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Incentive sensitization in binge behaviors: A mini review on electrophysiological evidence

Dustin Werle *, Philipp A. Schroeder, Ines Wolz, Jennifer Svaldi

University of Tuebingen, Department of Clinical Psychology and Psychotherapy, Schleichstrasse 4, 72076 Tuebingen, Germany

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A B S T R A C T

Introduction: Binge behavior not only refers to the consumption of substances such as alcohol or food, but is also used in relation to gaming, watching and gambling. Dependent on context it makes for a widespread, benign recreational activity or can pose a serious mental health problem with deleterious consequences. Incentive sensitization theory describes the attribution of salience towards stimuli strongly associated with dopamine-mediated reward as a result of repeated consumption. The sensitized neural networks cause cue-triggered craving and excessive desire, but thus, this mechanism may also be applicable to stimulus-induced behaviors not associated with classical withdrawal symptoms. Event-related potentials (ERP) are a useful method of examining motivated attention towards incentive stimuli. This mini review aims to synthesize ERP findings from different types of binge behaviors in order to compare cue-reactivity to incentive stimuli.
Methods: Studies investigating binge drinking, binge eating as well as binge watching, gaming and gambling were screened. To limit the influence of concurrent task demands, ERP studies applying picture viewing paradigms with incentive stimuli were selected.
Results: Across binge behaviors, evidence on altered mid-latency ERPs has been mixed. However, studies investigating later stages of attentional processes more consistently find enlarged P300 and late positive potentials (LPP) amplitudes to relevant cues.
Conclusion: An altered attentional processing of incentive stimuli reflecting motivated attention is in line with incentive sensitization theory. Considering the limited number of studies, especially regarding binge behaviors not involving substances, more research is needed to attain a more thorough understanding of incentive sensitization across binge behaviors.

1. Introduction

Binges, which typically refer to the consumption of substances such as alcohol or food in short periods of time, pose a serious public health problem in developed countries (e.g., Kessler et al., 2013; Morris, Dowell, Cercignani, Harrison, & Voon, 2018). Notably, the potential deleterious effects of binge behavior on psychological well-being are not bound to a specific substance. In fact, even when classical withdrawal symptoms as a marker of addiction are absent, bingeing can result in negative mental health consequences, such as a reduced quality of life and increased depression (e.g. Black, Moyer, & Schlosser, 2003; Kaptsis, King, Delfabbro, & Gradisar, 2016; Rieger, Wilfley, Stein, Marino, & Crow, 2005; Zastrow, 2017). Consequently, the term *binge* has recently been used to describe phenomena beyond substance use such as binge watching or binge gaming.

As a biopsychological theory of drug craving and addiction (Berridge & Kringelbach, 2015; Robinson & Berridge, 1993), incentive sensitization is proposed as a central process in addiction, with cue-reactivity, an altered reward system, and craving as fundamental mechanisms for the etiology and maintenance of substance use disorders. In line with the theoretical assumptions, a variety of drugs, but also drug-related stimuli increase dopamine levels in the brain (Robinson & Berridge, 1993), making such stimuli exceptionally attractive and wanted (though not necessarily liked). Notably, research suggests that the dopamine increase primarily serves to draw an individual's attention towards appetitive stimuli (e.g., food or drug-related stimuli) that predict reward

Abbreviations: BED, binge eating disorder; BN, bulimia nervosa; EEG, electroencephalography; EPN, early posterior negativity; ERP, event-related potential; IGD, internet gaming disorder; LPP, late positive potentials; OCD, obsessive compulsive disorder.

* Corresponding author.
E-mail address: dustin.werle@uni-tuebingen.de (D. Werle).

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(Franken, 2003; Schultz, 1998; Wickelgren, 1997), while at the emotional level, this (classically conditioned) response becomes evident as craving (Heinz et al., 2004; Volkow et al., 2006).

However, alterations of dopamine systems have not been exclusively shown in drug-related addictive behaviors but also in binge behaviors such as binge eating (Bello & Hajnal, 2010; Wang et al., 2011). In fact, even binge behaviors not involving substances like pathological gambling and binge gaming in internet gaming disorder (IGD) show neural dopamine mechanisms resembling those of drug addiction (Bergh, Eklund, Södersten, & Nordin, 1997; Joutsa et al., 2012; Weinstein, Livny, & Weizman, 2017). According to incentive sensitization theory, the sensitized neural dopamine system causes elevated craving upon being exposed to a cue associated with its activation, which has also been shown to play an important role in various types of binge behaviors (eating: Joyner, Gearhardt, & White, 2015; gaming: Weinstein et al., 2017; gambling: Tavares, Zilberman, Hodgins, & el-Guebaly, 2005). Finally, as theoretically postulated, there is an extensive indication of altered cue-reactivity expressed by motivated attention towards incentive stimuli across different types of binge behaviors both in alcohol and other drug addiction (Field & Cox, 2008) as well as beyond (eating: Stojek et al., 2018; gaming: van Holst et al., 2012; gambling: Hønsi, Mentzoni, Molde, & Pallesen, 2013). On these grounds, incentive sensitization theory has also been discussed as a possible framework to explain binge behaviors aside from alcohol and other drugs (Berridge, 2009; Hellberg, Russell, & Robinson, 2019).

Here we argue, that if incentive sensitization indeed depicts a common underlying process of a variety of binge behaviors, then similar results regarding postulated mechanisms should emerge. Given the high prevalence of binge behaviors (drinking: 18.2%, World Health Organization. (2018) (2018), 2018; eating: 4.5%, Hudson, Hiripi, Pope, & Kessler, 2007; watching: 72%, Flayelle et al., 2020; gaming: 1.6% of adolescents, Müller et al., 2015; gambling: up to 0.6%, Erbas & Buchner, 2012) and its associated impaired quality of life, a better understanding of the various binge behaviors' genesis and maintenance by more precisely investigating theory-driven mechanisms is crucial.

The present mini review aims to examine motivated attention as a central mechanism of incentive sensitization theory in different binge behaviors. Traditionally, reaction time experiments have been primarily used in the assessment of motivated attention with eye-tracking and electroencephalography (EEG) as more novel and direct measurement methods (Field & Cox, 2008; Hønsi et al., 2013; Stojek et al., 2018). Being a method closely related to neuronal processes and capable of capturing also covert attentional processes, EEG is a very convincing approach to the examination of motivated attention. Due to its high time-resolution and consequential ability of capturing the time course of attentional stimulus processing, event-related potentials (ERPs) have been applied to study the neural underpinnings of alcohol addiction early on (Begleiter, Porjesz, Chou, & Aunon, 1983; Iacono & Malone, 2011; Petit, Maurage, Kornreich, Verbanck, & Campanella, 2014). In other behavioral paradigms with various tasks, stimulus- or response-locked ERPs are thought to reflect different processes, rather associated with stimulus identification or evaluation (for a broader characterization of N200 and P300 across different paradigms please see: Patel & Azzam, 2005). Therefore, in order to limit the effects of concurrent task demands and investigate cue-specific effects according to incentive sensitization, we focused on paradigms not requiring high-level cognitive processes (e.g. inhibitory control) and investigate motivated attention processes related to craved stimuli in the present mini review.

More specifically, in picture viewing paradigms, ERPs in mid-latency and late processing stages depict arousal related to the motivational relevance of craving-related stimuli, starting about 200 ms after stimulus onset and maintaining for about 800 ms (see Schupp, Flaisch, Stockburger, & Junghöfer, 2006 for a review). The early posterior negativity (EPN), which shows a maximum peak at about 250–300 ms after stimulus onset, is one of the earliest ERPs found to be related to subjective stimulus arousal. The N200 partly overlaps with the EPN regarding its latency, it is however measured in frontal regions; although it was mostly investigated in behavioral inhibition tasks, it has also been related to arousal in affective picture processing (Olofsson, Nordin, Sequeira, & Polich, 2008). A more frequently examined ERP in the domain of motivated attention is the P300 which reflects subjective motivational properties of stimuli (Begleiter et al., 1983; Carrillo-de-la-Peña & Cadaveira, 2000). However, positivity outlasts the P300 timeframe at parietal, occipital and central positions (Foti, Hajcak, & Dien, 2009). The magnitude of these late positive potentials (LPP) is associated with subjective arousal ratings of the presented stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Weinberg & Hajcak, 2010).

In light of what just mentioned, the present mini review aims to synthesize ERP findings from studies across a variety of binge behaviors in order to examine motivated attention towards incentive stimuli as possible transdiagnostic mechanism. In line with our aims, we focus on the phenomenon of bingeing itself, regardless of whether it occurs within the scope of an underlying clinical diagnosis or without it.

Considering the lack of a uniform definition of binge behaviors across different studies, we provide a detailed overview of all samples and diagnostics in Table 1. For the sake of transparency, we also adopt the specific sample nomenclatures used in the original studies, when reporting their results (e.g. "heavy drinkers"/" alcohol dependent"/" binge drinkers").

2. Search strategy

Relevant studies were identified by searching the online databases PubMed and PsycINFO. The following search terms were used:

> binge eating OR binge drinking OR binge watching OR gaming OR gambling AND (ERP OR event-related potential OR LPP OR late-positive potential OR P300 OR P3 OR early posterior negativity OR EPN OR N200 OR N2)

Among the contemplable articles, we included all studies comprising passive perceptual processing of picture stimuli specific to the respective binge behavior (e.g. passive picture viewing, oddball tasks) and simultaneous reporting of ERPs in the domain of motivated attention. We decided not to include paradigms requiring high-level cognitive processes, since the examined ERPs interpretation vastly differs between specific tasks, which would in turn dilute the synthesis of different study results (Luck & Kappenman, 2012; Patel & Azzam, 2005). This procedure resulted in a total of 23 studies (binge drinking: 10 studies; binge eating: 8 studies; binge gaming/gambling: 5 studies; binge watching: no study).

3. Binge drinking, drinking

The majority of studies with binge drinking populations measured ERPs in auditory oddball, three-stimulus, or response inhibition paradigms. Comprehensive reviews also including alcohol addiction are available elsewhere (Iacono & Malone, 2011; Petit, Maurage, et al., 2014, for other drugs see also Littel, Euser, Munafò, & Franken, 2012). The existing studies with picture viewing in drinking populations investigated the effects of binge drinking both within, but also outside the framework of alcohol addiction. This is of particular interest, since binge drinking alone may be closely related to alcohol dependence, potentially forming a mutual spectrum (please see Lannoy, Billieux, & Maurage, 2014).

As expected from studies with alcohol addiction populations, the P300 amplitude in response to alcohol cues was enhanced in heavy drinkers (>27 drinks / month) as well as in alcohol dependent samples (Herrmann, Weijers, Wiesbeck, Böning, & Fallgatter, 2001; Namkoong, Lee, Lee, Lee, & An, 2004). Moreover, a study on recently detoxified alcohol dependent patients found a notable distinction between patients who relapsed and those who maintained abstinence: in comparison to

Table 1
Overview of original EEG studies investigating binge behavior in free picture-viewing tasks.

Study	EEG Component	Time Window [ms]	Electrodes	Sample (N)	Diagnostics	Stimuli	Result
1. Binge Drinking, Drinking							
(Ceballos et al., 2012)	N200	250–400	left medial frontal (LMFr), right medial frontal (RMFr), and midline frontal (MiFr) electrodes	Social drinkers (75)	Quantity-frequency of alcohol use	Oddball alcohol-related vs. household objects (between), vs. color nonsense shape pictures Preceded by a stressor vs. control task	N200 amplitude larger to object nontargets in the alcohol target subgroup in the control condition
	P300	350–600	left medial parietal (LMPa), right medial parietal (RMPa), and midline parietal (MiPa) electrodes				Larger P300 to alcohol targets in the alcohol target subgroup without stress
(Dickter et al., 2014)	P200	172–272	P1, P2, P3, P7, P9, O1, O2, Oz, P10, P4, P5, P6, P8, PO3, PO4, PO7, PO8, POz, Pz	Alcohol dependent (11) vs. escape drinking students (43)	MAST (self-report screening)	Alcohol-related vs. matched active vs. inactive scenes	No effects.
	N200	208–300	FPZ, FT10, FT7, FT8, FT9, Fz.				No group difference, but larger amplitude to alcohol cues in escape drinkers
(Herrmann et al., 2001)	P300	250–430	Fz, Cz, Pz	Heavy (15) vs. Light Drinkers (15)	Median split (27 drinks / month)	Alcohol-relevant (e.g. beer, booze, bottle) vs. neutral	Increased amplitude and correlation with consumption (Fz) in response to alcohol cues in heavy drinkers
(Kroczek et al., 2018)	LPP	450–700	Pz	Heavy (18) vs. Light Social Drinkers (16)	AUDIT cutoff (score 5/8)	Alcohol bottles vs. silhouettes vs. scrambled pictures	Increased mean activity in heavy drinkers
(Namkoong et al., 2004)	P300	250–500	F3, Fz, F4, C3, Cz, C4, P3, Pz, P4	Alcohol dependent (20) vs. HC (17)	DSM-IV criteria for alcohol dependence + 2 weeks abstinence	Oddball still-life photographs of Korean liquor (soju) vs. control images	P3 amplitudes of patients increased for alcohol pictures vs. neutral pictures
(Petit et al., 2012)	P100	90–160	Oz, O1, O2, P7, P8, POz	Binge Drinkers (18) vs. HC (18)	6 + drinks at one occasion (within 3 h) at most 3–4 times a week	Oddball alcohol-related vs. –unrelated vs. emotionally neutral pictures	P1 amplitudes higher to alcohol than control stimuli in binge drinkers Larger P1 amplitudes for longer and more intensive binge drinking habits No effects on latencies
	N200b	200–300	Oz, O1, O2				No effects on amplitudes and latencies
	P300b	350–650	Pz, P3, P4				No effects on amplitudes and latencies
(Petit et al., 2013)	P300	350–650	Pz, P3, P4, CP1, CP2, POz	Binge Drinkers (29) vs. HC (27)	6 + drinks at one occasion (within 3 h) at most 3–4 times a week	Oddball alcohol-related vs. –unrelated vs. emotionally neutral pictures	P3 amplitudes higher to alcohol than control stimuli in binge drinkers P3 latencies shorter for alcohol stimuli in both groups
(Petit et al., 2014)	P100	90–160	Oz, O1, O2, P7, P8, POz	Binge Drinkers (15) vs. HC (15)	6 + drinks at one occasion (within 3 h) at most 3–4 times a week	Oddball alcohol-related vs. –unrelated vs. emotionally neutral pictures	P1 amplitudes reduced after a year for all stimuli in binge drinkers P1 latencies longer after a year in both groups + stimuli
	P300	350–650	Pz, P3, P4, CP1, CP2, POz				P3 amplitudes reduced after a year for neutral stimuli in binge drinkers P3 latencies longer after a year in both groups + stimuli
(Petit et al., 2015)	P300	350–650	Pz, P3, P4, POz, Cz, Fz	Alcohol dependent relapsers (19) vs. non-relapsers (20) vs. HC (29)	DSM-IV diagnosis of alcohol dependence Self-report AUDIT	Oddball one-man drinking scenes (alcohol vs. non-alcohol)	Lower P300 amplitudes to alcohol in non-relapsers No effects for P300 latencies
	N200	200–300	Fz, Fcz, Cz	Students (correlative) who		Priming with Navon letters Alcohol vs.	N2 amplitudes not significantly correlated

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Table 1 (*continued*)

Study	EEG Component	Time Window [ms]	Electrodes	Sample (N)	Diagnostics	Stimuli	Result
(Ryerson et al., 2017)				ever had an alcoholic drink (67)	Number of occasions with 5+/4 + drinks in the past month	matched neutral picture	with number of binges in the last month (r = -0.23)
	P200	150–200	Fz, Fcz, Cz				No correlation (r < 0.22)
	P300	260–400	Cz, CPz, Pz				No correlation (r < 0.22)
2. Binge Eating							
(Aviram-Friedman et al., 2020)	LPP	300–495	frontal: F1, Fz, F2, FC1, FCz, FC2, right posterior: P2, P4, P6, P8, PO4, PO6, PO8, O2, left posterior: P1, P3, P5, P7, PO3, PO5, PO7, O1	OW with food addiction (31) vs. OW without food addiction (17) vs. HC (18)	Yale Food Addiction Scale (three or more symptoms present and a positive score on the clinical distress questions)	High calorie vs. low calorie vs. neutral pictures	300–450 ms: No differences 450–495 ms: lower amplitude change following high calorie food pictures compared to neutral pictures in OW with food addiction vs. OW without food addiction for frontal and right posterior electrodes. No difference between HC and both OW groups.
(Blechert et al., 2011)	EPN	220–310	O1, O2, Pz, P3, P4, P7, P8	AN (21) vs. BN (22) vs. HC (32)	DSM-IV criteria for AN or BN as assessed by the Eating Disorder Examination	High calorie vs. low calorie vs. pleasant vs. neutral vs. unpleasant pictures	AN: high calorie > low calorie > neutral BN: high calorie = low calorie > neutral HC: high calorie > low calorie = neutral
(Delgado-Rodríguez et al., 2019)	EPN	200–300	PO3, POz, PO4, O1, Oz, O2	BN (20) and subthreshold BN (4) vs. HC (24)	DSM-5 criteria for BN as assessed by the Eating Disorder Examination	Individualized high calorie vs. pleasant vs. neutral vs. unpleasant pictures	No group difference
	LPP	500–800	Cp1, Cp2, P1, Pz, P2				Enhanced amplitude for high calorie and pleasant pictures in BN vs. HC
(Lutz et al., 2021)	P300	350–400	P3, Pz, P4, PO3, POz, PO4	Full-syndrome or partially remitted BN (21) vs. HC (21)	DSM-5 criteria for full-syndrome or partially remitted BN as assessed by the Eating Disorder Examination	High calorie vs. low calorie vs. neutral pictures under neutral or negative mood	Larger mood-induced amplitude reduction in BN vs. HC for all stimulus categories (evident at 2 to 6 electrode positions)
	LPP	600–1000	P3, Pz, P4, PO3, POz, PO4				Larger mood-induced amplitude enhancement in BN vs. HC for both food categories (evident at 1 to 2 electrode positions)
(Sarlo et al., 2013)	P300	280–400	F3, F7, FC1, FC5, F4, F8, FC2, FC6, CP1, CP5, P3, P7, CP2, CP6, P4, P8	HC (33)	Eating pathology assessed dimensionally by Eating Disorder Inventory	High calorie vs. neutral pictures	No correlations with eating pathology
	LPP	500–1000, 1000–1500	F3, F7, FC1, FC5, F4, F8, FC2, FC6, CP1, CP5, P3, P7, CP2, CP6, P4, P8				Amplitudes positively correlated with bulimic tendencies, when instructed to reduce stimuli's appetitive value
(Schienle et al., 2017)	P200	150–200	F3, Fz, F4, C3, Cz, C4, P3, Pz, P4	BED (19) and low frequency BED (17) vs. HC (38)	DSM-5 criteria of BED and low frequency BED as assessed by a clinical psychologist	High calorie sweets vs. high calorie meat dishes vs. low calorie vegetarian food pictures	Enhanced amplitude to both food categories in BED vs. HC; Higher amplitude to food stimuli when inducing bitter taste in BED
	LPP	400–700	F3, Fz, F4, C3, Cz, C4, P3, Pz, P4				Enhanced amplitude to both food categories in BED vs. HC when inducing bitter taste
(Svaldi et al., 2010)	LPP	500–800	C3, C4, CP1, Cz, CP2, Pz	BED (22) vs. OW (22)	DSM-IV criteria for BED as assessed by the Eating Disorder Examination	High calorie vs. low calorie pictures	Enhanced amplitude to high calorie pictures in BED vs. HC; no differences on low calorie pictures
	SPW	1000–6000	C3, C4, CP1, Cz, CP2, Pz				Enhanced amplitude to high calorie pictures in BED vs. HC; no differences on low calorie pictures
(Wolz et al., 2017)	N200	180–350	AFz, AF3, F1, F3, AF4, F2, F4	BN (12) and BED (7) vs. HC (20)	DSM-5 criteria of BN or BED as assessed by semi-structured face-to-face interviews	Chocolate vs. neutral pictures primed by odor	Higher relative increase in amplitudes to chocolate vs. neutral pictures in BN/BED-group compared to HC

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Table 1 (*continued*)

Study	EEG Component	Time Window [ms]	Electrodes	Sample (N)	Diagnostics	Stimuli	Result
	LPP	300–1000	Pz, CP1, CP3, P1, P3, P5, CP2, CP4, P2, P4, P6				No group difference
3. Binge Watching, Gaming, Gambling							
(He et al., 2019)	P100	90–150	PO5, PO6	Internet Gaming Disorder [playing the online game "Strike of Kings"] (15) vs. HC (15)	IAT score > 79, IGAS score > 7, DSM-5 criteria of IGD as assessed by clinical interview	Cartoon faces out "Strike of Kings" vs. Realistic faces	IGD: Larger amplitude for cartoon vs. realistic faces in left hemisphere HC: No difference
	N170	150–210					IGD: Larger amplitude for cartoon faces vs. realistic faces in right hemisphere HC: Larger amplitude for cartoon faces vs. realistic faces in both hemispheres
	P200	210–270					IGD: Larger amplitude for cartoon faces vs. realistic faces in both hemispheres HC: No difference
(Kim et al., 2018)	LPP	350–700	CP1, CPz, CP2, P1, Pz , P2	Internet Gaming Disorder (20) vs. HC (23) vs. Obsessive-Compulsive Disorder (20)	Playing one of three games (League of Legend, FIFA, Sudden Attack) for > 4 h/day	Game related (League of Legend, FIFA, Sudden Attack) vs. OCD related vs. neutral images	IGD > HC for LPP to game-related cues (but not for OCD related cues). Limitation: effect was not found for all electrode sites, not controlled for multiple testing
(Lai et al., 2017)	LPP	200–300, 300–400, 400–500. 500–1000, 1000–1500	Occipito-temporal, central and frontal montages	Pathological Internet Use (16) vs. HC (14)	Having received a diagnosis of PIU during a one-year period (before study implementation)	Internet images vs. emotional images	For LPP group*condition interaction only in time window 300–400 ms: HC = emotional > internet pictures, n.s. for PIU -> Tendency for smaller difference between emotional pictures and internet pictures in PIU, but mostly not significant.
(Thalemann et al., 2007)	LPP	350–750	sagittal: F3, C3, P3; Fz, Cz, Pz; F4, C4, P4, coronal: F3, Fz, F4; C3, Cz, C4; P3, Pz, P4	Excessive (15) vs. casual (15) computer game players	Excessive gamers met min. three ICD-10 addiction criteria as measured by the questionnaire of Differentiated Assessment of Addiction, casual players were familiar with computer games and met none of the criteria for addiction	Computer game vs. alcohol vs. neutral vs. positive vs. negative images	Excessive > casual players for LPP to game-related cues, only at Pz electrode site, no group differences for all other stimuli. Excessive players: Game related cues were processed in a similar way as negative and positive cues (limitation: this effect was not statistically compared)
(Wölfling et al., 2011)	LPP	450–750	sagittal: F3, C3, P3; Fz, Cz, Pz; F4, C4, P4, coronal : F3, Fz, F4; C3, Cz, C4; P3, Pz, P4	Pathological Gamblers (15) vs. HC (15)	South Oaks Gambling Screen and DSM-IV criteria for PG	Gambling related vs. alcohol vs. neutral vs. positive vs. negative images	PG > HC for gambling related images at central electrode sites, but not for any other stimulus category. HC: gambling related = neutral < emotional ; PG: gambling related = emotional > neutral

Notes: AN = anorexia nervosa; AUDIT = Alcohol Use Disorders Identification Test; BED = binge eating disorder; BN = bulimia nervosa; DSM = Diagnostic and Statistical Manual; EPN = early posterior negativity; HC = healthy controls; IAT = Internet addiction test; ICD = International Classification of Diseases; IGAS = Internet game addiction scale; IGD = internet gaming disorder; LPP = Late Positive Potential; MAST = Michigan Alcohol Screening Test; OCD = obsessive–compulsive disorder; OW = overweight; PG = pathological gamblers; PIU = pathological internet users; SPW = slow positive wave.

relapsed patients, abstainers displayed attenuated P300 amplitudes towards alcohol compared to neutral cues (Petit et al., 2015). Beyond that, several studies investigated binge drinking irrespective of clinical diagnoses, with mixed results: Binge-drinking and control students did not differ in N200- and P300-reactivity towards alcohol cues (Petit et al., 2012) and no strong correlation between the number of binge drinking occasions in the past month and N200 or P300 amplitudes were observed (Ryerson, Neal, & Gable, 2017). In contrast, another study revealed increased P300-reactivity for alcohol related stimuli in the binge drinkers (Petit, Kornreich, Verbanck, & Campanella, 2013). In a follow-up study of the second sample, binge drinkers further showed a reduced P300 amplitude towards neutral stimuli but no change towards alcohol cues, one year after the initial assessment (Petit, Kornreich, Dan, Verbanck, & Campanella, 2014).

Another study on college students (Dickter, Forestell, Hammett, & Young, 2014) investigated the electrophysiological effects of alcohol addiction and escape drinking, which does not specify the quantity but motivation of drinking to avoid negative mood. There were no effects of alcohol addiction, but escape drinkers showed a larger N200 to alcohol images than non-escape drinkers (Dickter et al., 2014). In a sample of social drinkers, alcohol images elicited heightened P300 amplitudes, while N200 amplitudes were reduced compared to neutral objects, in some conditions (Ceballos, Giuliano, Wicha, & Graham, 2012). Finally, in a sample of student heavy drinkers according to their Alcohol Use Disorders Identification Test scores (AUDIT; Saunders, Aasland, Babor, De La Fuente, & Grant, 1993), the LPP mean activity was increased to alcohol content, but not to two stimulus control conditions nor in light social drinkers (Kroczek et al., 2018).

4. Binge eating

Several studies examined neural responses to food stimuli in different populations (see Chami, Cardi, Lautarescu, Mallorquí-Bagué, & McLoughlin, 2019; Wolz, Fagundo, Treasure, & Fernández-Aranda, 2015 for comprehensive reviews); however, just a few investigated negative mid-latency ERPs in binge eating samples. A sample of healthy controls showed increased EPN only towards high calorie food, whereas patients with bulimia nervosa (BN) displayed stronger EPN following both low calorie and high calorie food, compared to nonfood stimuli, indicating an enhanced processing of food stimuli in general (Blechert, Feige, Joos, Zeeck, & Tuschen-Caffier, 2011). Contrary to this, however, a study displaying personal binge food, as well as pleasant, neutral, and unpleasant pictures yielded no difference in EPN between a sample of BN and healthy controls (Delgado-Rodríguez et al., 2019).

The only study to investigate N200 amplitudes in a picture viewing task tested a mixed sample of patients with binge eating disorder (BED) and BN relative to a healthy control sample. Results indicate that patients showed a higher relative increase in N200 amplitudes to chocolate versus neutral pictures compared to controls, whereas no differences in LPP between the groups emerged (Wolz et al., 2017). Likewise, no food specific P300-alterations were found in a mixed sample of full-syndrome and partially remitted patients with BN, when compared to healthy controls. However, negative mood induced a stronger LPP amplitude enhancement in high calorie food for this BN sample (Lutz et al., 2021). Though, an overweight sample with food addiction displayed a lower LPP amplitude change (between 450 and 495 ms) following high calorie food pictures compared to neutral pictures, compared to an overweight sample without food addiction for frontal and right posterior electrodes (Aviram-Friedman, Kafri, Baz, Alyagon, & Zangen, 2020).

A study combining visual presentation with an additional sense examined the effect of inducing a bitter taste during picture viewing of high calorie and low calorie food. The induction of bitter taste reduced the magnitude of LPP and P200 in healthy controls whereas it enhanced these amplitudes in a sample of (sub)clinical BED (Schienle, Scharmüller, & Schwab, 2017). Furthermore, viewing pictures of binge foods amplified LPP in patients with BN relative to healthy controls (Delgado-Rodríguez et al., 2019). Additionally, the presentation of high calorie (but not low calorie) food stimuli led to an enhanced LPP and slow positive wave in individuals with BED compared to overweight controls without BED (Svaldi, Tuschen-Caffier, Peyk, & Blechert, 2010). Finally, amplitudes of LPP in healthy controls trying to reduce the appetitive value of depicted high calorie food were positively correlated with the Eating Disorder Inventory's (Garner, 1991) binge eating score (Sarlo, Übel, Leutgeb, & Schienle, 2013).

5. Binge watching, gaming and gambling

Eligible studies on mid-latency ERPs in this binge domain are rather sparse. However, one sample with internet gaming disorder playing one specific game showed larger P200 amplitudes following cartoon faces taken out of that very game compared to realistic faces, while healthy controls showed no such alteration (He, Zheng, Fan, Pan, & Nie, 2019). In order to attain a better understanding of the addiction-related attentional bias in IGD as well as the disorder's relation to compulsivity, another study compared patients with IGD, obsessive compulsive disorder (OCD) and healthy controls (Kim et al., 2018). Relative to healthy controls, patients with IGD displayed higher amplitudes specifically for game-related cues, but OCD-related cues provoked no LPP change (Kim et al., 2018). By contrast, another study found only limited evidence on LPP distinctions between a sample with internet addiction and healthy controls using internet images and emotional images (Lai et al., 2017). Importantly, this study did not specifically investigate internet gaming. Instead, it assessed internet use disorder and used images with different internet-related activities (social network, gaming, pornography and gambling).

Evidence of alterations in cue-reactivity via late positivity has also been found in a sample of excessive gamers, who showed significantly more extended LPP amplitudes at parietal regions evoked by game-related cues than healthy controls (Thalemann, Wölfling, & Grüsser, 2007). Similarly, gambling-relevant stimuli induced an increase in LPP amplitudes in pathological gamblers compared to healthy controls, whereas no differences emerged for gambling-irrelevant stimuli. Furthermore, gambling-related stimuli induced more craving in pathological gamblers than in healthy controls. Notably though, there were no associations between reported craving and LPP amplitudes (Wölfling et al., 2011).

Worth noting, no eligible study on binge watching was found.

6. Discussion

This mini review aimed to synthesize results on motivated attention as reflected by ERPs, in order to review evidence for incentive sensitization in binge behaviors. The electrophysiological results preliminarily point towards an altered attentional processing of incentive stimuli across different types of binge behaviors.

Cue-specific mid-latency ERPs have only been sparsely examined for binge watching, gaming, pathological internet use as well as gambling and have yielded mixed evidence for binge eating and drinking (Blechert et al., 2011; Delgado-Rodríguez et al., 2019; Dickter et al., 2014; He et al., 2019; Wolz et al., 2017). Inconsistencies in diagnostics and operationalizations pose an obstacle to the synthesis of different study results: Binge behaviors are often missing a coherent definition, leading to a broad spectrum of inclusion criteria even within binge behaviors (see e.g. Flayelle et al., 2020; Kuntsche, Kuntsche, Thrul, & Gmel, 2017). Likewise, different studies use distinct electrodes and time windows in the investigation of ERPs. These differences constitute possible reasons for ambiguous results concerning mid-latency ERPs (for an overview of diagnostics, electrodes and time windows see Table 1). Nevertheless, as they reflect subjective arousal related to the stimulus' motivational relevance, mid-latency ERPs play an important role in the investigation of incentive sensitization together with motivated attention and should not be neglected in future investigations. The influence of perceptual processing on mid-latency ERPs requires an especially diligent selection of stimulus material.

At the same time, late-stage motivated attention as reflected by enlarged P300 and LPP amplitudes occurred more consistently (Ceballos et al., 2012; Delgado-Rodríguez et al., 2019; Herrmann et al., 2001; Kim et al., 2018; Kroczek et al., 2018; Namkoong et al., 2004; Petit et al., 2013; Petit, Kornreich et al., 2014; Petit et al., 2015; Schienle et al., 2017; Svaldi et al., 2010; Thalemann et al., 2007; Wölfling et al., 2011). One study on pathological internet use (Lai et al., 2017), three on binge eating (Aviram-Friedman et al., 2020; Lutz et al., 2021; Wolz et al., 2017) and two on binge drinking (Petit et al., 2012; Ryerson et al., 2017) brought forth no significant or only very limited effects on P300 or LPP. As found in most studies, an increase in later ERP amplitudes to relevant cues in populations of different binge behaviors is in line with a common incentive sensitization process. In the future, synthesizing results of attentional markers apart from ERPs, such as eye-tracking or reaction time measurements could yield interesting complementary findings. If motivated attention is a common mechanism in different binge behaviors, not only electrophysiological but also behavioral measures should yield similar results across methods. Moreover, incentive sensitization theory's other central assumptions like alterations of dopamine systems (e.g. via fMRI studies) and craving should also be reviewed for binge behaviors, so as to further test the theory's applicability as a broader explanatory framework.

In order to limit the effects of concurrent task demands, the present mini review focused on picture viewing studies only. Notably though, there is an extensive body of literature focusing on other processes such as inhibitory control (see e.g. Chami et al., 2019; Luijten et al., 2014; Petit, Maurage, et al., 2014; Wolz et al., 2015). An integration for other paradigms across binge behaviors is appealing but should consider the respective theoretical aspects and paradigm-specific interpretations of the ERPs investigated.

Taken together, our mini synthesis points in the direction of motivated attention towards incentive stimuli in a variety of binge behaviors, displaying noteworthy overlaps, especially in enhanced LPP amplitudes. This sheds light on a potential common mechanism involved in the phenomenology of very distinct behavioral patterns and ultimately mental disorders. It raises the question, whether trainings targeted at modifying attentional processes (e.g. attentional bias modification trainings) could pose an overarching intervention possibility for these behavioral patterns, as there already is preliminary evidence of efficacy, especially for alcohol and other drugs (Heitmann, Bennik, van Hemel-Ruiter, & de Jong, 2018) as well as eating disorders (Renwick, Campbell, & Schmidt, 2013). However, more research on incentive sensitization and its sequelae is needed, not only on particular binge behaviors but also in a more integrative, transdiagnostic manner.

CRediT authorship contribution statement

Dustin Werle: Conceptualization, Investigation, Writing - original draft, Visualization. **Philipp A. Schroeder:** Conceptualization, Investigation, Visualization. **Ines Wolz:** Conceptualization, Investigation, Visualization. **Jennifer Svaldi:** Conceptualization, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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