be observed. In this paragraph we examine the effects of videogaming on qualitative and quantitative physiological measures of sleep, including those related to sleep structure: characteristics of each study included in the systematic review have been summarized in Table 2.

TST and SOL

Only four of the included studies examined total sleep time and sleep onset latency. Dworak et al.[51] found that interactive computer game consumption resulted in prolonged SOL, more time in stage 2 sleep, and less SWS as a percentage of TST. For this study 10 male adolescents were recruited: females were excluded to avoid the influence of menstrual phase and oral contraceptives, as well as for the well-known gender differences in videogaming (i.e., boys spend more than twice as much time playing VGs as girls). Each participant underwent 3 investigation sessions, with an interval between them of 1 week. In two of the experimental days children were exposed to interactive computer games (*Need for Speed-Most Wanted*; *Redwood City*) for 60 minutes, while in the third they were simply asked to watch a subjectively exciting video film on television (choosing between *Harry Potter and the Prisoner of Azkaban*, *Star Trek: Nemesis*, and *Mary Higgins Clark's Loves Music, Loves to Dance*). Before participants went to bed, polysomnographic measurements were conducted using a portable sleep data recorder. The participants slept in their own homes and also instructed to adhere to their normal evening routines and fill in a sleep diary. Results showed a significant increase of SOL after computer game stimulation compared with basal conditions.

A study proposed by Higuchi et al.[57] was conducted in sleep laboratory on 7 male volunteers. The subjects played a shooting game on a computer with a bright display (game-BD) or a dark display (game-DD) and performed simple tasks with low mental load as a control condition in front of a BD (control-BD) and DD (control-DD): these conditions were administered in randomized order. Videogaming took place between 23:00 and 1:45 hours, after which participants went to bed at 2:00 hours and slept until 8:00 in the morning. After the subjects had finished playing a computer game or control activity, theta power of EEG and subjective sleepiness were measured. Results showed that playing at the computer before going to bed increased sleep latency (+2,3 min), an effect that was possibly due to physiological arousal of CNS: it is well known, in fact, that performing mental tasks before sleep, significantly increases sleep latency (e.g.[58]). Furthermore, in the present study, the brightness of the display did not show any influence on sleep latency, as previously reported[59,60].

Additional confirmations of these findings come from the study conducted by Weaver et al.[46], already described above. This study found an increase of 3,5 minutes of SOL in subjects exposed to violent VGs for 50 minutes before bedtime: 11 adolescents experienced an increased SOL with respect to controls, whereas only 2 adolescents showed a reduced SOL. The difference between groups was significant, supporting the prediction that pre-sleep VG playing would worsen the falling asleep process. Nevertheless this effect, the authors concluded that such an increase of SOL is quantitatively slight and that it would not have a too negative influence on sleep.

One of the limitations of the studies discussed above is the amount of exposure to VGs that on average is around 60 minutes for every gaming session. According to some recent findings[46], a relatively low level of exposure to VGs may be insufficient to produce discernible effects. For these reasons, King et al.[52] investigated the impact of prolonged experience with violent VG on adolescent sleep. A total of seventeen males with no current sleep difficulties played a novel, fast-paced, violent VG before their usual bedtime on two different testing nights in a sleep laboratory. Subjects were exposed to either 50 or 150 min of videogaming directly before bedtime on each testing night: here, fifty minutes of videogaming exposure was considered "normal", instead videogaming for an uninterrupted 150 min period was considered "prolonged". On each testing night, using a PlayStation 3 console subjects played *Warhammer 40.000: Space Marine*, a VG asking for rapid actions and involving "strong violence". Videogaming was scheduled to conclude 10 min before the subjects usual bedtime to enable a check of polysomnographic and HR instruments. Before and after videogaming session, a questionnaire for sleep assessment was administered, while subjective level of sleepiness was evaluated immediately after playing. Results showed that a prolonged exposure to violent VG (150 min) leds to a 27 min decrease in adolescents' TST and a 7% loss of sleep efficiency, as compared with regular videogaming (50 min). Moreover, objective SOL increased of 3,5 min, although subjects were able to fall asleep within "healthy" limits (less than 30 min, as proposed by Espie et al.[61]). Prolonged videogaming had no significant effect on sleep architecture, yet a small effect was found for SWS. Furthermore, the same authors, reported that prolonged videogaming reduced adolescents' sleep efficiency to below the established clinical cut-off used to indicate sleep disruption (i.e. <85%, as suggested by Buysse et al.[62]). In contrast, sleep efficiency after regular videogaming was within the normal range. These findings suggest that prolonged videogaming may pose a clinically significant risk for sleep quality and quantity, even when sleep starts at the right time. Moreover, this study indicated that videogaming may disrupt sleep by displacing sleep time (i.e. delaying bedtime). Also, participants reported significantly lower satisfaction with the duration of videogaming after 50 min as compared with 150 min, desiring a further 37 min (compared with 14 min more for the 150 min condition) to feel they had played "long enough". Therefore, unmonitored regular videogaming seems unlikely to be self-limiting (i.e. cease at normal bedtime): this finding is consistent with qualitative research reporting that almost no amount of time is subjectively considered "long enough" for adolescent videogamers[63]. The desire to continue videogaming was significantly correlated to objective SOL in the regular videogaming condition, suggesting that

Table 2. Characteristics of each study included in the systematic review. Peracchia S, Curcio G.

References (Author, place)	AIMS	SAMPLE SIZE AND CHARACTERISTICS	VG USED	GROUPS CHARACTERISTICS	TIMING OF VG SESSION	TYPE OF SLEEP MEASUREMENTS
Higuchi et al.[57]	- To examine the effects of playing an exciting CG on pre/sleep physiological variables and sleep variables. - To examine the exposure to a light by gazing at a bright display affects pre/sleep physiological variables and nocturnal sleep variables	6 male students (age 24.7 ± 5.6 ys)	CC: performed simple tasks with low mental load EC: Shooting game	Epidemiological studies. CC and EC group are the same	1:45 hours for each conditions	- EEG - Visual Analog Scale (VAS)
Dworak et al.[51]	To investigate the effects of singular excessive television and CG consumption on sleep patterns and memory performance of children	11 male children (age 13.45 ± 1.04 ys)	VG: - Need for Speed Most Wanted 3 films: - Harry Potter and the Prisoner of Azkaban; - Star Trek; - Loves Music Loves to Dance	Randomized crossover trial. The participants adhered to their normal daily patterns but were not allowed to watch TV or play VG.	3 investigation days, session of 60 minutes of play	EEG
Ivarsson et al[69]	To study cardiac, sleep-related, and emotional reactions to playing violent (VG) versus no/violent (NVG) VG in adolescents with different gaming habits	30 male adolescents (age range 13-16 ys) 15 “high-exposed”, and 15 “low-exposed”	ViolentVG: -Manhunt NonviolentVG: - Animaniacs	15 boys were thus used to play violent computer/VG at least 3 hours daily (“high-exposed”), and the other half used to play 1 hour or less daily (“low-exposed”)	NA	Sleep Diary
Weaver et al.[46]	- To investigate the capacity of pre/sleep VG play¬ing to extend sleep latency and reduce subjective feelings of sleepiness in adolescents - To investigate arousing psychophysiologic mechanisms involved and the impact of pre/sleep VG playing on sleep architecture	13 male adolescents (mean age 16.7 ys)	EC: - Call of Duty 4: Modern Warfare; - Infinity Ward CC: film: - March of the Penguins	Cross-sectional study. CC and EC group	Adolescents began to either play the VG (EC) or watch the film (CC), both for 50 minutes. Two experimental session, 1 week apart	- Sleep Diary - Stanford Sleepiness Scale - EEG - EOG
Brunetti et al.[53]	To examine the associations between screen (VG ,TV) and non screen (talking on the phone, doing homework, reading) sedentary time, and sleep in adolescents.	1859 children, of grade 5th (age 10.0 ± 0.5 ys), 6th (11.7 ± 0.4 ys), 7th (12.9 ± 0.4 ys), 9th (15.2 ± 0.5 ys), and 11th (16.8 ± 0.5 ys). More than half (57%) of participants were female.	No VG	Cross-sectional survey. Only EC group	No VG	Questionnaires to evaluate: - Sleep duration, - Time spent daily in each of 6 sedentary behaviors screen activities (watching TV, using a computer, playing VG) and non screen activities (talking on the phone, doing homework, reading) - Daytime sleepiness
Van Den Bulck.[49]	To investigate the relationship between the presence of a TV set, a CG and/or an Internet connection in the room of adolescents and TV viewing, CG playing, and Internet use on the one hand, and time to bed, time up, time spent in bed	2546 adolescents (54.2% males), at first-year (mean age 13.16 ys) and fourth year (mean age 16.37 ys)	No VG	Prospective, uncontrolled observational study. Only EC group	No VG	Questionnaires to evaluate: - Sleep duration - Daytime sleepiness

Continuation Table 2.

King et al.[52]	To investigate the short term impact of adolescents' prolonged exposure to violent video-gaming on sleep.	17 male adolescents, (age 16±1 ys)	Warhammer 40.000: Space Marine	Experimental study. Adolescents were required to be "regular" VG players	Subjects were exposed to either 50 (regular) or 150 min (prolonged) of video-gaming directly before bedtime. Two testing nights, 1 week apart	- Sleep Diary - EEG
Ivarsson et al.[48]	To investigate how playing a violent/no/violet television game during the evening affects sympathetic and parasympathetic reactions during and after playing as well as sleep quality during the night after playing.	19 male adolescents (age 13.3± 0.7 ys; range 12–15 ys)	Violent VG: Manhunt Nonviolent VG: - Animaniacs	Experimental study. Violent and Non violent group	Two experimental sessions in their homes and one session without gaming	Sleep Diary
Wolfe et al.[47]	To look at the impact of video/gaming on daytime functioning by testing a mediation model using objective measures of video-gaming, sleep and performance in a controlled laboratory environment	21 adolescents (16 males) (age 17.6±1.8 ys; range 15-20 ys)	Bioshock Infinite	Cross-sectional survey. Only EC group	No more than 5 hours	Actigraphic registration
Exelman & Van Den Bulck[50]	To investigate the association of VG volume with sleep quality in adults via face-to-face interviews using standardized questionnaires	844 adults (56.2% women (age 46.0±17.76 ys)	No VG	Cross-sectional survey. Only EC group	No VG	- Pittsburgh Sleep Quality Index (PSQI) - Fatigue Assessment Scale (FAS) - Bergen Insomnia Scale (BIS) - Bedtime and rise time
Twenge et al.[54]	- To determine whether the self-reported sleep duration of U.S. adolescents changed between 2009 and 2015 - To examine whether new media screen time might be responsible for changes in sleep	369,595 students in 8th, 10th, and 12th graders school grade (13, 15, 17 ys)	No VG	Cross-sectional survey. Only EC group	No VG	Survey on line to evaluate sleep duration
Arrona-Palacios[56]	To compare the effects of time spent on VG during nighttime before going to sleep on the sleep-wake cycle, daytime sleepiness, and chronotype	568 students (288 girls) (age 14.08±0.72 ys) 287 from morning shift; 281 from afternoon shift	No VG	Cross-sectional survey. Only EC group	No VG	- Sleep timing questionnaire - Morningness–Eveningness Questionnaire (MEQ) - Epworth Sleepiness Scale

NOTE: CG: Computer Game; CC: Control Condition; EC: Experimental Condition; NA: Not Assessed.

cognitive engagement with a videogame may affect sleep onset when pre-sleep videogaming activity is considered insufficient[52].

Sleep Architecture

A limited number of studies have been published on changes in sleep architecture as a consequence of videogaming: in this section we will discuss the only 3 studies dealing with this issue.

The study of Dworak et al.[51], already delineated above, showed that playing VGs induces a shift of sleep stages, an effect that does not occur after other activities such as watching the TV. Participants that went to bed after exposure to interactive computer game playing, showed to spend more time in stage 2 and stage 4 with respect to baseline condition. Case-wise data showed considerable increases (over 50 minutes) of stage 2 sleep in seven out eleven investigated children. Furthermore, the percentage of sleep stages distribution showed a significant decrease in SWS after computer game consumption with respect to basal conditions: a decline of more than 5.0% of SWS was observed in seven participants and two of these showed a very significant reduction (10.02% and 13.27%, respectively). On the other hand, only one participant showed a decreased SWS percentage (higher than 5.0%) after TV consumption compared with basal conditions. The authors discuss these results as probably due to a significantly high level of arousal of children[51]. These data are inconsistent with those reported by Higuchi et al.[57] and Weaver et al.[46] which did not detect influence on SWS. There may be several possible explanations for this inconsistency: difference in participants' age, different type of VGs used and, finally, methodological differences in polysomnographic assessments.

Regarding sleep cycle (i.e., the ciclic alternating of NREM/REM phases during the night) only Higuchi et al.[57] reported significant results. The authors showed that total amount of REM sleep after playing computer games was significantly shorter than in control condition. Curiously, such a significant decrease in REM sleep was found only in the first NREM–REM sleep cycle and not in the following ones. A decrease in REM sleep has also been reported as reflection of the first night effect (FNE)[64,65], caused by sleeping in an unfamiliar environment and characterized by higher arousal also at EEG level[66]. In this case the decrease in REM sleep after performing the computer game in the present study may reflect a high arousal state in subjects[57]. Similary to these results, also King et al.[52] did find that prolonged videogaming had no significant effect on sleep architecture, yet a near-moderate effect was found for REM sleep, that resulted in a reduction of 12.6 min.

Conversely, some other studies did not confirm these changes in REM sleep (i.e.[46,51]). This inconsistency in the results may depend on marked differences in participants' age (mean age Higuchi et al.[57] was 24 years, while in Dworak et al.[51] was 13 years, and in Weaver et al.[46] was 16 years), sample size and gender unbalance within the studied samples.

Physiological measures

Is well known that playing VGs can influence parameters such as HR, cardiovascular reactivity and blood pressure[67,68]: these modifications could, in turn, change the sleep. This idea is the rationale for some studies in which physiological measures act as dependent variable.

Playing VG before bedtime, for example, seems to increase HR and the rectal temperature[57]. This study assessed rectal temperature and HR immediately after the subjects had finished playing a computer game for 1,45 hs. The results showed that rectal temperature after videogaming was significantly higher than after control conditions. In the same vein, HR also resulted significantly higher after playing than after control conditions, and it also resulted increased after the exposure to a bright display (BD) with respect to the condition of exposure to a dark display (DD).

Conversely, other authors did not detect any change on physiological arousal[46]. In this study (already described above) the authors measured the HR at 25 minutes (midway) through the pre-sleep activity. A post-activity measure of HR was taken directly upon the completion of each pre-sleep activity. Results indicated that heart rate was not associated with the effects of pre-sleep videogame playing on SOL and subjective sleepiness previously discussed. These results probably depend on methodological flaws, due to the time between the end of the activity and the effective recording (1 min), a time in which alterations of such measure may be "missing" or return to normal levels[46].

Some physiological changes can also result by the exposure to different kind of VGs before bedtime, that would induce different autonomic responses. Ivarsson et al.[48] have observed a number of relevant effects during the night after which the participants were exposed to violent condition, compared to non-violent. Nineteen boys played television games on two occasions in their homes and participated once without gaming. Heart rate, heart rate variability (HRV) and physical activity were measured both during gaming and along the following night. A sleep diary and questionnaires about gaming experiences and session-specific experiences were also asked to be filled in. Results indicated that during violent (vs. nonviolent) gaming, there was significantly higher activity of the very low frequency component of the HRV and total power (TP). During the night two main significant differences emerged: HR was lower after violent gaming than after the nongaming condition, and after playing a nonviolent game VLF was lower than after the nongaming condition. Therefore, some significant observations came to light: overall, during violent gaming (compared to nonviolent one) higher activity of the VLF component (related to various autonomous functions), higher power of LF (suggesting sympathetic activation) as well as higher HF (indicating vagal activation) were observed[48].

The same authors, some years later[69], carried out a study to investigate if reaction patterns differed between teenage boys with high exposure to VGs (≥3 h/d) and those with low exposure (≤1 h/d), during and after playing a violent and a nonviolent VG for 2 hours during two different evenings in their homes. Heart rate and HR variability have been recorded in 30 boys from before start until next morning. A questionnaire about emotional reactions was also administered after gaming sessions and a sleep diary on the following mornings. Results have shown that low-exposed gamers had higher HR and LF/HF ratio during sleep after the violent game compared to the nonviolent game, whereas high-exposed gamers showed an opposite trend. Moreover, violent gaming was associated with increased HR during playing. The authors concluded that both types of violence-related psychophysiological outcomes probably reflect increased sympathetic activation[69].

Effect of the use of VG on cognitive performance at awakening

Generally speaking, playing VGs has a strong influence on adolescents' everyday life. Some previous evidences claimed the idea that exposure to VGs could compromise a great variety of behavioural and cognitive characteristics (e.g. Dworak et al.[51]). Moreover, excessive consumption of games may also be associated to attention problems, hyperactivity, or psychiatric symptoms. To date only a few studies have been conducted on possible cognitive consequences as a results of changes in sleep pattern induced by an excessive exposure to VGs.

It is definitively accepted that sleep is essential for both health and development of children and plays an important role in memory and learning (e.g. Singer et al.[70] and Maquet[71]). It is assumed that the consumption of media after a learning phase, may compromise memory consolidation and performance[51]. Specifically, the insufficient quality of sleep and his reduction, is often associated to problems of the performance of declarative, procedural and working memory, as well as a poor concentration with consequently poor performance at different levels[72,73].

In particular, exposure to VGs before sleeping, causes a significant performance decline of verbal memory in the morning after with respect to basal condition, and the analysis of single case revealed a decline >20% on more than half of the sample[51]. These results were not confirmed in the condition in which the participants were exposed to TV watching.

Modern neuroscientific theories support the idea that strong emotional experiences, as playing action VGs and watching exciting films, may affect learning processes. It is assumed that the information newly learned are much more sensitive in the following period, when the consolidation occurs, and that the emotional experiences can thus significantly influence memory consolidation[71,74]. Interactive VGs are challenging, frustrating, exciting and often surprising, and during the play the subject may experience a range of emotions, accompanied by intense physiological changes[51] as described above.

Regarding visuospatial memory, one of the studies has highlighted a performance impairment in participants when they were exposed to VGs compared to basal condition and watching TV condition, but these results did not reach statistical significance[51].

However a more recent study did not detect any type of deficit at the level of working memory after a single exposure to VGs[47] probably because not all kinds of memories can be reasonably be influenced (see Table 1, section light gray). This study investigated adolescent VGs use prior to bedtime and its potential effects on subsequent sleep, working memory and sustained attention performance. Sample was composed by 21 participants: participants, once introduced into the sleep lab, completed baseline measures of working memory (computerised version of the Operation Span Task) and sustained attention (Psychomotor Vigilance Task). From 8:00 p.m., participants moved to their allocated sound-attenuated bedroom and began videogaming (it was used Bioshock Infinite, a narrative-driven first-person shooter game) until 1:00 a.m., and then they went to bed. The next morning participants completed again both tasks. Results showed that time spent in videogaming negatively correlated with sustained attention, with longer time spent videogaming resulting in greater decrements of sustained attention performance[47]. The findings of the present study support the mediation hypothesis in regard to sustained attention, but not working memory. The authors hypothesized that sustained attention performance is a more sensitive measure of sleep-related performance deficits when compared to working memory[47]. This would also be consistent with the notion for which VGs have an influence on performance implicated in sleep (or "sleep-dependent") and not directly on cognitive performance: in fact it is speculated that such an effect would be due to reduction of TST[52] that, in turn, will cause the decrease in sustained attention' ability[47].

DISCUSSION AND CONCLUSIONS

In general it is considered that the excessive consumption of media have a negative influence on health and wellness of their users. Most of the research conducted until today is focused on the effects of the exposure to media (in particular TV) and only recently a few investigations have explored the effects of consumption of VGs on sleep. Lack of sleep, as well as changes in sleep pattern, have been associated with numerous problems including daytime sleepiness[75], behavioural issues (including hyperactivity and poor concentration)[76] and accidents. As already mentioned sufficient sleep is necessary for maintaining the body's homeostasis, as well[71].

This review had the purpose to draw attention on this still unclear topic: fundamentally results from the literature indicate that videogaming can disrupt nightime sleep (by altering its architecture and temporal structure), alter physiological indices (mainly autonomic) and facilitate daytime disfunctioning (by increasing excessive sleepiness). The general consequences seem to be a reduced sleep and life quality, together with an impaired performance at awakening and during the day after videogames sessions.

It is well known that age represents one of the most important elements to determine as the human being sleeps. From birth to adulthood, sleep undergoes changes related to the quantity and quality of sleep, the components of various sleep stages, the temporal and percentage organizations of the states of alertness and the electroencephalographic activity. For example, during adolescence, significant changes of sleep as increased vigilance and delayed onset of sleep usually occur[77,78]. Also, stimuli coming from the outside world can influence sleep, as for example lighting, environmental noise, or exposure to media in the pre-sleep phase. In particular, activity as playing VGs, watching TV, reading e-books, texting with mobile phone and browsing in internet before falling sleep, determine a delay in bedtime[60,79] causing the reduction of TST, since individuals tend to go to bed later and to get up before, especially during weekdays[80]. This phenomenon is also related to excessive daytime sleepiness[49,81] and recent evidences suggest that exposure to VGs before bedtime can be a pre-sleep activity particularly disruptive for teenagers[60].

More specifically, some studies reviewed here showed that the use of VGs may cause a reduction of TST[49] and an increase of SOL[46,51,57] through some mechanisms as the increased physiological arousal, the delay to go to bed and the exposure to light monitor during the night[57,59]. To these effects can also be associated a reduction of pre-sleep sleepiness[46,69], probably due to an increase of CNS arousal that will consequently worsen sleep quality[69].

Some studies showed that consumption of VGs, respect to TV, increases different autonomic measures of children, as heart rate, blood pressure and respiratory rate: all these changes indicate an increased state of arousal in CNS[67,82]. Increased levels of arousal have previously been associated to difficulty in falling asleep and frequent nocturnal awakenings[49,83]. This may be a valid explanation for sleep impairments in people who plays exciting, violent and competitive VGs[84]. Moreover, some studies showed a change of HR after exposure to VGs mainly in subjects defined as "no-gamers" when exposed to violent games[69], effect probably due to a limited "habituation" of these individuals to violent scenes. Nonetheless, such autonomic changes did not influence subsequent sleep, with the only exception of a reduced pre-sleep sleepiness[69].

With respect to sleep measures, the few studies available in literature indicate very conflicting results. The observed reduction of SWS[51] was not confirmed by other studies[46,57]; similary the REM sleep decrease reported in one investigation[57], was subsequently refuted by Weaver et al.[46] and Dworak et al.[51] studies. Overall, the issue of post-videogaming sleep appears confused and contradictory, due to the few data currently available in the literature.

A side-effect of sleep architecture (i.e., reduction of TST and increase of SOL) after exposure to VGs, is the induction of daytime disfunctioning. This could explain the worsening of some cognitive abilities (i.e. verbal memory or sustained attention) upon awakening after evening exposure to VGs[47,51]. This laboratory outcome could be also interpreted as a decrease in everyday performance: scholastic/academic in children and young, and at work in adults. Studies with PET showed a significant release of neurotransmitters in the brain (mainly dopamine and noradrenaline) while playing a VG[85], and this is believed to be part of learning processes, reinforcement of behavior and emotion[86] a basic step for memory processing. Several neuroscientific evidences support the fundamental role that sleep has on learning and processing of memories[74]. Presumably, REM sleep and SWS are involved in the consolidation processes, in which SWS is fundamental for the formation of traces of explicit memory[87]. During SWS, low levels of acetyilcholine facilitate the transmission of information from the hippocampus to the cortex, while high levels of acetyilcholine during REM sleep permit to the neocortex to submit a process of re-analysis and develop new representation feed-forward for behaviour[79]. Considered that SWS is involved in many processes of memory consolidation and that the exposure to VGs reduces quantity of SWS, one might conclude that exposure to VGs before to fall asleep could induce troubles in explicit memory consolidation process[51].

Also, previous results indicate that a single night of prolonged exposure to VGs can have a strong impact on attention skills. The ability to maintain attention is fundamental for adolescent developing because is at the basis of a series of cognitive tasks[88]. At school, the attentional decline adversely affects academic performance, above all during the examination[89]. This may partly explain some results that showed a positive correlation between use of VGs and low academic performance[90].

Nonetheless, the present review has some limitations that undermine the conclusions and their possible application to everyday life. The main limit is the very limited number of studies present in literature: methodological issues (different research protocols and measures used, non-randomized designs) and sampling flaws (very low sample size, different age ranges of participants, unbalancing between genres), strongly reduce the ability to harmonize and generalize the results, narrowing the possibility to associate clinical significance to the relationship VG-sleep.

Another relevant problem is linked to what is intended to be a VG. Indeed terms as "PC", "Internet", "electronic media" or "TV" are often identified as related to videogaming. But, as well described in the literature, there are many differences between exposure to real VGs, and TV, PC or internet. It is thus mandatory in future research paying more attention to the type of instrument or electronic support (console, VG for PC, portable VG, etc) as well as the specific VGs used to expose participants.

Also, regarding to sleep outcomes is important to keep in mind that sleep can change also due to several other factors. A decline in average sleep duration and quality, with adverse consequences on general health, may depend by all activities made before going to bed (as reading of horror book or novels, for example), as well as by other factors linked to previous day' activities. Or also by the simple exposure to blue-light emitted by electronic media[60]: it is well known that this artificially enriched light produces alerting effects, suppresses melatonin, and induces a phase-shift of the biological clock[90,91]. Recent neuroimaging studies demonstrate that wavelength, duration and intensity of light exposure strongly modulate brain responses, at subcortical (hypothalamus, brainstem, thalamus), limbic (amygdala and hippocampus), and, in turn, cortical (frontal, temporal) level, influencing final behaviour. Future research would thus try to distinguish the intrinsically role played by VGs in influencing sleep behavior and the role of such concurrent factors.

Finally also in this field is present the publication bias: both researchers and publishers tend to prioritize studies observing "significant" results rather than those indicating negative findings[45].

Given these limitations, future research will strongly have to take into consideration some key points: to assess exposure to VGs in more consecutive nights; to assess possible gender differences in VGs-sleep relationship; to pay attention to sample size and composition of investigated samples; to study possible sleep effects between gambler and no-gambler; to assess the role of monitor emitted lighting during VGs, separating the effects of videogaming itself.

In summary, exposure to VGs before falling asleep can have important effects on the subsequent sleep characteristics, in both children/adolescents and adults. The reduction of TST, increase of SOL and the possible change of components of sleep (mainly SWS and REM) identified in the study investigated, are clear indicators of poor sleep quality, higher tiredness and fatigue that may have repercussion on cognitive and behavioural activities of the subsequent waking. In fact, some cognitive abilities as sustained attention and verbal memory, can result worsened as a consequence of VGs exposure. Since the relevance of sleep for health and life quality, a great effort is required to address additional research for clarifying the role of acute and chronic exposures to videogames.

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