

## ORIGINAL ARTICLE

# Eye Tracking of Attentional Allocation During Processing of Game Technologies: Association with Daily Playtime and Gaming Consequences

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## Main Points

- Association of video game daily playtime and eye tracking of attentional preference for video game scenes is investigated.
- Video game daily playtime and video game consequences are positively related to attentional preference for video game scenes.
- Evidence of loss of control (i.e., binge gaming) contributing to greater attentional preference for video game scenes is also reported.
- An underlying approach-oriented system (modified by video game habits), common to all addictive disorders, is suggested.

## Abstract

This study used eye tracking as a measure of attention to examine how preference for video gaming images may change across a continuum of video gamers (casual to heavy). During the eye tracking procedure, participants (ages 18 – 26,  $N = 73$ ; 43 men, 30 women) viewed 45 image pairs, presented in random order, composed of video gaming, alcohol, and neutral images. Following, participants completed questionnaires about video gaming and alcohol behavior. Findings showed that self-reported measures of experience, including video gaming quantity (i.e., daily playtime) and consequences, showed a significant positive relationship to eye tracking metrics of initial fixation and dwell time toward video game images. Results also showed that participants who reported loss of control (i.e., binge gaming) also demonstrated greater preference for video game images. The findings suggest that the attentional allocation during the processing of video game images in young adults may be enhanced by experience such as daily playtime. Changes in attentional allocation and cue reactivity may further contribute to the development of problematic video gaming behavior through prioritization of video gaming over other appetitive behaviors. These findings have basic science and clinical implications, including treatment for gaming disorder.

**Keywords:** Addictive behavior, attentional biases, eye tracking, internet gaming disorder, substance addiction, video games

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## Introduction

Worldwide, an estimated 2.7 billion individuals play video games, generating an estimated \$159.3 billion (NewZoo, 2020). Further, in the United States, the popularity of video gaming is evidenced by the quickly growing economic sector that reported

\$35.4 billion of software revenue in 2019, an 18% increase from prior years (Entertainment Software Association [ESA], 2020). Research suggests that while most video game play is casual, with positive social and mental benefits, between 1% and 10% of individuals exhibit problematic video game habits (Feng et al., 2017; WePC, 2018). However,

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consideration of cognitive factors that contribute to the development of gaming behavior on a continuum, from a recreational activity into an excessive, problematic behavior, remains understudied.

Changes in cognitive processing during the development of addictive behaviors in adolescents are suggested in a theoretical model proposed by Wiers and colleagues (2007). According to Wiers, substance use in adolescents involves two aspects, explicit attitudes (either positive or negative) and implicit, automatic cognitive responses. For example, more (or less) experience with substances (e.g., alcohol) causes the formation of more (or less) attentional preference for objects that predict its consumption, an implicit, automatic cognitive response. Concerning the development of addictive behaviors, the model of Brand and colleagues (2019) also includes implicit, automatic cognitive responses. According to Brand et al. (2019), using the internet or other medium to access gaming, gambling, pornography shopping, and so on, causes gratification (positive reinforcement). Importantly, gratification may lead to an increase (i.e., change in implicit, automatic cognitive response) in cue reactivity and cravings to objects (e.g., gaming technology images) that predict the rewarding behavior (e.g., video gaming). While gratification characterizes early-stage addiction, Brand and colleagues suggest a shift from decreasing gratification to increasing compensation as the addictive behavior persists. Additionally, as executive function over the addictive behavior decreases, implicit automatic cognitive responses toward gaming stimuli (i.e., loss of control) increase. Loss of control is a hallmark characteristic of chemical (Starcevic, 2013) and behavioral (Grant et al., 2010) addiction and is associated with an increase in negative consequences/dysfunction.

Thus, implicit, automatic cognitive responses that develop into preferential allocation of attention toward objects that predict use are important characteristics of addictive behaviors (Starcke et al., 2018). The preferential allocation of attention toward objects that predict use is demonstrated in individuals with problematic alcohol, nicotine, and cocaine use (Field & Cox, 2008; Jones et al., 2018). Evidence also suggests that the preferential allocation of attention to addictive versus neutral stimuli also exists in problematic gambling, sexual behavior, and video gaming (Ciccarelli et al., 2016; Jeromin et al., 2016; Mechelmans et al., 2014). For instance, in problematic gambling, one study showed that compared to non-gamblers, problematic gamblers identified gambling images faster than neutral images (Ciccarelli et al., 2016). Mechelmans (2014) found that individuals with compulsive sexual behavior showed a preferential allocation of attention toward sexual images over neutral images, compared to control participants. Finally, Jeromin (2016) measured reaction time (RT) in adults using an addiction Stroop test showing that gamers experienced greater attention allocation toward computer-related words as compared to non-gamers.

For these reasons, the purpose of the current study was to investigate preferential patterns in attentional allocation toward images that predict gaming behavior and associate these preferences with gaming disorder symptoms (Ceballos et al., 2009). Attentional bias toward addictive stimuli is ubiquitous in the chemical and behavioral addiction field (Ceballos et al., 2009;

Ciccarelli et al., 2016; Jeromin et al., 2016; Mechelmans et al., 2014) such that clinical trials of attentional bias modification training are under investigation for the treatment of several addictive disorders (Heitmann et al., 2018, for review). Eye tracking is a robust measure of attentional allocation as it is not dependent on a behavioral response (i.e., RT). Modern eye tracking systems use sampling rate combined with region of interest (ROI) analysis to provide a continuous measurement of attentional allocation. Thus, the current study used eye tracking as an objective method to assess controlled and implicit, automatic cognitive processing of video gaming, neutral, and alcohol image pairs (Ceballos et al., 2009).

The current study was guided by the hypothesis that if excessive, problematic gaming *should* be considered an “addiction” (Ferguson & Colwell, 2019), then individuals with excessive, problematic gaming behavior would demonstrate cognitive responses similar to individuals with problematic addictive behavior. Thus, we predicted that participants would preferentially allocate attention toward the gaming or alcohol images, as compared to neutral images (i.e., common household items) (Ceballos et al., 2009). Another prediction stated that self-reported measures of experience, including quantity and frequency of the problematic behavior and symptoms/consequences of use, would be positively associated with eye tracking measures of automatic (initial ocular fixation) or controlled (dwell time) processing for the gaming or alcohol versus neutral cues. The alcohol-related items were included as a substance use comparison in the current study, given previous reports of continuous measures of attention and association with consumption and consequences of alcohol use in college students (Ceballos et al., 2009).

## Methods

### Participants

Participants were university students (ages 18–26,  $N = 73$ ; 43 men, 30 women) who played at least 1 internet game in the last month. Participants were recruited via an online research recruitment tool and were paid for their participation. Concerning video game characteristics, 6.85% responded positively to three criteria for gaming disorder (loss of control, increasing priority given to gaming over other activities, and continued use despite negative consequences; Billieux et al., 2019), 13.7% responded positively to five or more of nine criteria for *DSM-5* (section 3) internet gaming disorder (IGD; Lemmens et al., 2015). Concerning bingeing characteristics, 35.6% met criteria for heavy episodic “binge” video game criteria (Gilbertson et al., 2019), 58.9% met gender-specific cut-points for binge drinking (NIAAA, 2004), and 21.92% met criteria for both binge drinking and gaming. Participants listed their ethnicity as White (76.7%), Asian (13.7%), Black (1.37%), Hispanic (2.74%), or undeclared (5.48%). All procedures were approved by the Institutional Review Board at anonymous review, and participants gave written informed consent for laboratory procedures.

### Screening

Prior to the laboratory session, participants were screened for psychotherapeutic history, neurological, and medical disorders that could affect cognitive function. Participants also completed a vision questionnaire specific to eye tracking (Pernice & Nielsen, 2009) and had at least 20/40 corrected vision.

## Questionnaires

### Quantity and Frequency of Alcohol and Video Gaming

The self-reported consumption of alcohol was measured with the Daily Drinking Questionnaire-Revised to assess the consumption of standard drinks for beer, wine, and liquor each day of the week for what participants considered a typical and heavy week during the past 30 days (Collins et al., 1985). Participants were also asked about heavy episodic drinking (NIAAA, 2004) and the maximum number of drinks that they consumed in a 24-hour period during the past 30 days (alcohol consumption—max drinks per day).

The self-reported quantity (i.e., hours per day) of video gaming behavior was also measured for each day of the week (Lemmens et al., 2015). Participants were also asked about the maximum number of hours played in a single 24-hour period in the past 30 days (video gaming consumption—max hours per day). Participants playing video games for an episode of six or more consecutive hours in the last 30 days were designated as engaging in heavy episodic/binge video gaming behavior (Gilbertson et al., 2019; reSTART, 2015). The quantity of video game play was previously used as admission criteria for in-patient “internet addiction” treatment (reSTART, 2015).

### Alcohol Consequences

The Young Adult Alcohol Consequences Questionnaire is a 48-item questionnaire that measures alcohol-related consequences that are experienced by young adults (Read et al., 2006). Scores range from 0 to 48, with higher scores indicating more alcohol consequences. Internal consistency was excellent,  $\alpha = .914$ .

### Video Gaming Consequences

Video gaming consequences were measured using the IGD Scale (Lemmens et al., 2015). The IGD Scale includes 27 items to measure preoccupation, tolerance, withdrawal, persistence (loss of control), escape, problems (increasing priority given to gaming over other activities), deception, displacement, and conflict (continued use

despite negative consequences). Participants meeting suggested DSM-5 diagnostic criteria met at least five of the nine suggested criteria (American Psychiatric Association [APA], 2013). Scores range from 0 to 27, with higher scores indicating more video gaming consequences. Internal consistency was acceptable,  $\alpha = .826$ .

## Eye tracking Paradigm

### Alcohol and Video Gaming Images

Image pairs were composed of neutral, video gaming, and alcohol-related items ( $n = 15$  per image type) presented side-by-side on the computer screen, counterbalanced for side of screen (Figure 1). The video gaming pictorial images included 15 color images of different video gaming systems (e.g., Nintendo 64, PlayStation Vita, Xbox 360) chosen as “millennial gamers,” ages 18–34, would have experience identifying these gaming systems (ESA, 2020). The alcohol pictorial images included 15 color images of alcoholic beverages (e.g., beer, wine, liquor). Fifteen color images of common household items (e.g., stool, chair, clock) were used as neutral condition images (International Affective Picture System; Lang et al., 1997). Each image was presented on a white background and paired with an image from a different category. Internal consistency of the task was measured during a separate reaction time (RT) block, consistent with other studies of attentional bias (Field et al., 2018). Internal consistency of the task was acceptable for video gaming/neutral,  $\alpha = .750$  and alcohol/neutral  $\alpha = .776$  image pairs. Gender differences in RT (Dykiert et al., 2012) were not observed in the current study ( $p > .076$ ). Briefly, during the RT task, participants viewed image pairs and responded to either video game images or alcohol images (counterbalanced order). The RT block was also counterbalanced with the eye tracking block to avoid order effects. RT was *not* a primary variable of interest in the study

### Apparatus and Procedure

Eye tracking was completed in a dimly-lit room using the ASL EYE-TRAC® 7 with a sampling rate of 60 Hz, accuracy (difference between the recorded and actual eye position) of 0.5°, and



Figure 1. a-c. Eye Tracking Task Sample Images and Timing Characteristics. Participants Viewed 45 Image Pairs Presented in Random Order, With Each Image Pair Presented Once Per Block (Paradigm Software, 2014). Gaming (a), Alcohol (b), and Neutral (c) Images Were Paired to Create Gaming/Alcohol, Alcohol/Neutral, and Neutral/Gaming. Image Type Was Counterbalanced for l – r Presentation on the Computer Screen. Participants Were Instructed to Fixate on the Fixation Image (Cross-Hair), Which Was Displayed for 1 Second. Following, an Image Pair Was Presented for 3 seconds, and Participants Were Instructed to Look Anywhere on the Screen. As the Images Were Presented on the Same Location on the Screen, Coordinates Were Derived Using the Paradigm Software to Designate an ROI, Used for Later Analysis of the Images.

Table 1.

Means and Standard Deviations of Participant Demographic Characteristics

Variable (N = 73)	M (SD)
Age (years)	18.84 (1.25)
Education (years)	13.49 (0.89)
Daily playtime	4.93 (3.29)
Gaming consequences	8.55 (4.60)
Alcohol consumption	6.00 (5.28)
Alcohol consequences	8.24 (7.45)

Note: Alcohol consumption (average maximum standardized drinks) was measured using the Daily Drinking Questionnaire Revised (DDQ-R) from Collins et al. (1985); alcohol consequences were measured using the Young Adult Alcohol Consequences Questionnaire from Read et al. (2006) and ranged from 0 to 48; daily playtime (average maximum hours per day) was measured using the DDQ-R modified for gaming from Collins et al. (1985); gaming consequences were measured using the Internet Gaming Disorder scale from Lemmens et al. (2015) and ranged from 0 to 27.

spatial resolution/precision better than  $0.5^\circ$  (Applied Science Laboratories). Images were presented using Paradigm Software and were  $152.14 \text{ mm} \times 125.68 \text{ mm}$  with the visual angle between the fixation position and the inner edge of each image of  $3.58^\circ$ . As the images were presented on the same location on the screen, coordinates were derived using the Paradigm Software to designate an ROI, used for later analysis of the images. During the testing session, participants were seated in front of the eye tracking equipment (60.96 cm from the computer screen) and instructed to use the chin rest while the images were viewed. They were then instructed to fixate on the fixation image (e.g., a cross-hair cursor), displayed for 1000 ms (Graham et al., 2011). Following, participants were instructed to look anywhere on the computer screen as they viewed the 45 image pairs (video gaming/neutral, alcohol/neutral, video gaming/alcohol), presented in random order. Each image pair was presented for 3000 ms with each image pair presented once per block (two total). Participants were not told about the purpose of the study in any of the materials used during the experimental procedure, and self-report questionnaires were completed after the eye tracking portion of the study.

Table 2.

Association of Video Gaming Quantity and Consequences

	Gaming Consequences	College GPA	Avg Hrs Week	Avg Hrs Day	Peak Hours Week	Peak Hours a Day	Hours Over Weekend
Gaming consequences	–						
College GPA	–.092	–					
Average hours a week	.476**	–.240*	–				
Average hours a day	.484**	–.213	.967**	–			
Peak hours a week	.437**	–.198	.860**	.854**	–		
Peak hours a day	.401**	–.231	.838**	.853**	.964**	–	
Hours over weekend	.347**	–.254*	.748**	.715**	.610**	.633**	–

Note: Gaming consequences were measured using the Internet Gaming Disorder scale from Lemmens et al. (2015). Participant video gaming characteristics measured using the Daily Drinking Questionnaire Revised modified for gaming from Collins et al. (1985). Participant video gaming questions asked participants to report the number of hours played, for each day of the week, for average and peak weeks.

\* $p < .05$ ; \*\* $p < .001$ .

## Eye Tracking Variables

Two eye tracking variables were quantified in the current study, dwell time and initial fixation. Dwell time, or summed fixations to an image, was considered an index of controlled processing. Initial fixation was considered a measure of attentional importance or salience to the individual.

## Results

### Demographics

Statistical analyses were completed using SAS Version 9.4 (SAS Institute, Inc., Cary, NC, USA). Demographic characteristics of the participants are listed in Table 1. Binge video gamers ( $M_{\text{binge}} = 10.38$ , standard deviation ( $SD_{\text{binge}} = 5.46$ ) reported significantly more internet gaming consequences versus participants not meeting binge criteria [ $M_{\text{control}} = 7.53$ ,  $SD_{\text{control}} = 3.74$ ;  $t(38.25) = -2.373$ ,  $p = .023$ ,  $d = 0.60$ ], and a lower college grade point average (GPA) [ $M_{\text{binge}} = 3.12$ ,  $SD_{\text{binge}} = 0.49$ ;  $M_{\text{control}} = 3.40$ ,  $SD_{\text{control}} = 0.46$ ;  $t(70) = 2.329$ ,  $p = .023$ ,  $d = 0.58$ ]. The association of video gaming consequences and video gaming quantity is included in Table 2.

### Attentional Allocation During Processing of Gaming and Alcohol Images

Means and SDs for eye tracking variables are presented in Table 3. Participants showed attentional allocation to video gaming versus control images (dwell time,  $t(72) = -12.717$ ,  $p < .001$ ,  $d = 1.48$ ; initial fixation,  $t(72) = -11.761$ ,  $p < .001$ ,  $d = 1.37$ ) and alcohol versus control images (dwell time,  $t(72) = 6.533$ ,  $p < .001$ ,  $d = 0.76$ ; initial fixation,  $t(72) = 4.725$ ,  $p < .001$ ,  $d = 0.55$ ). Participants also showed greater attentional allocation to video gaming images (dwell time,  $t(72) = 6.937$ ,  $p < .001$ ,  $d = 0.81$ ; initial fixation,  $t(72) = 4.182$ ,  $p < .001$ ,  $d = 0.48$ ) when compared to alcohol images.

Concerning orthogonal measurement, binge gamers had a greater dwell time on video gaming images when paired with control images [ $M_{\text{binge}} = 50.37$ ,  $SD_{\text{binge}} = 10.80$ ;  $M_{\text{control}} = 42.30$ ,  $SD_{\text{control}} = 11.93$ ;  $t(71) = -2.858$ ,  $p = .006$ ,  $d = 0.70$ ]. Binge gamers also had more initial fixations to video gaming images for the video gaming neutral image pair as compared to non-binge gamers [ $M_{\text{binge}} = 18.38$ ,  $SD_{\text{binge}} = 2.35$ ;  $M_{\text{control}} = 16.72$ ,  $SD_{\text{control}} = 2.49$ ;  $t(71) = -2.783$ ,  $p = .007$ ,  $d = 0.68$ ]. Binge gamers also had less dwell time to alcohol images when paired with video gaming images

Table 3.  
Means and Standard Deviations of Attentional Allocation During Processing of Image Pairs

Variable	Gaming/Neutral		Alcohol/Neutral		Gaming/Alcohol	
	Gaming M (SD)	Neutral M (SD)	Alcohol M (SD)	Neutral M (SD)	Gaming M (SD)	Alcohol M (SD)
Dwell time**	45.17 (12.11)	19.78 (8.39)	38.82 (10.96)	26.08 (9.19)	40.30 (11.83)	25.75 (9.45)
Initial fixation**	17.31 (2.55)	10.72 (2.87)	15.42 (3.07)	12.53 (2.90)	15.86 (3.52)	12.49 (3.73)

Note: Differences in dwell time and initial fixation for gaming/neutral, alcohol/neutral, and gaming/alcohol image pairs, measured in milliseconds. Paired samples *t*-test revealed significant differences for each image type within the image pair for dwell time and initial fixation, respectively.

\*\* $p < .001$ .

$[M_{\text{binge}} = 22.74, SD_{\text{binge}} = 9.39; M_{\text{control}} = 27.41, SD_{\text{control}} = 9.16; t(71) = -2.065, p = .043, d = 0.50]$ .

### Association of Attentional Allocation and Daily Playtime

Self-reported measures of experience (i.e., video gaming consumption—max hours per day) were associated with eye tracking measurements for video gaming images (dwell time,  $r = .379, p = .001$ ; initial fixation,  $r = .257, p = .028$ ) when paired with the neutral images. Concerning video gaming symptoms (i.e., consequences), these were associated with eye tracking measurements for video gaming images (dwell time,  $r = .323, p = .005$ ; initial fixation,  $r = .291, p = .012$ ) when paired with neutral images. Concerning alcohol (i.e., alcohol consumption—max drinks per day), this was associated with eye tracking measurements for alcohol when paired with the neutral image (dwell time,  $r = .270, p = .021$ ). The association of self-reported alcohol consequences was not related to eye tracking metrics ( $p > .489$ ).

### Discussion

The current study considered the attentional allocation during processing of image pairs (video gaming/neutral, alcohol/neutral, and video gaming/alcohol) using eye tracking and examined the relationship to self-reported measures of experience (consumption and consequences associated with alcohol or video gaming behavior). Unexpectedly, the attentional preference for gaming technologies was positively related to daily playtime and consequences associated with excessive video gaming. Wiers (2007) theorized that addictive behaviors develop following repeated experience with substances facilitating automatic and controlled attentional processing of images or cues that predict its eventual consumption. Thus, an approach-oriented system is strengthened by repeated experience, compromising the regulatory executive system. Concerning video gaming images, both automatic and controlled processing of cues were positively associated with video gaming consumption (maximum hours) and consequences (video gaming symptoms) when paired with neutral images. That is, greater hours playing video games co-varied with the number of initial preferences (measured .017 seconds following stimulus presentation) for the video gaming image, indicating salience, or importance, of the images to the participant. More importantly, video gaming symptoms were positively associated with more initial preferences and greater gaze length of video gaming versus neutral images. Consistent with Weir's model, these data demonstrate that the measurement of quantity of video gaming behavior, in addition to consequences, is important in characterizing problematic video gaming behavior. The data also support the

existence of an approach-oriented system (for video gaming) that is strengthened by repeated experience and could possibly compromise a regulatory executive system, common to all addictive disorders.

Indeed, upon completion of categorical analyses of eye tracking metrics for binge versus non-binge video gamers, differences in the eye tracking metrics were noted. Binge gamers had greater controlled (i.e., dwell time) and automatic (i.e., initial fixation) processing of video gaming images when paired with neutral images, as compared to non-binge gamers. In addition, the findings of a lower academic performance and an increase in gaming disorder symptoms in binge criteria individuals support the literature showing that technology-based binge behavior can have negative consequences on a college population (Hou et al., 2019). This may be especially pertinent when students may have responsibilities outside of class (e.g., work, sports, or clubs). The findings show that greater quantity of video gaming in a single session (i.e., heavy episodic use or binge gaming) could be a risk factor for gaming disorder, particularly as longer gaming sessions could be an indication of loss of control over video gaming behavior (Billieux et al., 2019). Additionally, cumulative lifetime gaming hours were not measured in the current study and are an important area of future research. Together, these findings reinforce the idea that measurement of quantity of video gaming behavior be considered along with gaming symptoms in gaming disorder research.

These eye tracking results are similar to those reported by Ceballos and colleagues (2009), which showed that measures of alcohol quantity and frequency were positively related to initial preference (i.e., initial fixation) and gaze length (i.e., dwell time) for the alcohol-related image, which is indicative of automatic and controlled processing, respectively. Attentional allocation to addictive versus neutral images was also supported by the findings of the current study. Concerning the alcohol images, these findings replicate those of Sharma and colleagues (2001), who showed that problem drinkers spent more time on alcohol-related words while using an alcohol Stroop test, as compared to non-problem drinkers. Concerning attentional allocation in behavioral addiction, Ciccarelli and colleagues (2016) reported attentional allocation to gambling versus neutral cues in individuals with gambling disorder versus control participants. Concerning direct comparison of substance (i.e., alcohol) and non-substance (i.e., gaming) stimuli, participants demonstrated greater preference of the non-substance (i.e., gaming) stimuli; however, these results are preliminary and warrant replication.

While the current study was not designed as a treatment study, nor was it designed to only include individuals with gaming disorder (as the continuum of gaming symptoms was of interest), the findings may have clinical implications. Attentional bias modification training, or computerized training designed to retrain cognitive biases that develop during addiction and other mental health disorders, is under investigation for treatment of anxiety disorders, depression, alcohol use disorder, nicotine dependence, post-traumatic stress disorder, and binge eating disorder (de Voogd et al., 2016). Given the variety of paradigms, participant recruitment considerations (clinical diagnosis) and length of treatment, among other factors, the retraining of cognitive bias has met with limited success as a treatment strategy for addictive disorders (Heitmann et al., 2018). However, consideration of attentional bias modification training as an investigative treatment strategy for gaming disorder (Rabinovitz & Nagar, 2015) and other internet addictions (Chia & Zhang, 2020) may be a possible implication of these findings.

#### Limitations, Directions/Suggestions for Future Research and Conclusion

These findings are limited by a number of factors. While the percentage of participants meeting suggested *DSM* criteria for gaming disorder was slightly higher than that typically reported in regional population studies of the United States (Eichenbaum et al., 2015), participants in the study largely did not meet criteria for suggested gaming disorder (APA, 2013). However, 35% of participants met criteria for at least one heavy video gaming episode (i.e., binge) of six or more consecutive hours of video game play in the past 30 days. As consensus regarding heavy episodic video gaming behavior (e.g., loss of control) has not yet converged in the literature (Gilbertson et al., 2019), our study contributes to the measurement conversation by also considering quantity and frequency (Sobell & Sobell, 1995) of video gaming behavior, in addition to a *DSM*-suggested criteria approach. Additionally, 20.55% of the sample met at least two gaming disorder criteria (loss of control, increasing priority given to gaming over other activities, continued use despite negative consequences; Billieux et al., 2019). The non-clinical sample was consistent with the purpose of the study to understand gaming disorder by associating measures of cognitive processing with self-reported measures of experiences with alcohol or video gaming. Future studies should include a greater number of participants meeting criteria for gaming disorder, particularly those studies assessing attentional allocation.

Also, video gaming images used in the study were relatively simple. Specifically, video gaming images included were limited to single items on a white background (the space between images was standardized gray-green; by Paradigm Software) and consisted of video gaming systems and controllers. The images were chosen to be similar to alcohol and neutral impoverished images consistent with other large image sets used in emotion processing, substance abuse, and problematic behavior literature (Ciccarelli et al., 2016; Graham et al., 2011; Lang et al., 1997). The current study also used a wide variety of console images, whereas, smartphones are also used to play games. This may have impacted the findings since female gamers (18 – 34) most often play games on smartphones (69%), while male gamers (18 – 34) typically play on gaming consoles (69%; ESA, 2020). As this study emphasized implicit attentional processing, other sources of attentional allocation such as

novelty or nostalgia were not measured. The current study also did not examine what types of games were played by participants (e.g., shooters, fighting, puzzle) and effects on attentional allocation, or gaming disorder symptoms.

In summary, these findings suggest a relationship between allocation of attention to gaming technologies and self-reported daily playtime and video gaming consequences. Results indicated that as the number of video gaming hours played increased, there was a greater dwell time to video gaming images. Also, video gaming symptoms were positively associated with more initial preferences and greater gaze length of video gaming versus neutral images. These results support the continued study of attentional allocation in individuals with problematic video gaming behavior and have implications for the use of eye tracking in understanding attentional allocation in behavioral addiction. The manuscript contributes to the literature as it includes measures to quantify loss of control/binge gaming. The study also suggests that the model of the development of addictive behavior in adolescents (Wiers, 2007) could potentially guide future research in understanding both the automatic and controlled cognitive responses contributing to the development of problematic video gaming behavior in adolescents and young adults.

**Ethics Committee Approval:** Ethics committee approval was received for this study from the Institutional Review Board at anonymous review (approval no. 2019/007044, dated August 27, 2019).

**Informed Consent:** Written informed consent was obtained from participants in this study.

**Peer-review:** Externally peer-reviewed

**Author Contributions:** DJL and RJG designed the study. DJL and RJG conducted the literature searches and provided summaries of previous research studies. DJL and RJG conducted the statistical analyses. ED assisted in study design and the writing of the manuscript. DJL and RJG wrote the first draft of the manuscript and all authors contributed significantly to and have approved the final manuscript. All authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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