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Mechanisms Influencing Older Adolescents' Bedtimes during Videogaming: The Roles of Game Difficulty and Flow

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Abstract

A relationship between evening technology use and sleep has been established, and models suggest various mechanisms to explain this relationship. Recent updates to these models also suggest the influence of individual difference factors, such that the relationship between technology and sleep varies between young people. Flow is an experience of immersion and time distortion that could vary between adolescents when using technology. The aim of the present study was to investigate the effects of flow on the self-selected bedtimes of adolescents when videogaming. 17 older adolescent, experienced videogamers (age=15.9±0.83 yrs) played a new videogame on two school-night evenings in a sleep laboratory. Game difficulty was set to 'hard' one evening (flow condition), and the other set to 'easy' (disrupted flow). Measures of trait and state flow were taken, along with heart rate during videogaming, and bedtime measured objectively with real-time cameras. An interaction effect for heart rate indicated an elevated heart rate in the easy condition after 150-min of gaming (p<.02). No significant differences were found in bedtimes between the easy and hard conditions (p=.77). Adolescents high on trait flow played for longer and selected significantly later bedtimes than their low trait flow peers, but only for the hard (flow) condition (12:22 A.M vs 10:53 P.M, p=.004). Likewise, adolescents with high state flow went to bed significantly later than those low on state flow (12:24 PM vs 10:52 PM, p=.001), again, only in the hard condition. These findings suggest that individual and situational characteristics may amplify the effects of technology use on the 'sleep' of adolescents, and provides support for the displacement of bedtime hypothesis.

Keywords: adolescent; sleep; videogaming; flow; bedtime; technology use.

Introduction

Homes have witnessed fluctuations in the popularity of videogaming consoles, from the rise and fall of second generation consoles from 1983 to 1985 (i.e., Atari, Colecovision), to the resurgence of the fifth generation consoles led by the transition from 2D to 3D polygon graphics (e.g., Sony's PlayStation) in the early 1990s[1]. From 2011 to 2015, videogaming has still been an increasingly popular activity and social pastime, particularly for adolescents, with increases between 12-18%[2,3]. Average daily videogame usage of adolescents is at least 1 hr duration[4,5], and 1 in 3 adolescents play videogames between 3 and 9 hrs daily on weekdays[6]. Consistent with increased usage is that technological devices are also becoming more accessible. Accessibility to sole owned media devices (but not shared devices) predicts the number of hours spent videogaming on weekdays and weekends[6]. The expansion of videogaming during an adolescent's day has the potential to displace (i.e., delay) their bedtime, and thus sleep[7-9]. Delayed bedtimes in the context of fixed wake-up times (e.g., due to school) that occur during adolescence can lead to the truncation of the sleep period and sleep restriction[10], which in turn can have negative socio-emotional, cognitive and functional consequences (e.g., lower grades)[11-13]. However, although school week wake-up times remain fixed for adolescents, there is individual variability in extrinsic (e.g., parent-set bedtimes, access to technology) and intrinsic factors (e.g., perception of the consequences of risky events), which may influence bedtimes, and therefore sleep timing and total sleep time[6,14-16]. Identifying which adolescents may be 'at risk' is important to prevent detrimental effects on their overall health and well being.

A recent systematic review reported that videogaming is associated with both delayed bedtimes and reduced sleep quantity in adolescent samples[17]. Quantification of these studies shows a small effect of increased use of videogaming with delayed bedtimes (mean weighted r_w=0.12), yet a negligible effect with sleep duration (r_w=0.03)[18]. Detailed analysis of experimental studies shows minimal influence of videogaming on sleep quantity (+2.9-10 mins[19]; -7.3 mins[20]). However, emerging evidence suggests that individual differences play an important role in the *bedtimes* of adolescents playing videogames. Adolescents who perceive fewer negative consequences of risky events self-select significantly later bedtimes[15], and "high exposed" videogamers experience reduced bedtime alertness as compared to "low exposed" videogamers following violent videogaming[14]. Adolescents who identify as an 'evening type' (i.e., prefer later bedtimes) are more likely to use a computer and/or play videogames[21,22]. Thus, it has been suggested that "*future studies should collect* *more data about background characteristics of the participants*" (Ivarsson et al., 2013, p.395)[14].

'Flow' has been identified as a key intrinsic factor influencing the duration of videogaming and the time at which adolescents choose to go to bed[23]. Flow is defined as a psychological state whereby an individual experiences flowing "*from one moment to the next, in which he is in control of his actions, and in which there is a little distinction between self and environment, between stimulus and response, between past, present, and future*" (Csikszentmihalyi, Larson, & Prescott, 1977, p.34)[24]. Flow states are typically experienced during enjoyable and engaging activities including, but not limited to, reading and technology use, and time distortion may be experienced by individuals when immersed in a flow state[25-28]. It is proposed that technology use, such as videogaming, creates a flow state when there is a balance between difficulty or challenge of the media, and the skill of the player[29]. Flow may therefore be an important factor influencing the relationship between videogaming and sleep, due to the fact adolescents lose track of time and therefore bedtime can be displaced.

Flow can be further differentiated into 'trait flow' and 'state flow'. Trait flow is the innate disposition for an individual to experience flow during activities, whereas state flow is the extent to which flow is experienced in a particular activity[30]. Moreover, trait flow is closely linked to personal characteristics[31]. The distinction between trait and state flow has been made during various engaging activities, such as music and sport[32,33]. However, despite research demonstrating the existence and importance of flow during technology use and videogaming[6,25,28], to our knowledge, no studies have investigated the extent to which flow experiences are more trait driven (i.e., individual factor) or state driven (i.e., engendered by the conditions of the environment) and whether these affect bedtimes. The current study will investigate the degree to which trait and state flow experiences influence videogaming duration, and in turn, adolescents' self-selected bedtimes, in a controlled laboratory environment.

We expect that game difficulty will be related to the amount of flow (state and trait) experienced during videogaming. This is based on the findings that flow is produced by a balance of challenge and skill[29]. Indeed, game developers are acutely aware of sustaining users engagement by using artificial intelligence (i.e., dynamic game balancing), that automatically balances the game experience away from boredom (too easy) and frustration (too challenging)[34]. Therefore, we predict when skill is held constant, for example in a sample of experienced videogamers, that differences in boredom/challenge (e.g., 'easy' vs 'hard') will produce differing amounts of flow (H1: Hypothesis 1). Secondly, we predict that state and trait flow experiences will influence self-selected bedtimes after videogaming, with later bedtimes indicative of higher flow (H2: Hypothesis 2). This proposition is based on research which demonstrates that flow states are related to time distortion during videogaming[25-28]. If adolescents experience time distortion during time-naïve conditions, this time distortion will lead to a displacement of bedtime.

Methods

Participants

We recruited 17 male and female participants (M= 15.9±0.83, 15-17 yrs, M=12, F=5) through Facebook advertising, Flinders University website advertisements, and via emailing local Adelaide metropolitan high schools. The minimum age criterion of 15 yrs was chosen to ensure adolescents were able to play the MA15+[1] rated game *Rise of the Tomb Raider*. Adolescents completed a 20-min screening telephone interview. Screening comprised of questions on videogaming behaviour (Gamer Experience Survey)[35], sleep patterns and general health (General Information and Health Questionnaire)[20,36] and mood (Depression Anxiety and Stress Scale: DASS-21)[37]. Inclusion criteria were; age between 15-17 yrs; no prior experience with the videogame; being a "good sleeper" (i.e., weekday bedtime within 1.5 standard deviation of 10.30pm (mean=10:16pm±64.6 mins[16]; sleep latency <30 min[38]; a self-perceived sleep difficulty staying or falling asleep of less than 2 nights/wk); and being an "experienced gamer" (self-rated active, frequent or expert videogame player, 76.5% played "*frequently*" or "*often*"; and/or playing >1 hr of videogames/day; mean=9.8±8.1 hrs/wk). Exclusion criteria were; clinical levels of anxiety or depression; evidence of a sleep disorder (e.g., delayed sleep-wake phase disorder, insomnia, and/or restless legs syndrome); excessive caffeine consumption (>200mg per day)[39,40]; any cigarette, drug, or alcohol consumption[41-43]; or medications known to affect sleep[44]. Informed consent was obtained from all adolescents' parents/guardians. Ethical approval was granted by the Flinders University Social and Behavioural Research Ethics Committee.

Design

[1] In Australia, MA15+ videogames are classified as containing strong content that is legally restricted to people aged 15 years and older (http://www.classification.gov.au/Guidelines/Pages/MA15+.aspx)

The current study used a within-subjects design. The independent variables were game difficulty (easy, hard), self-reported trait flow (high, low), and self-reported state flow (high, low). The dependent variable was self-selected bedtime.

Procedure

The study was advertised as a "videogaming and sleep" study that would investigate the relationship between how engaging videogames are, and the effect this has on sleep and the body". No mention was made about the observation of bedtimes. Interested adolescents completed the Game Engagement Questionnaire (GEQ – trait flow measure)[45] amongst the screening battery. Each adolescent attended the Flinders University Sleep Laboratory for testing on 2 separate weeknights within the same calendar week, spaced at least 1 night apart to prevent carry-over effects (e.g., sleepiness from previous night's sleep restriction). Data collection occurred during the school terms between May and August 2016. Weeknights were chosen to ensure adolescents would have motivation to self-select a bedtime that was balanced between their desire to continue game playing and their need to get enough sleep for school the next day. Upon arriving at the laboratory at 8:00PM, adolescents were shown to their sound-attenuated temperature-controlled bedroom, allowed to change into night attire, given written instructions of the experimental protocol (i.e., *they can play the videogame for as long as they like but must finish by 1am as they will be woken at 7am sharp*), chose two low caloric snacks (e.g., crackers and cheese dip, crisps), research assistants fitted their HR monitors and chest straps, and adolescents given an opportunity to ask any questions. Caffeine and technology use (i.e., laptops, tablets or mobile phones) and physical activity were restricted upon their arrival. Adolescents sat upright at the top-end of the bed began playing the videogame on an Xbox One console from 8.30PM, sitting on their bed[2]. Consoles were connected to a 32-inch LED flat screen TV (1366 x 736 HD resolution), and were placed within 1 metre of the foot of the bed. Bedrooms were dark with the exception of the TV and a small lamp emitting low-level warm light (450 lumens, <10 lux; Hioki Lux Meter; Hioki E.E. Corporation, Nagano, Japan). Bedroom doors were closed from 8:30PM, and adolescents were monitored via web-streaming IP cameras until their self-selected bedtime.

Adolescents played two difficulty levels ('*Adventurer*'=Easy, or '*Seasoned Raider*'=Hard) across the 2 testing nights (condition difficulty). Condition order was counterbalanced across participants. Mann-Whitney *U*-tests indicated no effect of testing

[2] Consoles and television screens were placed beyond the foot of the bed.

order on self-selected bedtime, $U = 30$, $z = -.58$, $p = .56$; $U = 28$, $z = -.37$, $p = .71$. Play was unrestricted until 1:00AM where adolescents were instructed to turn off consoles, in order to obtain a minimum amount of sleep for school[46]. Upon finishing videogaming for the evening, adolescents were given the Flow State Scale (FSS)[47] to complete. Participants were woken at 7:00AM the following morning, given breakfast, completed the visual analogue scales, and then they dressed themselves for school. Adolescents were collected by parents/guardians from 8:00AM onwards. On the second morning, in addition to the VAS, adolescents were given a written debriefing sheet and remuneration (AUD$50 gift voucher). A total of 18 participants were enrolled in the study, however 1 participant was excluded from the 2nd night of the study due to failure to engage in the protocol. After entire study data were collected, adolescents were sent a debriefing information informing them about the true intent of the study (i.e., the effect of flow on bedtimes whilst videogaming / not the arousing effect (increased heart rate) of videogaming on sleep).

Materials

Technology use

Rise of the Tomb Raider (Square Enix, 2015) was chosen as it was a newly released (<6 mo), novel game, and previous research suggests such single-player story-based games are engaging[15,20,48]. *Rise of the Tomb Raider* was one of very few games available that enabled manual manipulation of game difficulty (i.e., free from dynamic game balancing)[34]. The average minimum completion time of 14-15 hrs[49], was >9 hrs of total game play allowed across the 2 laboratory testing nights, and is a similar completion time to other games used in previous videogaming-and-sleep studies[15]. Adolescents played the game without any social engagement (e.g., in-game chat) as such social interaction can vary between pairs/groups of adolescents, and thus exert a confounding influence on the study's variables of interest.

Self-selected bedtime

Bedtimes were defined as the time adolescents turned off the game console and TV in order to initiate sleep. Bedtimes were recorded in 'real time' via live video camera monitoring (TECHview IP Camera Model QC-3832 for Windows; infrared lens, viewing angle of 80° and vision up to 15m), and were defined as the time adolescents turned off the game console and TV.

Flow

Two subjective measurements of flow were obtained. Trait flow was assessed using the Game Engagement Questionnaire (GEQ)[45], a 19-item self-report measure with four subscales (absorption, flow, presence and immersion). The GEQ uses a 3-point Likert scale (*no* = 1, *maybe* = 2, *yes* = 3), which assesses how adolescents usually feel when playing video or computer games. Example items include '*I feel like I can't stop playing*' and '*Playing seems automatic*'. Higher scores mean higher trait flow. Internal consistency for the GEQ is high, ranging from between α= 0.85-0.91[23,45]. In the current study internal consistency was α= .85. When the sample was split into two, no significant differences were found in the usual school-night bedtimes between those low (10:16 PM ± 80.1min) and high (10:34 PM ± 53.7min) on trait flow, $t(13)=0.84$, $p=.34$.

State flow was assessed using the Flow State Scale (FFS)[47]. The FSS is a 36-item measure which yields a total flow score, and 9 subscales of flow; challenge-skill, action-awareness, clear goals, unambiguous feedback, concentration, sense of control, loss of self-consciousness, transformation of time and autotelic experience. Adolescents were asked to rate the items in relation to their videogaming experience. Responses were rated on a 5-point Likert Scale, from 1= *strongly disagree* through to 5 = *strongly agree*. Example items include '*The way time passed seemed to be different from normal*', '*I performed automatically*', and '*I was completely focused on the task at hand*'. Higher scores indicate higher levels of state flow. Internal consistency for the FSS has been good in previous work, α =0.83[50], and the current study, α=0.79 -0.96[3]. A moderate correlation were found between the FSS (state) and GEQ-F (trait) measures in the hard condition: $r(15)=0.46$, $p=.08$, but not the easy condition, $r(15)=0.07$, $p=.80$, suggesting some overlap, yet distinction between the two variables.

Heart rate

Heart rate was used as a proxy objective measure for flow states, as previous research has demonstrated a link between heart rate and self-reported flow (i.e., greater flow states approximate lower heart rates)[51], and our previous studies investigating the link between videogaming and adolescents' sleep also used heart rate[20,36] (as opposed to heart rate variability[14,52]). Recent research on the relationship between flow and HR demonstrates that flow is associated with moderate (rather than high or low) sympathetic arousal, but has a linear relationship with parasympathetic arousal[53]. Heart rate (in beats per minute [BPM]) was measured using Polar RS800CX and Polar RS400 watches. Both models use a WearLink

[3] The two alpha values represent assessments for each of the two experimental conditions.

wireless transmitter, were activated in 'free training' mode, and were shown in heart rate view, which displayed speed/pace/calories stopwatch and heart rate. Additionally, both the RS800CX and RS400 models have identical accuracy (±1%) and heart rate measuring range (15-240 BPM; Polar RS400 & RS800CX manuals). The watch was activated by researchers simultaneously to the start of game play, and recording ceased upon morning waking. This allowed measurement of heart rate across game play and up to self-selected bedtimes. Heart rate data were binned into 10-min intervals, and analysed using the Polar Protrainer v.5 software (Polar Electro; Kempele, Finland). This approach of measuring heart rate across multiple time points during game play is more refined than some previous studies[36] and is consistent with more recent research[20].

Visual analogue scales

A series of 100 mm visual analogue scales (VAS) were developed for the present study and provided to adolescents in the morning to assess their enjoyment of the game (i.e., "*I enjoyed videogaming/I did not enjoy videogaming*", and "*I wanted to keep videogaming/I did not want to keep videogaming*"), and sleep quality ("*poor/excellent*"), respectively. Motivations for self-selected bedtime were assessed by response to the question "*Why did you decide to sleep when you did*", with response options, '*I felt sleepy*', '*I wanted to be rested for the next day*', '*I had enough of the game*' and '*I was conscious it was getting late*'[15]. Participants placed a marker along a continuous line from *Agree* (=0) to *Disagree* (=100) in response to each of the questions, and each item was scored as the distance from the left end of the line to the marker.

Results

A 2 (condition: easy vs hard) x 28 (time: 10-min intervals) repeated-measures ANOVA was conducted on HR data during videogaming as a manipulation check to confirm that flow was induced. A significant interaction was found between 'condition' and 'time', $F(27,432)$, =1.71, p=.02 (Figure 1). HR in the hard condition remained lower regardless of length of videogame play, however, HR elevated after approximately 150 min in the easy condition.

< Insert Figure 1 about here >

A paired sample t-test on FSS scores (state flow) showed no significant differences between the easy (M= 147.5, SD= 40.6) and hard conditions (M=134.4, SD= 27.3), t (13) =1.48, p = .16, Cohen's d=0.39. No significant correlations were observed between HR and

FSS scores in either the easy, *r*(12)= 0.03, *p* = .93, or hard conditions, *r*(14)=-.22, *p*=.45. No significant correlations were found between GEQ-F (trait flow) scores and HR in the easy, *r*(12)=0.08, *p*=.80, or hard conditions, *r*(15)=-0.26, *p*=.35.

For the easy condition, bedtimes were not correlated with HR, *r*(13)=0.24, *p*=.44, FSS (state) scores, *r*(16)=0.07, *p*=.81, or GEQ-F (trait) scores, *r*(15)=0.34, *p*=.21. For the hard condition, bedtimes showed a moderate negative correlation with HR that approached significance, *r*(16)=-0.42, *p*=.11, and significant positive correlations with FSS, *r*(14)=0.71, *p*=.004, and GEQ-F scores, *r*(14)=0.66, *p*=.01. However, a paired samples *t*-test showed there was no significant difference between self-selected bedtimes during the easy (M= 11:37 PM, SD= 93.1 min) as compared to the hard condition (M=11:32 PM, SD= 107.3 min), *t*(15) =0.29, *p* = .77. The mean difference of 5 min shows there was no meaningful difference in bedtimes between both game conditions.

As previous research has emphasised a focus on individual differences[14], we explored whether self-selected bedtimes varied due to individual differences in trait or state flow (Figure 2). When a median split was applied to GEQ-F (trait) data (i.e., low vs high trait flow), an independent samples *t*-test showed no differences in bedtimes in the easy condition (low trait = 11:20 PM ± 104.0min; high = 11:56 ± 81.5min), *t*(13)=1.23, *p*=.24, however, adolescents with higher trait flow self-selected significantly later bedtimes (12:22 A.M ± 74.8min) than those with lower trait flow (10:53 P.M ± 79.0min) in the hard condition, *t*(12)=3.61, *p*=.004. Likewise, a median split was performed on FSS (state flow) data. During easy gameplay, no significant differences were found between adolescents low (11:46 PM ± 102.3min) or high (11:29 PM ± 78.6min) on state flow, *t*(15)=0.62, *p*=.54; however, adolescents high on state flow during the hard game play went to bed significantly later (12:24 PM ± 84.6min) than those low in state flow (10:52 PM ± 67.4min), *t*(14)=4.06, *p*=.001.

< Insert Figure 2 about here >

Motivations for gaming cessation and for self-selected bedtimes

Adolescents experienced high enjoyment during videogaming, a high desire to keep videogaming and did not experience gaming satiety (Table 1). A series of paired-sample *t*-tests indicated no significant differences across 'hard' or 'easy' conditions on these measures. Adolescents were motivated by sleepiness, needing to be rested for the next day's commitments, and had an awareness of the late hour when self-selecting bedtimes. A series of paired-sample *t*-tests indicated no significant differences between adolescent's desire to be rested and time conscientiousness across 'hard' or 'easy' conditions. However participants reported being significantly less motivated by feeling sleepy when self-selecting bedtimes during 'hard' videogaming as compared to 'easy' videogaming, $t(16) = 2.49$, $p= .024$.

< Insert Table 1 about here >

Discussion

For several years, empirical research has taken a simplified approach to examining the association between technology use and sleep in young people[7,8,17]. However, emerging research[14,15] suggests individual difference factors (e.g., risk-taking, gamer experience) may play an important role in influencing the relationship between videogaming and sleep during adolescence, but that these are under-investigated[14]. We have previously identified a new factor, flow, which showed in a survey of 422 adolescents that greater trait flow was related to longer videogame duration and later bedtimes[23]. In the present laboratory study, there was evidence that trait flow, was again, linked to later self-selected bedtimes (as was state flow), which, due to its possible mechanism of time distortion[25-28] may impact negatively on sleep subsequent to videogaming.

Based on the notion that more difficult videogames would create a balance between challenge and skill for the experienced videogamer[29], we predicted that flow would be induced during the hard difficulty level (H1). Flow has been shown to be negatively related to heart rate (i.e., the greater the flow, the lower the heart rate)[51]. We found that heart rate remained at consistent low levels during videogaming in the hard condition (i.e., when there was a match between challenge and the videogamer's skill). Yet, when our sample of experienced videogamers were provided with the same videogame, with difficulty set to 'easy', heart rate significantly increased after 150min (2hrs 30 min) of gameplay. This suggests that flow was disrupted, possibly due to a mismatch between game challenge and the player's skill, and thus supports H1. However, in our study, both self-reported state and trait flow were not significantly related to heart rate in the present study. The extent to which sustained periods of videogaming impacts physiological measures, such as heart rate, has been measured by a small number of studies[14,20,52]. These studies suggest that some game factors, such as content (e.g., violence), significantly predict heart rate during videogaming, but that other game factors (e.g., duration) do not. The current study broadens this limited area of research by the discovery that disrupting flow may have an eventual impact on adolescents' physiology during videogaming. Increased arousal has been suggested as a key mechanism through which technology use may impact sleep[8,54] and the current study provides some support for this mechanism. Interestingly, heart rate has a circadian decline in the evening as individuals approach to sleep onset[55], thus we speculate that the constant heart rate and flow state during the 'hard'conditions masked this circadian decrease in heart rate.

We found that simply providing a situation of disrupting flow (i.e., providing an easy game difficulty that is below players' skill level) was not enough in and of itself to influence self-selected bedtimes of adolescents in our sample (H2). Instead, adolescents' with high levels of trait flow selected a bedtime ~1.5 hrs later than their low trait flow counterparts. Yet, this only occurred during a situation that engendered optimal flow conditions for these experienced gamers (i.e., hard game difficulty). When flow conditions were disrupted (i.e., easy game difficulty), high trait flow adolescents went to bed 36-min later than their low trait flow peers. These abovementioned differences were discerned using a self-reported measure (the Game Engagement Questionnaire)[45] that was administered amongst screening questionnaires, and then, ~1-2 weeks later, observing adolescents turning off their game to attempt sleep via an objective measure (i.e., real-time camera viewing). This provides some support for the short-term stability of trait flow and its unique contribution to adolescents bedtimes immediately after videogaming. Similarly, adolescents self-reported their state flow experiences after each night of videogaming. The findings show that adolescents who reported high state flow went to bed significantly later than their low state flow peers, but only when flow conditions were optimal (i.e., hard condition; bedtime difference ~ 1.5 hrs). These findings thus provide some support H2 and provide stronger support for the displacement hypothesis (i.e., pre-bedtime activities displacing sleep)[7] as a mechanism linking technology use and 'sleep'. Interestingly, no significant differences in bedtimes occurred during the easy game difficulty condition (bedtime difference = 17 min). Another way of viewing these findings, is that regardless of whether adolescents reported high or low state flow scores, when the game difficulty was easy, bedtimes were not meaningfully different.

When designing the present study, we learned that very few console videogames are now delivered with manual difficulty level settings. Conversely, game developers are increasingly automating game difficulty, which tailors the balance between challenge and enjoyment for each individual player[34]. Whilst videogames are meant to be an enjoyable pastime, 'dynamic game balancing' can create optimal flow conditions, which can make it difficult for some gamers to stop. This may be a contributing factor to excessive gaming at the expense of engaging in other important areas of life (i.e., social, vocational, occupational, health). At this extreme end, adolescents may be at risk of developing Internet Gaming Disorder (IGD)[56]. While we acknowledge that the majority of adolescents are unlikely to develop IGD, we note that the implications from our study are that it is not just adolescents high on trait or state flow who need to improve their self-regulation, but there is an onus on game developers to be cognisant of the potential harms from flow induced by dynamic game balancing.

Also of note was that adolescents selected later bedtimes in the laboratory than when they are usually at home. This may be due to the lack of time devices in the sleep laboratory setting, which may have created time distortions associated with flow experiences[25-28]. However, bedtimes in the laboratory during easy game difficulty conditions (i.e., when flow was likely disrupted), were still later than adolescents' usual bedtimes in their home environment. Thus, it may be that adolescents' usual bedtimes are influenced by their parents. Although older adolescents do no usually have a parent-set bedtime[16,57], we nevertheless suspect many adolescents would not risk being caught videogaming beyond midnight on a school night, nor take part in excessive gaming on consecutive school nights. Findings from visual analogue scales in the present study indicated that adolescents were primarily motivated to choose bedtimes based on social obligations (i.e., school the next day), and thus it is likely that this is a more conscious decision in the home environment. However, aside from self-regulation, guidelines about videogaming are almost exclusively focused on parents reviewing the classification or content of the game[58]. Non-government agencies have suggested broader guidelines for videogaming use which mirrors many of the government suggestions for online/internet use, e.g. placing limits on content and duration. However neither government or non-government advice or guidelines take account of the emerging evidence base, which suggests that a number individual factors (risk-taking, gamer experience, flow) may explain the negative impact that videogaming has on sleep or tailor their advice to account for individual risk factors. Expansion of government based guidelines around healthy technology use to have relevance to videogaming as a specific form of media and to account for individual variation or risk are certainly warranted.

Limitations

Although the findings from the present laboratory study concur with our previous survey findings[23], replication of these studies is nevertheless needed in order to raise confidence in the notion that high flow states during videogaming lead to later bedtimes. Within-subjects designs in a controlled laboratory setting can assist in reducing individual and external confounds, respectively, however they are limited in their external validity. Thus, independent studies with larger samples are warranted. Also, conducting similar studies in the field (i.e., home environment) would assist in translating these laboratory findings to the real-world, and has been performed in previous videogaming-and-sleep studies[14]. The present study's overarching aim was to examine the effect of the individual difference factor, flow, on adolescents' bedtimes. We did not measure the subsequent sleep of adolescents, nor their daytime functioning the next day. Sleep and daytime functioning are also aspects of technology-and-sleep models[8], and thus also require further examination.

Conclusion

Videogaming is broadly acknowledged to have negative effects on sleep[8,17]. The present study extends our knowledge by the discovery of a novel individual factor – flow - which influences the relationship between videogaming and sleep during adolescence. Flow was found to predict self-selected bedtimes during 'hard' game difficulty conditions, where there was a balance between challenge and skill. Similarly, our proxy physiological measure (i.e., low heart rate) indicated adolescents were more likely to experience flow states when there was a balance between challenge and skill. Although the experimental design of the study limits extrapolation of the findings to real-world videogaming behaviour, the finding of another individual difference factor being a key determinant of the impact videogaming has on 'sleep' is an important one. As such, recommendations about moderating videogaming behaviour for game development companies, parents and young people should be expanded to account of these individual factors, and mitigate the negative impact of videogaming on sleep during adolescence.

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Table 1: Motivations to cease videogaming (Means (SDs), *t*-statistics)

	Easy videogaming	Hard videogaming	*t*-statistic
Enjoyment	1.84 (2.58)	1.72 (1.96)	.16 (n.s)
Cessation desire	3.07 (2.51)	2.73 (2.38)	.41 (n.s)
Satiety	7.27 (2.35)	6.08 (3.45)	1.24 (n.s)
Feeling sleepy	2.92 (3.11)	4.99 (3.49)	-2.49*
Desire to be rested	3.40 (2.72)	4.41 (3.12)	-1.58
Time conscious	2.54 (2.61)	3.51 (3.53)	-.98

Note: *p <.05; Lower scores indicate that participants agreed they self-selected their bedtimes due to feeling sleepy, wanting to be rested and were conscious of the time. Higher scores for ‘Enjoyment’ indicate more enjoyment of the videogame.

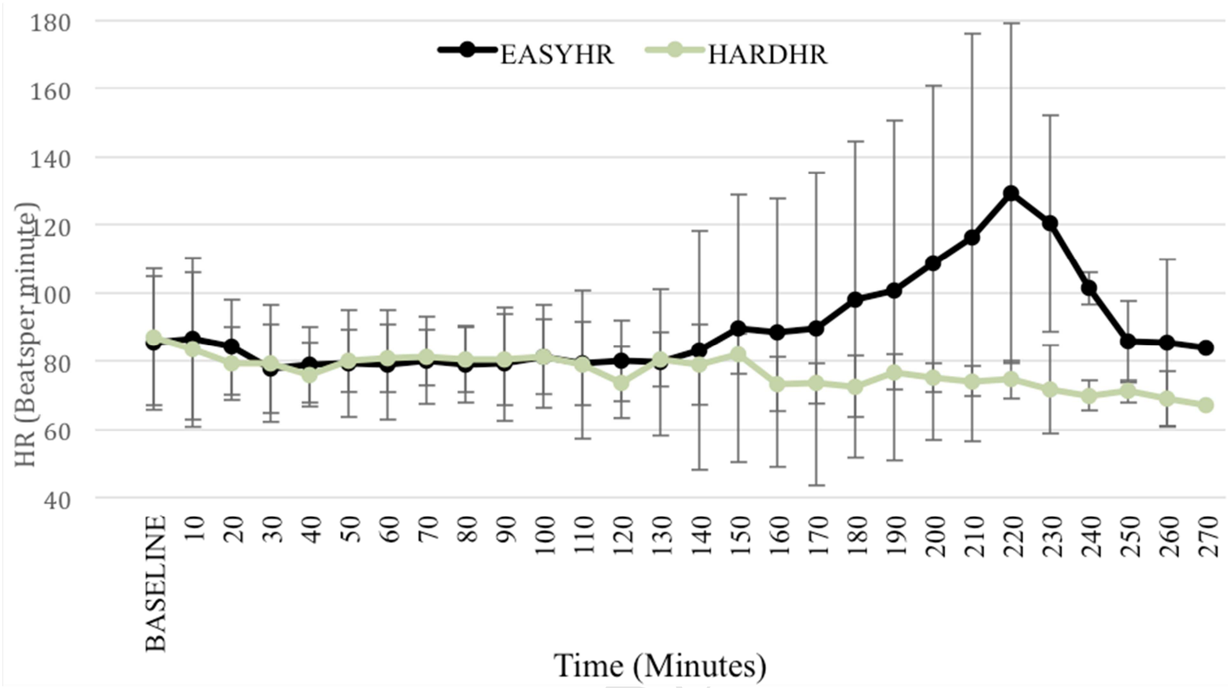

Figure 1: The effect of game condition and length of game play (time) on heart rate (HR). Note: errors bars = standard errors; each participant's HR data anchored to the beginning of game play.

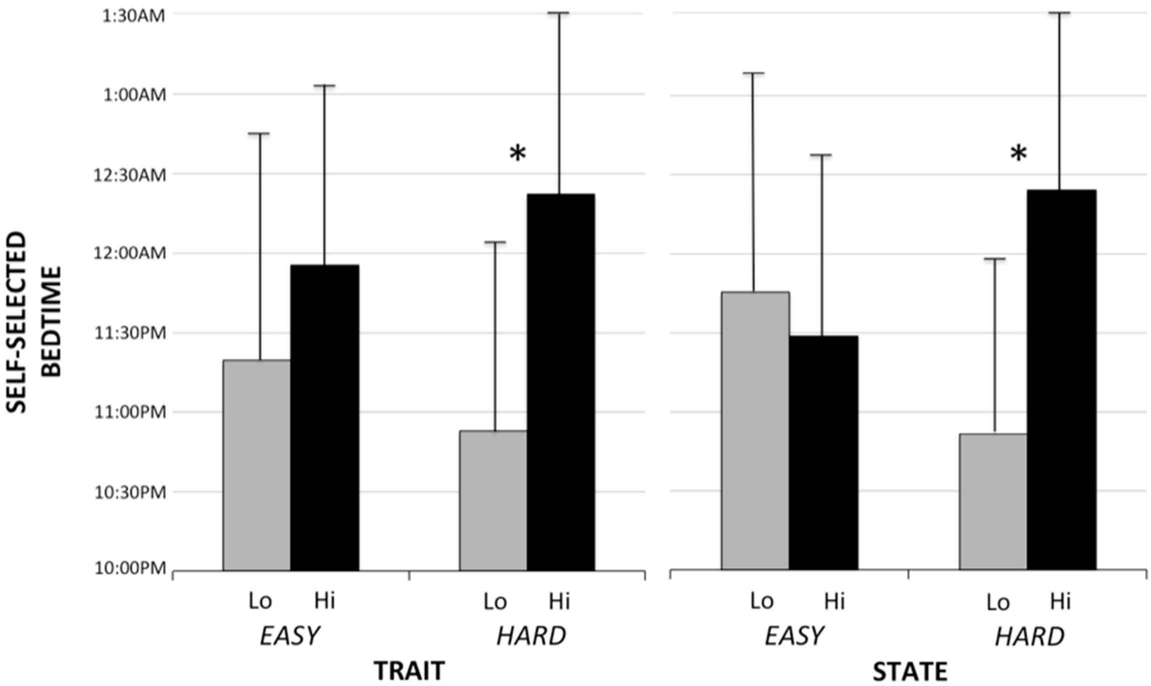

Figure 2. The effect of state and trait flow on self-selected bedtimes during easy and hard videogaming difficulty. * = significant difference between adolescents low and high on flow.

Highlights

- Flow during videogaming is a balanced state between challenge and engagement
- Flow may be observed as evidenced by differences in heart rate after 150-min of videogaming
- Game difficulty that engenders a flow state does not affect adolescents' bedtimes
- Adolescents with high trait flow have later bedtimes when game difficulty is balanced
- Adolescents who report high state flow have later bedtimes when game difficulty is balanced