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REVIEW PAPER

Problematic Gaming and Gambling: A Systematic Review of Task-Specific EEG Protocols

Dovile Simkute[1] · Artemisa R. Dores[2,3] · Fernando Barbosa[3] · Inga Griskova-Bulanova[1]

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Abstract

Even though gaming and gambling bear similar problematic behavioral aspects, there are no recognizable neurophysiological biomarkers or features characterizing and/or distinguishing these conditions. A systematic review of the literature with a focus on methods was performed in PubMed, Scopus, Web of Science (Web of Science Core Collection), EBSCOhost Research Databases (APA PsycINFO; APA PsycArticles; OpenDissertations; ERIC) databases. Following search terms were used to search the databases: ERP, "event related potential*", EP, "evoked potential*", SS, "steady state", EEG, electroencephal*; gam*. Data about the participants (total number, gender, age), main aim of the study and information about the experimental setup (experimental task description, stimuli used, ERPs measured (latency windows and placement of the electrodes), process evaluated) was extracted. A total of 24 studies were revised (problematic gaming – 16, pathological gambling – 8). The experimental protocols could be grouped into 3 main target domains (Cue-reactivity, General Information processing and Reward Processes & Risk Assessment). Sample-related limitations (small sample sizes, gender differences, differences between the groups regarding potential confounding variables) and heterogeneity regarding the experimental tasks, implementation and interpretation reviewed. Gambling-related research is highly focused on the investigation of the reward-related processes, whereas gaming-related research is mostly focused on the altered aspects of more general information processing. A vast heterogeneity regarding the ERP experimental paradigms being used and lack of clear guidelines and standardized procedures prevents identification of measures capable to reliably discriminate or characterize the population susceptible to addictive behavior or being able to diagnose and monitor these disorders.

Keywords Behavioral addictions · Gaming · Gambling · Electroencephalography · Event related potentials

Extended author information available on the last page of the article

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Introduction

Substance addictions stand as an old and common problem worldwide. These are highly researched both from the etiological and treatment point of view (Clay et al., 2008). Yet, it is not long ago since the notion that certain behaviors might be addictive as well has become an interest of research. Addictive behavior disorders share many similarities with substance use disorders (SUDs), such as the desire to engage in a rewarding behavior, loss of control, withdrawal, and unsuccessful effort to cut down certain behavior, despite the negative consequences (American Psychiatric Association, 2013; Lejoyeux et al., 2000; Smith & Seymour, 2004; Sussman & Sussman, 2011; World Health Organization, 2018). However, the term behavioral addictions covers many types of diverse activities, such as compulsive buying, sexual addiction, internet addiction, etc. (Jorgenson et al., 2016; Robbins & Clark, 2015) that makes research and conclusions in the field complex. Lately, particular attention has been paid to the investigation of neurobiological mechanisms underlying these disorders with a special focus on gambling and gaming.

The popularity of these activities, especially in the field of gaming, is growing rapidly. In 2020, the population of active video gamers reached 2.7 billion people worldwide and was estimated to reach 3.07 billion people by 2023 (Statista, 2020). Around 26% of the population, i.e. around 1.6 billion people worldwide, gamble (Global Gambling Statistics, 2020). Importantly, gaming and gambling are closely related to the resources of time and money. Only in the United States, consumers spent more than 35 billion USD on video game content during 2019 (Clement, 2021) and more than 7% of participants worldwide admitted spending more than 20 h a week playing video games in 2020 (Statista, 2020). The worldwide gambling market is currently evaluated in almost 59 billion USD in 2020 and is forecasted to reach more than 92 billion by 2023 (Lock, 2020). Industries of gaming and gambling show no signs of slowing down, which leads to the prediction that even more and more people will get involved.

Contrary to SUDs, there are no toxic psychoactive compounds exposed in gambling or gaming, and both can be described as harmless leisure activities in most cases. In general, both activities are pleasurable and rewarding (Anselme & Robinson, 2013; Wang, 2012). Moreover, there is an overlap between the activities, sometimes named "gamblification" or digital media convergence (Morgan Stanley Research, 2012), bringing new concerns into the field (Derevensky & Griffiths, 2019). In some cases, it is hard to distinguish boundaries between gaming and gambling due to the crossover of some products, platforms, and networks (King et al., 2015). Some authors argue that gaming disorder might be related to gambling content in games (Gainsbury et al., 2015) and not necessarily to gaming itself (King et al., 2015; King et al., 2014), and suggest differentiating gaming, gambling, and overlapping activities as different conditions (King et al., 2015). Currently, Problem Gambling (PG) is the only non-substance related condition included into DSM-5 as an addictive disorder (American Psychiatric Association, 2013) while Internet Gaming Disorder (IGD), sharing similarities with PG and SUDs (Müller et al., 2014; Sanders & Williams, 2019), is specified as the next candidate for inclusion. The 11th Revision of ICD (World Health Organization, 2018), presented both gambling and gaming disorders as disorders due to addictive behaviors. In order not to stigmatize the entire field, some gaming behavior advocates call for in-depth investigations before announcing gaming as a separate disorder (Rooij et al., 2018).

For most people high involvement in gaming or gambling does not necessarily mean problematic involvement; however, currently existing criteria for discrimination between

problematic and non-problematic behavior receives a lot of criticism (Billieux et al., 2015; Dullur & Starcevic, 2018; Király et al., 2015). IGD and PG are both characterized by impaired control over behavior, devoted priorities over other interests, and ignored negative consequences occurring due to the excessive involvement (World Health Organization, 2018). Results from previous neuroscience studies suggest that behavioral disorders share brain structural and functional similarities to those observed in SUDs, namely structural changes in Dorsolateral Prefrontal Cortex, Anterior Cingulate Cortex, Insula (Sun et al., 2017), altered dopaminergic function (Kayser, 2019), diminished activation during reward expectancy (Balodis & Potenza, 2020), as well as diminished behavioral control, leading to risky decision making (Lee et al., 2018). Moreover, current findings point to the fact that all addictive disorders share common underlying factors (Kuss et al., 2018; Potenza, 2001; Weinstein, 2017).

Changes occurring in the brain at either stage of problematic behavior can be investigated using neuroimaging methods. However, most of these methods are expensive and their use in wide-scale or multiple testing studies is cost-ineffective. An alternative approach is offered by electroencephalography (EEG), a much cheaper non-invasive technique, providing real-time measurement of brain activity (Bunge & Cognition, 2009). Time-locked EEG changes, or Event-Related Potentials (ERPs), elicited by meaningful sensory, affective, cognitive or motor events serve as temporal indices of cortical activity (Helfrich & Chapter, 2019) and enable investigation of functional correlates and changes in neuronal processing in many conditions (Sur & Sinha, 2009). ERPs are broadly used in addiction-related research (Campanella et al., 2014; Houston & Schlienz, 2018) and various paradigms, such as oddball, Go/No-Go, Stroop, Cue-reactivity, to name a few, are employed to tackle the neuronal correlates of different cognitive and affective processes in the brain (Habelt et al., 2020). Even though gaming and gambling bear similar problematic behavioral aspects, there are no recognizable neurophysiological biomarkers or features characterizing and/or distinguishing these conditions. To enhance our understanding and ability to define the level of homogeneity and heterogeneity between gaming and gambling, further studies should consider employing measures that could be compared and used across studies, including at the neurobiological level. It is crucial to develop protocols for investigation of brain activity that could potentially not only gather information on specific changes in the brain functioning, but also act as potential biomarkers for diagnostic and monitoring purposes.

To our knowledge, no attempt has been made so far to systematically overview the experimental paradigms and ERP components used in EEG research in the field of gaming and gambling. Thus, the goal of this paper is to review and systematize task-specific EEG protocols that are used to investigate the neurophysiological correlates of problematic gaming and gambling behavior, as well as the reported functional meaning of such correlates, in order to inform the selection of methods in further research in the field.

Materials and Methods

Protocol and Registration

This systematic review was registered on 26th October 2020 in PROSPERO International Prospective Register of Systematic Reviews (Registration number: CRD42020179280; the registered review protocol can be accessed on https://www.crd.york.ac.uk). This review

was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

Eligibility Criteria

Study characteristics were defined by specifying the PICOS criteria presented in the Table 1 to describe ERPs (or evoked potentials) paradigms used to investigate the population of gamers and gamblers and problematic gaming/gambling behavior. Only studies involving adult participants were included. Empirical studies exploring functional changes or variations in the brain activity due to or associated with excessive gaming or gambling behavior were selected. This review was limited to studies investigating ERPs measured with electroencephalography (EEG). Studies with control groups or focusing on gaming/gambling groups only were included. Only articles in English language, available as the full text and published in a peer-reviewed journal were considered for inclusion. No publication date restrictions were applied. Reviews, meta-analyses, editorials, conference abstracts, unpublished articles, and expert opinions were excluded.

Although the criteria for inclusion in the review were the employment of EEG and investigation of ERPs, some of the included studies were not limited only to the defined criteria and additional materials/methods were used. These studies are included in the review, however only the experimental EEG part investigating ERPs is discussed below.

Information Sources

Studies were identified by searching electronic databases and scanning references of the articles included in the review. Search was performed in PubMed, Scopus, Web of Science (results from Web of Science Core Collection), EBSCOhost Research Databases (databases at EBSCOhost comprised APA PsycINFO; APA PsycArticles; OpenDissertations; ERIC). Publication year started from 1969, as the articles available on the databases were published from that year onwards. The last search was conducted on July 2022.

Search Strategy

The following search string (ERP OR "event related potential*" OR EP OR "evoked potential*" OR SS OR "steady state") AND (EEG OR electroencephal*) AND (gam* NOT gamma) were used to search the databases (all in titles and abstracts). The syntax for the searches in every database is provided as Supplementary Material, Table S1.

Table 1 The PICOS criteria for the search

abbr	Criteria	Definition
P	(Population)	Adult (aged 18 +) participants
I	(Interventions)	Problematic/excessive gaming or gambling behavior
C	(Control)	Healthy controls or an alternative condition (e.g., non-behavioral addictions, disorders)
O	(Outcome)	ERP components, such as P300, N200, MMN, FRN, SSVEP, etc
S	(Study type)	Empirical studies

Selection Process

Databases were scanned based on the defined search terms and search results were exported to RIS or XML format files. Extracted data were imported to Rayyan—a web-tool for systematic reviews (Ouzzani et al., 2016). Duplicates were detected automatically by the tool, screened by one of the reviewers, and studies juxtaposing author names, titles, and abstracts were deleted. Eligibility assessment of remaining articles was independently undertaken by two reviewers. Articles were screened by titles and abstracts, as well as full text whenever necessary. The Cohen's kappa coefficient of inter-rater reliability was 0.93, showing an almost perfect agreement rate between both reviewers. All disagreements were discussed and whenever a consensus was not reached, the case was resolved by an experienced 3rd reviewer.

To ensure that all relevant papers were included in the review, a manual search among the references from included articles was performed. All articles considered relevant based on the titles were selected for the abstract review. A summary of the study selection process using PRISMA flow diagram (Page et al., 2021) is presented in Fig. 1.

Data Collection Process

First, the risk of bias of the selected studies was assessed using the Risk of Bias Form as presented in Table 2 (Supplementary material, Table S2). Then, data was extracted from each included study and every step of data collection (filling of the variables table, verification, and summarization of extracted data) was taken by the 1st reviewer and revised by the 2nd reviewer. Extracted information included: study identification information (name of the first author, year of publication), main aim of the study, description of participants (including age and gender), experimental task and task instructions, descriptions of the stimuli, ERP component measured.

This is a methodological review that primarily focuses on the experimental methods rather than research findings and aims to provide a comprehensive and descriptive overview of the methodologies employed in the included studies. Consequently, no detailed analysis of the individual research outcomes or assessment of the specific measures within each study were inspected.

Results

Study Selection

In total, 918 papers were identified in the database search process. Screening for duplicates resulted in 610 unique articles for titles and abstracts screening. After that, 30 articles were selected for full-text assessment as potentially relevant studies. After full-text reading, 20 articles were included in the review and 10 articles that did not match the criteria were excluded. Additional 91 papers were added for the screening process after the inspection of the reference lists of the included articles. From these, 10 papers were selected for full-text assessment and four of them were included in the review. After a thorough screening process, a total of 24 studies met all the eligibility criteria and were reviewed.

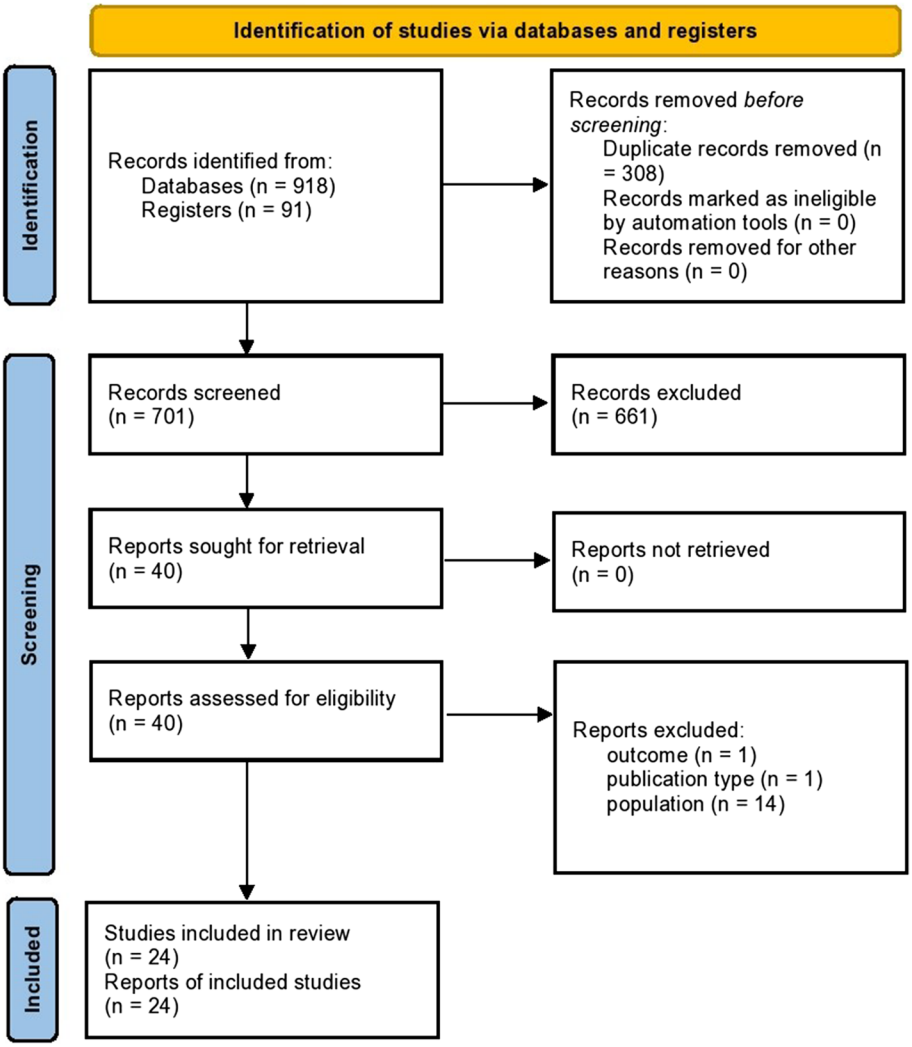

Fig. 1 PRISMA flow diagram of literature search

Studies that did not meet all inclusion criteria and reasons for their exclusion are presented as Supplementary Material, Table S3.

Study Characteristics

Participants

Sixteen out of 24 studies investigated problematic gaming behavior, while eight studies looked into pathological gambling behavior as presented in Table 3. Thirteen studies included healthy participants as controls, two studies compared problematic gamblers to both healthy controls and cocaine-dependent individuals (Torres et al., 2013a, 2013b),

Table 2 Risk of bias form for assessing the applicability of the studies

Item	Description
1	Was the problematic or excessive gaming or gambling behavior investigated? Was the aim of the study relevant and clearly stated?
2	Was the sample described in detail?
3	Was the methodology (EEG recording settings, preprocessing steps, evaluation methods and other relevant information) described in detail?
4	Was the paradigm explained and provided in full detail (detailed description of experimental task, characteristics of stimuli)?
5	Were ERPs measured? Was the assessment of components provided in full detail (description of components measured, time windows for component identification, electrodes sites selected)?
6	Were the analysis method(s) appropriate and reliable?

two studies compared individuals with IGD, healthy controls, and individuals with obsessive–compulsive disorder (Kim et al., 2018; Kim et al., 2017), and one study (Park et al., 2017) included individuals with alcohol use disorder alongside IGD. Three studies included casual computer game players (Duven et al., 2015; Heuer et al., 2021; Thalemann et al., 2007) as a control group, and occasional gamblers (Miedl et al., 2014) or non-problematic gamers (He et al., 2019)/gamblers (Ulrich & Hewig, 2018) were also selected as controls in other studies.

Only male participants were enrolled in ten out of 24 studies. Study sample sizes ranged from 21 to 79 participants; however, group sizes ranged from 10 (Oberg et al., 2011) to 40 (Kim et al., 2021) participants. Average age of IGD participants across included studies was 23.6 (SD = 2.4), and of PG participants it was 29.8 (SD = 5.1).

In 17 studies, subjects' assignment to IGD and PG groups was based both on structured interviews and self-reports, while in the remaining studies only self-reports were used. The summary of inclusion criteria into disorder group and instruments used to assess the symptoms' severity is presented in Supplementary material, Table S4. To note, 19 of the included studies assessed intelligence and/or most common comorbidities, such as depression, anxiety, and impulsivity. However, five studies did not provide any information on additional (neuro)psychological assessment.

Only few authors provided details on the type of activity in which participants were problematically enrolled: participants in the study by Littel et al. (Littel et al., 2012) considered themselves as frequent World of Warcraft players, classified as multiplayer online role-playing game (Obst et al., 2018). S.N.Kim et al. (Kim et al., 2018) used cues in the task accordingly to the games participants were involved (League of Legend, FIFA, Sudden Attack). Participants in the study by Miedl et al. (Miedl et al., 2014) were slot-machine gamblers, while Wölfling et al. (Wolfling et al., 2011) described problematic group in detail with slot machine gambling being the most favored kind of gambling, followed by roulette, card games, sport betting, and others. Remaining studies included in the review investigated gaming and gambling as a homogenous activity, i.e. without further specification.

Experimental Paradigms

An auditory oddball paradigm was used in three IGD studies (Park et al., 2016, 2017; Park et al., 2017), while a Go/NoGo protocol was applied in other five studies, four focusing on

Table 3 Overview of the main aims and methodological characteristics of the studies included in this review

#	Authors	Main aim of the study	Participants (N = total participants number, gender, age [$M \pm SD$])	Experimental task	Task description	Stimuli	ERPs measured
1	Torres et al., 2013a)	To compare the differences between PG, CDI and HC	$N = 64$, M/F 21 PG (19/2) [31.43 ± 5.92] 20 CDI (20/0) [34.75 ± 6.51] 23 HC (21/2) [30.13 ± 8.63]	Go/NoGo	Two phases: 1. Pre-switch phase, 100 trials. A button press on Go trials, no response on NoGo trials 2. Post-switch phase, 100 trials. A button press on NoGo trials, no response on Go trials	Go trials: a letter (80%); NoGo trials: a different letter (20%) 200 stimuli in total	N2
2	Torres et al., 2013b)	To compare the EEG response to feedback in PG vs CDI vs HC	$N = 64$, M/F 21 PG (19/2) [31.43 ± 5.92] 20 CDI (20/0) [34.75 ± 6.51] 23 HC (21/2) [30.13 ± 8.63]	Probabilistic reversal learning task	Instruction to choose the correct stimuli	2 squares in different colored lines in each trial 4 phases of 40 trials each, colors corresponding to the correct and wrong choices shifted after every phase 4 outcomes: rewarded correct selection, penalized wrong selection, false negative feedback by selecting the correct stimuli, false positive feedback by selecting the wrong stimuli	FRN P3

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
3	Kim et al., 2017)	To compare response inhibition in IGD vs OCD	*N* = 77, M/F 27 IGD (24/3) [26.5 ± 6.1] 24 OCD (19/5) [25.0 ± 5.7] 26 HC (18/8) [24.7 ± 4.7]	Go/NoGo task	A button press on Go trials, no response on NoGo trials	Go trials: "S" stimuli (71.4%); NoGo trials: "O" stimuli (28.6%) 600 stimuli in total	Go-N2 NoGo-N2 Go-P3 NoGo-P3
4	Kim et al., 2018)	To compare cue-related reactivity in IGD vs OCD	*N* = 63, M/F 20 IGD (19/1) [24.5 ± 4.2] 20 OCD (15/5) [25.3 ± 6.1] 23 HC (15/8) [24.8 ± 4.7]	Cue-reactivity task	Instruction to look carefully at the slides	Gaming-relevant cues of popular games, OCD-related cues, and neutral pictures 252 stimuli (7 in each category presented 6 times)	LPP
5	Park et al., 2017)	To compare ERPs between IGD, AUD and HC and to explore relationships between ERPs and neurocognitive functioning in IGD and AUD	*N* = 77, M 26 IGD [22.69 ± 4.76] 22 AUD [28.36 ± 5.40] 29 HC [24.66 ± 3.80]	Auditory oddball task	A button press to targets	Standards: low-frequency tone (85%); Targets: high-frequency tone (15%) 300 stimuli in total	P300 N100
6	Duven et al., 2015)	To compare cue-reactivity and identify differences between PCG and CG	*N* = 27, M 14 PCG [24.29 ± 5.84] 13 CG [23.31 ± 3.01]	Semi-natural gaming design	Instruction to acquire as many tokens as possible within 20 min in a virtual 2D maze	20 hidden tokens	N100, N200 P200, P300

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
7	Heuer et al., 2021)	To examine the specific attentional processes contributing to bias towards computer-related stimuli in IGD and CG	*N* = 43, M/F 20 IGD (17/3) [24.5 ± 3.2] 23 CG (21/2) [24.2 ± 3.2]	Visual search task	Report the orientation of a target presented among non-target objects	Photographs of objects: computer-related, sports, cars Target: addiction-relevant (computer) or neutral (sports) Distractor-absent trials (1/3): target presented among 7 neutral objects (cars). Distractor-present trials (2/3): one of the objects from a different object category 1080 trials	NT SPCN *PD (did not emerged in the task)*
8	Thalemann et al., 2007)	To compare the processing of gaming-relevant stimuli in ECP vs CG	*N* = 30, M 15 ECP [28.75 ± 6.11] 15 CG [25.73 ± 8.14]	Cue-reactivity paradigm	Carefully watch presented addiction-relevant and addiction-irrelevant cues	Gaming-relevant cues of popular games; Gaming-irrelevant cues of neutral, positive, negative, and alcohol-related material 10 blocks of 5 stimuli	LPC

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
9	Miedl et al., 2014)	To compare risk assessment and reward processing in PG vs OG	*N* = 24, M 12 PG [33.8 ± 7.8] 12 OG [35.8 ± 9.5]	Experimental Blackjack task	Official blackjack rules: instruction to hit until total points of 17 or higher by taking another card or choosing to stand	50 low-risk trials with 12 or 13 points with 34% probability of losing while drawing a card; 50 high-risk trials with 15 or 16 points with 54% probability of losing while drawing a card over all high-risk trials. Losses for 50% of the high-risk and 50% of the Low-risk trials	Mean amplitude values of ERPs: (reward processing 100–150 ms and 390–440 ms; risk-assessment 380–420 ms and 600–800 ms post-stimulus onset)
10	He et al., 2019)	To examine the automatic processing of IGD in regard to realistic and cartoon faces	*N* = 30, M 15 IGD [20.97 ± 1.65] 15 non-IGD [21.02 ± 1.70]	Reversed deviant standard oddball paradigm	Instruction to look carefully at the fixation point "+" and press the key when "+" becomes larger or smaller	Standards: 15 realistic greyscale faces; Deviants: 15 greyscale cartoon faces of the Internet game "Strike of Kings" 2 blocks, 480 trails each. In block 2 stimuli exchanged vice versa. Probability of presentation 80% to 20%	P100 N170 P200 MMN

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
11	Ulrich & Hewig, 2018)	To compare the processing of near outcomes and outcome sequences in PG vs nonPG	*N* = 40, M/F 20 PG (18/2) [25.70 ± 5.72] 20 nonPG (18/2) [25.10 ± 5.78]	1. Wheel of fortune paradigm 2. Coin toss paradigm	Two tasks: 1. Wheel of fortune: instruction to bet on one of two colors in the wheel and try to stop the wheel on the respective color 2. Coin toss: instruction to bet on the outcome of the toss of a coin	1) Wheel of fortune. Outcomes: full wins, narrow wins, full misses, near misses. Every outcome occurred 32 times, 128 trials total 2) Coin toss. The frontside or the backside of a coin as the outcome, 8 three-outcome sequences occurred 30 times 249 trials total, 50% wins, 50% losses	P300 P2 N2 FRN (P2-N2 difference)
12	Oberg et al., 2011)	To compare the effects of reward feedback in PG and HC	*N* = 21, M 11PG [23] 10 HC [22]	Computerized version of the Iowa Gambling Task	Instruction to choose 'Bet Low' or 'Bet High'	The pseudorandom win/loss sequence for either small or large bet (randomized within runs of 20 trials), 4 blocks of 100 trials Win/loss probability of 60%/40% for the small bet; Win/loss probability of 40%/60% for the large bet	FRN P300

Table 3 (continued)

#	Authors	Main aim of the study	Participants (N = total participants number, gender, age [$M \pm SD$])	Experimental task	Task description	Stimuli	ERPs measured
13	Kim et al., 2021)	To investigate attentional bias toward game-related cues in IGD compared to HC	$N = 79$, M/F 40 IGD (36/4) [25.28 ± 5.56] 39 HC (29/10) [25.13 ± 3.25]	Cue-reactivity task	Look at the slides	Four categories of stimuli: in-game screen captures of 3 popular games and neutral pictures Each category of 7 different pictures (repeated 6 times)	LPP
14	Littel et al., 2012)	To compare error processing and response inhibition in EG vs HC	$N = 52$, M/F 25 EG (23/2) [20.52 ± 2.95] 27 HC (10/17) [21.42 ± 2.59]	Go/NoGo task	A button press on Go trials, no response on NoGo trials	Go trials: letters appearing sequentially on the screen (e.g., A B C D, 88.4%); NoGo trials: repetitions of the previously presented letters (e.g., A B C C, 11.6%) 4 blocks, 710 stimuli in total	ERN Pe NoGo-N2 NoGo-P3

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
15	Wolfling et al., 2011)	To compare the processing of gambling-relevant and–irrelevant stimuli in PG vs HC	*N* = 30, M/F 15 PG (12/3) [34.93 ± 9.77] 15 HC (13/2) [34.27 ± 5.34]	Cue-reactivity paradigm	Instruction to look carefully at the slides	Gambling-relevant cues; Gambling-irrelevant cues of neutral, positive, negative, and alcohol-related material 6 blocks of 25 stimuli (5 in each category presented 5 times)	LPP
16	Park et al., 2016)	To compare P300 in IGD and HC To examine the relationship of P300 to the severity of IGD symptoms	*N* = 49, M/F 26 IGD (20/6) [23.04 ± 4.15] 23 HC (20/3) [25.04 ± 4.29]	Auditory oddball task	A button press to targets	Standards: low-frequency tone (85%); Targets: high-frequency tone (15%) 300 stimuli in total	P300 correct responses to deviant tones
17	Park et al., 2017)	To determine markers associated with symptom changes and related to the treatment response	*N* = 47, M 18 IGD [22.61 ± 5.10] 29 HC [24.66 ± 3.80]	Auditory oddball task	A button press to targets	Standards: low-frequency tone (85%); Targets: high-frequency tone (15%) 300 stimuli in total	P300
18	Park et al., 2020)	To investigate the neurophysiological mechanisms of error processing in IGD compared to HC	*N* = 68, M/F 34 IGD (30/4) [25.9 ± 6.0] 34 HC (30/4) [25.5 ± 4.3]	Go/NoGo task	A button press on Go trials, no response on NoGo trials	Go trials: "S" stimuli (70.7%) NoGo trials: "O" stimuli (29.3%) 600 trials in total	ERN CRN Pe

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
19	Park et al., 2021)	To investigate the neurophysiological mechanisms of IGD	*N* = 64, M/F 33 IGD (31/2) [25.00 ± 5.14] 31 HC (26/5) [25.00 ± 3.17]	Go/NoGo task	A button press on Go trials, no response on NoGo trials	Go trials: "S" stimuli (70.7%) NoGo trials: "O" stimuli (29.3%) 600 trials in total	Go-N2 NoGo-N2 Go-P3 NoGo-P3
20	Fathi et al., 2022)	To evaluate the proactive and reactive inhibitory controls in VGA and HC	*N* = 60, M 30 VGA [20.39 ± 3.03] 30 HC [19.91 ± 1.94]	Selective Stop-Signal task	On Go trials react by pressing two buttons at the same time On Stop trials suppress the hand to the side of Stop stimuli	Go trials (60%): Reactive condition—noninformative cue, Proactive condition – informative arrow pointing to the left or right Stop trials (40%): red circle at the left or right location 700 trials: 350 reactive, 350 proactive	P3-cue Go-P3 Stop-P3 Stop-N2

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
21	Peng et al., 2017)	To compare the process of facial expressions in IGD vs HC	*N* = 32. M/F 16 IGD (13/3) [20.75 ± 0.36] 16 HC (12/4) [20.25 ± 0.4]	A backward masking task	Instruction to discriminate the target faces presented and followed by a scrambled face as a mask	Standards: 80 faces with neutral expressions; Targets: 80 faces with emotional (happy and sad) expressions 2 blocks, each of 160 trials. Happy block: 20 happy and 20 neutral faces presented 4 times. Sad block: 20 sad and 20 neutral faces presented 4 times	N170
22	Hewig et al., 2010)	To examine the neurophysiologic basis of PG	*N* = 43, M 21 PG [23.00 ± 3.2] 22 HC [23.54 ± 4.5]	Computerized version of Blackjack task	Instruction to get 21 points by betting a small or large stake and choosing to accept or reject the faced down card	Card set composed of cards with the point value of 2, 3, 4, 7, 8, 9, 10, and 11. Starting value varying between 11 and 21 880 single game trials	P300

Table 3 (continued)

#	Authors	Main aim of the study	Participants (*N* = total participants number, gender, age [*M* ± *SD*])	Experimental task	Task description	Stimuli	ERPs measured
23	Lole et al., 2015)	To compare incentive value processing and whether these able to differentiate the responses of PG and HC	*N* = 36, M/F 16 PG (11/5) [34.80 ± 16.79] 20 HC (9/11) [28.75 ± 11.19]	A simulated electronic gaming machines (EGM) task	Instruction to choose 'Bet Low' or 'Bet High'	Win outcomes (15%): Large Win (4 identical symbols) or Small Win (3 identical symbols in sequence); Loss outcomes (70%): Near-Win (different symbol between 2 or 3 same symbols) or Losses (neither a win nor near-win) Total of 8 different symbols appearing at random in a displayed row of 4 columns, 450 trials	P300 [P3b] FRR: FRN and FRP N100
24	Raiha et al., 2020)	To examine the reward processing systems in IGD vs HCs	*N* = 74. M 35 IGD [22.06 ± 3.65] 39 HC [21.95 ± 3.47]	The simple gambling task	Instruction to choose 'Low Risk' or 'High Risk'	Two choices: "9" for low risk, "99" for high risk 1 practice block of 10 trials, 6 main blocks of 80 trials	FRN P300 SPN

AUD – Alcohol Use Disorder, CDI – Cocaine Dependent Individuals, CG – Casual Computer Game Players, CRN – Correct Response Negativity, ECP – Excessive Computer Game Players, EG – Excessive Gamers, ERN –Error-Related Negativity, F – Females, FRN – Feedback Related Negativity, FRP – Feedback Related Positivity, FRR – Feedback Related Response, HC – Healthy Controls, IGD – Internet Gaming Disorder, LPC – Late Positive Complex, LPP – Late Positive Potential, M – Males, M/F – Males/Females, MMN – Mismatch Negativity, NT – Target Negativity, OCD – Obsessive–Compulsive Disorder, OG – occasional gamblers, PCG – Pathological Video Game Players, PD – Distractor Positivity, Pe – Error Positivity, PG – Problem Gamblers, SPCN – Sustained Posterior Contralateral Negativity, SPN—Stimulus-Preceding Negativity

IGD (Kim et al., 2017; Littel et al., 2012; Park et al., 2021; Park et al., 2020), and one on PG (Torres et al., 2013a). The Selective Stop-Signal task was used in one IGD study by Fathi et al. (Fathi et al., 2022). Additionally, two IGD studies evaluated processing of facial stimuli: Peng et al. (Peng et al., 2017) employed the Backward Masking task, using facial expressions of emotion, whereas He et al. (He et al., 2019) implemented a Visual Reversed Deviant-Standard Oddball Paradigm using realistic and cartoon images of faces. A cue-reactivity paradigm aiming at processing of gaming/gambling-relevant cues was employed in three IGD (Kim et al., 2018; Kim et al., 2021; Thalemann et al., 2007) and one PG study (Wolfling et al., 2011), while one study (Heuer et al., 2021) assessed bias towards computer-related stimuli in IGD by using a Visual Search task. Only one IGD study elaborated semi-natural 2D gaming design (Duven et al., 2015). In contrast, various betting tasks were used in five PG studies: an experimental version of the Blackjack task (Hewig et al., 2010; Miedl et al., 2014); the Simulated Electronic Gaming Machine task (Lole et al., 2015); the Iowa Gambling Task (Oberg et al., 2011); the wheel of Fortune; and the Coin Toss (Ulrich & Hewig, 2018). Torres, Catena, Cándido et al. (Torres et al., 2013b) studied responses to feedback using the Probabilistic Reversal Learning task in a PG group. Only one study used a simple gambling task for IGD investigation (Raiha et al., 2020). A description of the tasks and stimuli used in the studies is provided in Table 3.

ERP Components

Detailed summary of the ERP components assessed in the included studies are provided in Table 3 and Table 4.

The P300 was evaluated in seven studies and measured basically along the fronto-centro-parietal line. P300 subcomponents—P3a and P3b – were measured in two studies. Moreover, one study (Hewig et al., 2010) measured ERPs at around 300 ms in frontocentral sites, and other (Miedl et al., 2014) measured positive waves with a peak latency within the 380–420 ms time window in frontal, central, parietal, and temporal sites, but it is not clear whether these components could be classified as P3/P300. Feedback-related responses (FRR), namely feedback-related negativity (FRN), and feedback-related positivity (FRP) were measured in five studies, mainly at frontocentral electrodes. Four papers investigated the NoGo-N2 components, mostly at fronto-centro-parietal locations, plus one study investigated the similar Stop-N2 component (Fathi et al., 2022). The Late Positive Potential (LPP), N100, and NoGo-P3 were measured in three studies, and the similar Stop-P3 was assessed in one study. The N170, P200, Error-related negativity (ERN), Error-related positivity (Pe), and Go-P3 were assessed twice. All the following components were measured only once: P100, N200, Go-N2, P3-Cue, Late Positive Complex (LPC), Mismatch negativity (MMN), Correct Response Negativity (CRN), Sustained Posterior Contralateral Negativity (SPCN), Stimulus-Preceding Negativity (SPN), and Target Negativity (NT). Few studies (Hewig et al., 2010; Miedl et al., 2014) presented components by naming them according to the latency: 100-150 ms, 390-440 ms, 380–420 ms, 600-800 ms, 300 ms post-stimulus components.

To illustrate the heterogeneity of experimental protocols that were implemented in the reviewed studies, the extracted results are grouped into domains that were targeted, namely Reward Processes and Risk Assessment, Cue-reactivity, and General Information processing.

Table 4 An overview of ERP components used in studies included in the review

Authors	ERP measured	Latency windows and electrodes	Process evaluated (according to the authors)
Raiha et al., 2020)	SPN	– 200 to 0 ms (before feedback) at C3, C5, FC3, FC5, C4, C6, FC4, FC6	reward expectation
Park et al., 2020)	CRN	0–110 ms at Fz, FCz *(on correct trials)*	-
He et al., 2019)	P100	90 to 150 ms at PO5/PO6	processing of early automatic perception
Park et al., 2017)	N100	80-180 ms at Fz, FCz	initial sensory or attentional selection process
Duven et al., 2015)	N100	100–180 ms at F3, C3, P3, Fz, Cz, Pz, F4, C4, P4	processing of stimuli by multimodal presentation
Lole et al., 2015)	N100	142 ms at Fz	assess differences how different outcomes processed between the groups
He et al., 2019)	N170	150–210 ms at PO5/PO6	face-specific processing
Peng et al., 2017)	N170	150–230 ms P8, PO8	unconscious emotional facial perception in early face processing
He et al., 2019)	P200	210 to 270 ms at PO5/PO6	information processing between the perception and the recognition
Duven et al., 2015)	P200	150–250 ms at F3, C3, P3, Fz, Cz, Pz, F4, C4, P4	-
Oberg et al., 2011)	Early FRN	largest differences between wins and loss waveforms 176-196 ms and 236 – 256 ms respectively at FCz	valence processing
Ulrich & Hewig, 2018)	FRN	P2-N2 difference. Wheel of fortune: P2 peak 175–275 ms, N2 peak 275-450 ms. Coin Toss: P2 peak 150–250 ms; N2 peak 200–350 ms at FCz (P2-N2 difference)	performance monitoring – reward prediction errors
Torres et al., 2013b)	FRN	difference between average amplitude in the 220–350 ms post-feedback and positive peak in the 150–220 ms interval at Fz, FCz	unexpected negative outcomes feedback evoked activity
Raiha et al., 2020)	FRN	250–350 ms after the feedback onset at FCz, Fz, Cz	outcome evaluation
Lole et al., 2015)	FRR:FRN,FRP	250–350 ms at F3, Fz, F4, P3, Pz, P4	incentive value processing: FRN elicited by loss, FRP elicited by win outcome
Duven et al., 2015)	N200	180 – 300 ms at F3, C3, P3, Fz, Cz, Pz, F4, C4, P4	-
Kim et al., 2017)	NoGo-N2	130 – 280 ms at F1, Fz, F2, C1, Cz, C2	early stage of inhibitory control/conflict monitoring
Littel et al., 2012)	NoGo-N2	220 – 320 ms at Fz, FCz, Cz, CPz, Fz, PO3, PO4, Pz, P3, P4, CP5, CP6	inhibition
Torres et al., 2013a)	NoGo-N2	difference between the most positive peak in 160–220 ms and most negative peak in 240–300 ms time window at Fz, FCz, Cz	inhibition – related cognitive activity
Park et al., 2021)	NoGo-N2	150–300 ms at Fz, FCz	response inhibition
Park et al., 2021)	Go-N2	150–300 ms at Fz, FCz	response inhibition and cognitive processes
Fathi et al., 2022)	Stop-N2	200 – 350 ms at Fz, F3, F4	early stages of inhibition

Table 4 (continued)

Authors	ERP measured	Latency windows and electrodes	Process evaluated (according to the authors)
Heuer et al., 2021)	NT	200–300 ms at PO3/4, PO7/8	facilitation of initial deployment of attention towards relevant information
Heuer et al., 2021)	SPCN	300–500 ms at PO3/4, PO7/8	continued attentional processing
Park et al., 2020)	Pe	145–435 ms at Cz, CPz, Pz	conscious recognition and evaluation of the error
Littel et al., 2012)	Pe	200–400 ms at Pz, FCz Cz, CPz	conscious recognition of the error/ motivational significance to the error
Park et al., 2016)	P300	248–500 ms at FCz, Cz, CPz, Pz	auditory information processing and cognitive function
Park et al., 2017)	P300	248–500 ms at Cz, CPz, Pz	attention allocation and working memory capacity
Park et al., 2017)	P300	248–500 ms at CPz, Pz	attention allocation and working memory capacity
Duven et al., 2015)	P300	200–600 ms at F3, C3, P3, Fz, Cz, Pz, F4, C4, P4	attention and outcome evaluation
Oberg et al., 2011)	P300	310–350 ms at Cz	response to reward signals
Ulrich & Hewig, 2018)	P300	250–600 ms (coin toss) and 300–650 ms (wheel of fortune) at Pz	processing of motivationally salient stimuli
Raiha et al., 2020)	P300	350–450 ms (after the feedback) at CPz, Pz	attentional control
Kim et al., 2017)	NoGo-P3	250–450 ms at C1, Cz, C2, P1, Pz, P2	later stage of inhibition process in cognitive and motor domains
Littel et al., 2012)	NoGo-P3	320–500 ms Pz, FCz, Cz, CPz	reset or closure of a preceding inhibition process
Park et al., 2021)	NoGo-P3	250–500 ms at Cz, CPz, Pz	-
Park et al., 2021)	Go-P3	250–500 ms at Cz, CPz, Pz	subsequent processes of response inhibition (stimulus evaluation, attentional recourses allocation)
Lole et al., 2015)	P3b	250–600 ms at F3, Fz, F4, P3, Pz, P4	
Torres et al., 2013b)	P3	P3 analyses on a score computed as the average amplitude for the last 50 ms of each segment referred to the average amplitude during the immediately preceding 100 ms time window at Fz, FCz, Pz	incentive value processing
Fathi et al., 2022)	P3-cue		measured to test if P3 can affect FRN
Fathi et al., 2022)	Go-P3		attentional resources allocation to targets, stimulus evaluation, correct response activation
Fathi et al., 2022)	Stop-P3		
		300–550 ms at Cz, C3, C4	attention, information update, response selection
		280–500 ms at Cz, C3, C4	withholding a prepotent motor response
		280–500 ms at Cz, C3, C4	
He et al., 2019)	MMN	average amplitudes measured in 300–400 and 400–500 ms ranges at PO5/PO6	automatic detection and analysis to changes in stimulus features

Table 4 (continued)

Authors	ERP measured	Latency windows and electrodes	Process evaluated (according to the authors)
Thalemann et al., 2007)	LPC	350–750 ms at F3, C3, P3, Fz, Cz, Pz, F4, C4, P4	differentiates affective and emotion-irrelevant cues
Kim et al., 2021)	LPP	mean values of amplitudes 400–700 ms at CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, P4	represent attentional bias evoked by emotionally salient stimuli
Kim et al., 2018)	LPP		represent motivated attention to emotionally salient stimuli
Wolfling et al., 2011)	LPP	mean values of amplitudes 350–750 ms at CP1, CPz, CP2, P1, Pz, P2 average activity 450–740 ms at F3, C3, P3, Fz, Cz, Pz, F4, C4, P4	measurement for attention enhancement towards stimuli
Hewig et al., 2010)	Unnamed ERPs	270–320 ms at FCz	neural response to unexpected rewards; frontocentral distribution: not classic parietal P3 or P300
Miedl et al., 2014)		100–150 ms at F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8	reward processing—attentional processing
Miedl et al., 2014)		390–440 ms at F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8	reward processing—attentional processing
Miedl et al., 2014)		380–420 ms at F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8	risk assessment—cognitive processing of motivationally relevant wins
		600–800 ms at F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8	risk assessment—cognitive processing of motivationally relevant wins
Park et al., 2020)	ERN	0–110 ms at Fz, FCz	initial, unconscious error detection
Littel et al., 2012)	ERN	0–75 ms at Fz, FCz, Cz, CPz	fast and automatic initial error detection

CRN – Correct Response Negativity, ERN – Error-related Negativity, FRN – Feedback Related Negativity, FRP– Feedback Related Positivity, FRR – Feedback Related Response, LPC – Late Positive Complex, LPP—Late Positive Potential, MMN – Mismatch Negativity, NT – Target Negativity, PD – Distractor Positivity, Pe – Error Positivity, SPCN – Sustained Posterior Contralateral

Reward Processing/Risk Assessment

Reaction to reward was studied in seven out of 24 studies. Five of those (Hewig et al., 2010; Lole et al., 2015; Miedl et al., 2014; Oberg et al., 2011; Ulrich & Hewig, 2018) investigated reward processing in gambling condition, and only two in IGD (Duven et al., 2015; Raiha et al., 2020).

Considering IGD, Duven et al. (Duven et al., 2015) utilized a semi-natural gaming design (2D Computer Game) and aimed to identify whether the response to the reward would be characterized by enhanced motivational attention or by reduced sensitivity. The N100, N200, P200, and P300 components were measured with the main focus on P300 (as a reflection of attention and outcome evaluation) and N100 (reflecting multimodal stimuli processing). To investigate the reward processing systems in IGD, Raiha et al. (Raiha et al., 2020) employed a simple gambling task to measure stimulus-preceding negativity (SPN), feedback-related negativity (FRN), and P300, reflecting reward expectation, outcome evaluation, and attentional control, respectively. A Delay Discounting task was also performed during the study, but ERPs were not measured.

More versatile approaches were used in the research on gambling. Hewig et al. (Hewig et al., 2010) used a computerized version of the Blackjack to investigate the positive potential with a latency of 300 ms after card presentation as a component that is considered to reflect the response to reward. Authors aimed to explore whether persistence to gamble, despite negative consequences in problematic gamblers, is attributed to the insensitivity to punishment or hypersensitivity to reward. A Blackjack scenario in a quasi-realistic game design was employed by Miedl et al. (Miedl et al., 2014). These authors expected that early and later time windows of ERPs in response to reward processing and risk assessment would be modulated differently between Problem Gamblers (PG) and Occasional Gamblers (OG). A game similar to the Iowa Gambling Task (IGT (Bechara et al., 1994)) was used by Oberg et al. (Oberg et al., 2011) to investigate the effects on reward processing. Visual feedback (indicating win or loss) from high- and low-risk bet conditions were analyzed to evaluate reward feedback processing. The P300 as a component reflecting risk, the FRN reflecting valence processing, and the early-FRN indicating response sensitivity to reward. A simulated Electronic Gaming Machine (EGM) task, imitating the ones commonly used in gambling machines, was developed by Lole et al. (Lole et al., 2015). The P3b component was analyzed as reflecting incentive value processing and FRR (FRN and FRP) were extracted to analyze brain responses to feedback. Finally, to explore the processing of near outcomes (near wins and losses) and outcome sequences, Ulrich and Hewig (Ulrich & Hewig, 2018) employed two paradigms: the Wheel of Fortune and the Coin Toss. During both tasks, P300 amplitudes (as reflecting perception of the outcomes) and FRN (linked to reward prediction errors and indicating evaluation of the outcome) were measured.

Cue-Reactivity

Four studies in IGD/PG employed cue-reactivity tasks where relevant and irrelevant cues to problematic behavior were presented. Kim and colleagues (Kim et al., 2021), as well as Thalemann et al. (Thalemann et al., 2007) hypothesized that excessive computer game players would show stronger reactivity toward computer game-relevant cues and measured Late Positive Complex (LPC), which is considered as a component modulated by intrinsic motivational relevance and differentiating affective from emotion-irrelevant cues. Kim et al. (Kim et al., 2018) aimed to examine the cue-related attentional bias

in IGD by looking at the Late Positive Potential (LPP), a component (similar to LPC) that reflects selective attention and motivational relevance to emotionally salient stimuli. Finally, gambling related cues were investigated by Wölfling et al. (Wolfling et al., 2011), who also used a cue-reactivity paradigm and employed the LPP component as a measure for attention enhancement toward stimuli.

Finally, a computerized Visual Search Task with addiction-related and neutral stimuli was employed by Heuer et al. (Heuer et al., 2021) to investigate the attentional processes towards computer-related stimuli in IGD. Authors assessed Target Negativity (NT) and Sustained Posterior Contralateral Negativity (SPCN), both reflecting the attentional processing towards relevant information.

General Information Processing

Nine studies addressed response initiation- and inhibition-related processes in IGD/PG, and two investigated face processing in IGD. However, classical paradigms aiming at the evaluation of response selection, initiation, and inhibition were used mostly in IGD research.

Park et al. (Park et al., 2016, 2017; Park et al., 2017) sought to investigate whether continuous exposure to images and sounds during video game playing has an impact on cognitive functions. Authors employed a standard auditory oddball task to explore attention allocation and working memory in individuals with Internet Gaming disorder and measured the amplitudes of P300 components. Park et al. (Park et al., 2017) additionally investigated an auditory N100 component as an index of initial sensory or attentional selection processes.

Kim et al. (Kim et al., 2017) hypothesized that Internet Gaming Disorder and Obsessive–Compulsive Disorder (OCD) groups would show deficits in early and late stages of inhibitory control compared to controls as measured by Go-N2, NoGo-N2, Go-P3, and NoGo-P3 components. The same components during Go/No-Go task were also assessed by Park et al. (Park et al., 2021). Littel et al. (Littel et al., 2012) assessed the NoGo-N2 and NoGo-P3, together with Error-Related Negativity (ERN) as the component reflecting automatic error detection and Error-Related Positivity (Pe) as matching conscious error recognition. The latter two components (ERN and Pe) were also assessed by Park et al. (Park et al., 2020), employing a Go/No-Go task to investigate the neurophysiological mechanisms of error processing. Contrary to the previously described IGD studies and in order to avoid floor and ceiling effects, Torres, Catena, Megías et al. (Torres et al., 2013a) divided the Go/No-Go task into pre-switch and post-switch stages, where the assignation of the response from the Go stimuli switches to NoGo stimuli and measured Go/NoGo-N2 in PG.

To evaluate the different types of inhibitory control in video games-addicted subjects, Fathi et al. (Fathi et al., 2022) used selective Stop-Signal task suitable to evaluate both reactive and proactive inhibitions, and analyzed P3-Cue, P3-Go, P3-Stop, and N2-Stop components.

Two studies (He et al., 2019; Peng et al., 2017) investigated unconscious and automatic processing of face recognition in the IGD. In the study by Peng et at. (Peng et al., 2017), a visual backward masking paradigm with emotional faces (happy and sad) used as targets was employed, and the N170 at P8/O8 was measured as a component reflecting automatic early-stage processing of faces. He et al. (He et al., 2019) used a reversed deviant standard

oddball paradigm to investigate automatic face recognition and processing, expecting IGD participants to display an increased sensitivity to addiction-related clues (cartoon face) vs real faces. The P100, P200, N170, and MMN components at PO5/PO6 electrode sites were measured.

Only one study (Torres et al., 2013b) addressed feedback processing in PG using ERP. Authors used a Probabilistic Reversal Learning Task (response-outcome association learning task) to analyze the response to feedback during reversal learning in Problem Gamblers, Cocaine Dependent Individuals, and Healthy Control groups. The Feedback Related Negativity (FRN), as a component reflecting feedback-related cortical activity and response to feedback, was employed.

Discussion

The main purpose of this review was to systematically analyze the available literature on the application of EEG-based paradigms to investigate processes in the brain that are changed during or are associated with gaming/gambling problems or disorders. We pursued to systematize task-specific EEG protocols and illustrate the heterogeneity of implemented approaches in the included studies. Below we also overview methodological limitations of included studies, which make it difficult to draw robust conclusions on the use of ERPs as a tool to investigate the neurobiological basis of gaming and gambling disorders. However, it must be emphasized that the focus in this review is on the methodological options and issues of the reviewed studies and not their results.

The first and possibly the greatest constraint complicating the comparison among the studies comes from the fact that frequently no common cut-offs or diagnostic criteria for the conditions of interest are used, and a wide diversity in terminology exists, especially in gaming disorder. Indeed, criteria for diagnosing IGD varied considerably across the studies. To note, scores for relevant variables in IGD studies, such as gaming hours per week or average gaming hours per day overlapped with rates in excluded studies (Supplementary material, Table S3) where IGD condition was not classified as problematic. To illustrate, Peng et al. (Peng et al., 2017) and Park et al. (Park et al., 2016) described the IGD group as spending > 30 h a week on playing computer games, while a group of participants spending on average 43.4 h per week on gaming was defined as "high gamers" by Bailey et al. (Bailey et al., 2010) or "frequent gamers" by Stockdale (Stockdale et al., 2017). Importantly, terms such as "Excessive Gamers" (EG (Littel et al., 2012)), "Excessive Computer Game Players" (ECP (Thalemann et al., 2007)), "Pathological Video Game Players" (PCG (Duven et al., 2015)), or "Video Game-Addicted Subjects" (VGA (Fathi et al., 2022)) were used to describe the same condition as IGD. In 2013, the American Psychiatric Association already pointed out that research on gaming is less clear because the literature suffers from the lack of standard definitions. This review shows that the problem persists and needs to be addressed.

Another important aspect to consider is that different gaming and gambling types are quite heterogeneous, possibly based on different underlying preferences for gambling/gaming modalities, different individual motives for getting involved into these activities, and factors leading to addiction (López-Fernández et al., 2020). However, only few authors of the reviewed studies (Kim et al., 2018; Littel et al., 2012; Miedl et al., 2014; Wolfling et al., 2011) drew attention to the type of activity in which participant were enrolled. These might explain possible incongruent results in the literature and further complicates synthesis across the studies.

Additional factor possibly affecting consistency in observations is the comorbidity. Higher rates of mental health problems, such as depression, anxiety, ADHD, social phobia, and certain personality traits, such as impulsivity, aggression, or sensation-seeking, are constantly observed in individuals with excessive engagement in either gaming or gambling (Darvesh et al., 2020; Kessler et al., 2008; Richard et al., 2020; Shaffer & Korn, 2002). There is a growing evidence suggesting that individuals with gaming or gambling disorders may share similar neurobiological alterations with other mental disorders, such as attention deficit hyperactivity disorder (ADHD), anxiety, and depression. For example, gray-matter volume reductions or altered activity in the prefrontal cortex is also commonly observed in individuals with ADHD, anxiety, and depression (Arnsten, 2009; Bishop, 2009; Moon et al., 2014; Shad et al., 2012). These disorders also share similar features related to reward processing, such as changes in dopamine receptor availability (Berry et al., 2019; Peciña et al., 2017; Volkow et al., 2009). However, further research is needed to determine whether these similarities reflect shared underlying mechanisms and their implications for the development and treatment of gaming and gambling disorders, as well as other mental disorders. Although nineteen of the included studies reported additional psychological evaluation that could shed light on comorbidities, the remaining reports did not provide any information on such assessments. Lack of clear guidelines and standardized procedures in assessing/reporting comorbidities can cause the overestimation or underestimation of the effects of the investigated processes on gaming and gambling disorders. It should be pointed out that almost all reviewed works reported sample-related limitations: authors indicated small sample sizes (Park et al., 2016, 2017; Park et al., 2020; Park et al., 2017; Torres et al., 2013b), differences between groups regarding potential confounding variables (age, gender, IQ) (Kim et al., 2018; Littel et al., 2012; Park et al., 2016; Peng et al., 2017) or inclusion of male participants only (Duven et al., 2015; He et al., 2019; Hewig et al., 2010; Miedl et al., 2014; Oberg et al., 2011; Park et al., 2017; Park et al., 2017; Raiha et al., 2020; Thalemann et al., 2007) as limiting the observed results. It is noteworthy that even when participants of both sexes were included in the studies (14 studies out of 23), the ratio between male and female participants was unequal in most studies and the samples were mostly male-based: the percentage of female participants higher than 25% was observed only in two studies (Littel et al. (Littel et al., 2012) – 36,5%; Lole et al. (Lole et al., 2015) – 44,4%), while in six studies female participants were below 15% (Heuer et al. (Heuer et al., 2021) – 12,5%; Park et al. (Park et al., 2020) – 11,8%), Park et al. (Park et al., 2021) – 10,9%; Torres, Catena, Cándido et al. (Torres et al., 2013b) – 6.25%; Torres, Catena, Megías et al. (Torres et al., 2013a) – 6.25%; Ulrich & Hewig (Ulrich & Hewig, 2018) – 10%). This raises a concern of generalizability of the findings to the population at large.

Noticeably, similarities between substance use disorders and behavioral addictions are mentioned in almost every study investigating gaming or gambling behavior. Despite that, only few authors included other problematic groups (cocaine dependent individuals, alcohol use disorder group) for direct comparison in their research (Park et al., 2017; Torres et al., 2013a, 2013b). Another important aspect considering control groups is that most authors chose only healthy participants as a control, while a few included individuals engaged in gaming or gambling for recreational purposes. Selecting casual gamers/gamblers as a control group allows investigating the properties of excessive/problematic behavior instead of gaming/gambling per se.

The abovementioned limitations might explain inconsistent and even conflicting results in the existing literature, but such results are out of the scope of this methods review. The overview of methodological ERP-related aspects of the neurophysiological correlates of

problematic gaming and gambling behavior and reported functional meaning of such correlates is provided below to illustrate the heterogeneity in the field.

The influence of rewards, punishments, and previously experienced outcomes under similar conditions (Mazur, 2012) seem to be disrupted in addictions (Charney & Nestler, 2009), but studies on this domain are characterized by a large heterogeneity regarding the experimental tasks (e.g., Semi-natural Gaming Design, Blackjack, Iowa GT, Wheel of fortune, etc.), their implementation, and also interpretation of behavioral results. This heterogeneity extends to the EEG set-ups, electrode-sites where ERP are measured, and the functional meaning of ERP components. For example, all studies included in the reward processing and risk assessment domain investigated P300 or P300-like component. Changes in P300 amplitude are well described in addiction research: people with substance use disorders, such as smokers (Anokhin et al., 2000), cocaine (Moeller et al., 2004), or alcohol users (Liu et al., 2020), or those at risk of SUDs (Hesselbrock et al., 2001; Iacono et al., 2002) demonstrate alterations in P300 amplitude. In reviewed studies, the P300 was described as a component reflecting attention allocation to motivationally salient stimulus (Ulrich & Hewig, 2018), such as a response to positive outcomes (Duven et al., 2015; Lole et al., 2015; Oberg et al., 2011). However, only a handful of studies described P300 in this way. Lole et al. (Lole et al., 2015) looked at the P3b subcomponent linked to valence differences in the global P300 as a reflection of incentive value processing. As P300 is described as a positive wave peaking at around 300 – 400 ms following stimulus presentation (Patel & Azzam, 2005), study by Miedl et al. (Miedl et al., 2014) might also be relevant, as authors investigated reward and risk processing by mean amplitude values at the latencies of 390 – 440 and 380 – 420 poststimulus. However, the positive amplitude at 300 ms latency arising as a neural response to the unexpected rewards investigated by Hewig et al. (Hewig et al., 2010), according to the authors cannot be described as classic parietal P3 or P300 component due to the frontocentral distribution.

Increased reactivity to addiction-related cues is frequently shown in substance use disorders (Field et al., 2006; Perry et al., 2014). Attentional shift towards relevant stimuli is considered an important aspect to the development and maintenance of the addictive behavior (Field & Cox, 2008) and research suggests that drug cues are processed similarly to emotional stimuli (Minnix et al., 2013). Surprisingly, only four studies employed specific cue-reactivity tasks in order to investigate the attentional shift towards gaming (Kim et al., 2018; Kim et al., 2021; Thalemann et al., 2007) or gambling (Wolfling et al., 2011) stimuli. Specific Cue Reactivity might be the domain investigated with the most homogeneous methods, as highlighted in this review: participants in all studies addressing this domain were instructed to look carefully at disorder-relevant and disorder-irrelevant cues during EEG recordings. The Late Positive Complex (LPC) or Late Positive Potential (LPP) were employed as neurophysiological measures in all studies. These potentials are considered to increase in amplitude over central and parietal sites during the presentation of motivationally or emotionally relevant stimuli, reflecting an increased arousal (Minnix et al., 2013) and allocation of attention to such stimuli (Hajcak et al., 2009). Thus, all authors interpreted the results as representing increased attention towards relevant stimuli.

Attentional bias towards addiction-relevant stimuli in IGD was also assessed by employing a Visual Search task and analyzing three lateralized components not used in previous IGD studies, which are associated with facilitation of attentional processes – Target Negativity (NT), Sustained Posterior Contralateral Negativity (SPCN), and Distractor Positivity (PD); the latter did not emerge in the task (Heuer et al., 2021). While most of the cue-reactivity studies are designed to examine the bias to the addiction-relevant stimuli itself, here authors sought to investigate specific attentional processes in charge of impaired

disengagement of attention from disorder-related stimuli. Furthermore, unlike other studies using game-relevant cues of popular games as stimuli in the cue-reactivity tasks, authors employed computer-related stimuli instead, such as computer gear, to address the role of conditioning processes in IGD.

Addiction emerges as an imbalance in the information processing and integration among various brain circuits and functions (Campanella et al., 2014; Volkow et al., 2016). Given the increase in the everyday use of technology over recent decades, interdisciplinary scholars have considered its impact on human cognition (Johnson, 2006; Small et al., 2020), namely from the information processing perspective. However, a limited number of studies utilized ERP paradigms for this purpose: our review identified nine studies addressing general information processing. Again, even when a common experimental protocol such as the oddball or Go/No-Go is used, we still observe a great level of heterogeneity regarding the task implementation, EEG set-ups, electrode-sites where ERP components are measured, and the functional meaning of the measured ERP.

One of the most frequent characteristics defining individuals in gaming/gambling studies is impulsivity (Ioannidis et al., 2019; Ryu et al., 2018), which may be described as a deficit in response inhibition (Chen et al., 2021; Olmstead, 2006). The neurophysiological correlates of response inhibition and its relation to impulsivity in gaming/gambling were investigated using visual Go/No-Go tasks, but the above-mentioned heterogeneity problem still holds in this case. Both N2 and P3 NoGo components are associated with inhibitory processes (Pires et al., 2014). Alterations in NoGo-N2 are described consistently in SUDs or impulsive populations, while changes in NoGo-P3 are not as stable across studies (Littel et al., 2012). NoGo-N2 was investigated in all reviewed Go/No-Go experimental studies (except (Park et al., 2020)), while only M. Kim et al. (Kim et al., 2017), Littel et al. (Littel et al., 2012) and Park et al. (Park et al., 2021) explored NoGo-P3 as well. Considering measurement of the components, Littel et al. (Littel et al., 2012) described N2 and P3 amplitudes as average amplitudes in the provided time windows, M. Kim et al. (Kim et al., 2017) defined N2 as the most negative and P3 as the most positive peaks in the provided time windows and Torres, Catena, Megías et al. (Torres et al., 2013a) specified NoGo-N2 as the difference between the most positive and the most negative peaks in the provided time windows, although all authors described components as reflecting inhibition related cognitive processes.

Another well-established and commonly used task to investigate response inhibition is the Stop-Signal task (Beppi et al., 2020; Jahfari et al., 2010). Considering all EEG studies included in the review, only one employed the Stop-Signal task (Fathi et al., 2022). Authors assessed response inhibition as a heterogenous construct and evaluated proactive and reactive components of inhibition in IGD. Even though both NoGo-N2 and Stop-N2 are negative components showing similar frontal amplitude around 200–350 ms after the No-Go or stop-signal (SS) (Beppi et al., 2020; Johnstone et al., 2007), Go/No-Go and Stop-Signal tasks assess distinct processes – action restraint and action cancellation respectively. Direct comparison of these components could lead to contradictions (Hoyniak, 2017) and further research employing the Stop-Signal task is needed.

A different approach to the Go/No-Go task was taken by Park et al. (Park et al., 2020). Only incorrect responses to No-Go trials and components reflecting error processing – Error-Related Negativity (ERN), Error Positivity (Pe) and additionally Correct Response Negativity (CRN) – were investigated, while Littel et al. (Littel et al., 2012) investigated both error-processing (ERN, Pe) and response inhibition (NoGo-P3, NoGo-N2). ERN and Pe are considered as markers for behavior adaptation (Lutz et al., 2021) linked to performance monitoring of goal-directed behavior (Ullsperger et al., 2014), with ERN possibly predicting self-control (Overmeyer et al., 2021) and being suggested as a possible

biomarker for SUDs after widely explored in addiction research (Euser et al., 2013; Gorka et al., 2019; Marhe & Franken, 2014; Marhe et al., 2013; Riesel et al., 2019). The procedure of Go/No-Go task and ERP analysis were quite similar in both studies (Littel et al., 2012; Park et al., 2020), with both identifying differences in ERN amplitudes between IGD and control groups. Considering the different outcomes in regard of Pe, authors of the later study (Park et al., 2020) specified themselves the possible cause of such differences: participants in their study were recruited from a Medical Center as individuals seeking treatment due to the excessive gaming, while the group of excessive gamers in the study of Littel et al. (Littel et al., 2012) were students considering themselves as frequent World of Warcraft players, assigned to the problematic group based on the scores of Video Game Addiction Test (VAT). This also remains a valid reason for all other studies, as the severity of participants' engagement into problematic behavior is diverse between the studies.

Excessive gamers are often described as less engaging in social activities and having less or poorer social skills (Lemmens et al., 2011; Lo et al., 2005), which leads to the assumption that IGD individuals should demonstrate decreased sensitivity to social cues. This assumption has been tested through experiments focused on unconscious face recognition and processing, using oddball (He et al., 2019) and visual backward masking (Peng et al., 2017) tasks. The major limitations described above also apply to these studies. Moreover, even though low social involvement is often mentioned in IGD, studies on this domain lack ecological validity, as no additional assessments of social life or skills were performed in any of the studies.

Summing-up, various neuroimaging approaches have been used to investigate the neurobiological underpinnings in both gaming and gambling behaviors. The EEG technique, being cost effective and easily implemented, could be easily used for this purpose. Nevertheless, just a few studies employing EEG and ERPs were conducted previously (Benchebra et al., 2019; Choi et al., 2014; Fauth-Bühler & Mann, 2017; King et al., 2015; King et al., 2012; Mallorquí-Bagué et al., 2017; Sanders & Williams, 2019; Walther et al., 2012). In this systematic review we collected and systematized information on the task-specific EEG paradigms that were used to study brain activity in gaming and gambling disorders. Importantly, our review revealed that studies of gambling and gaming are characterized by a vast heterogeneity regarding the ERP experimental paradigms being used, and even when authors use similar paradigms, they often apply variable set-ups, investigate different brain potentials, and measure them in different ways, which may hinder the synthesis of the findings and delay robust evidence as to the neurophysiological basis of PG/IGD. Additionally, certain paradigms or ERPs were used only once, thus raising the question of reproducibility of the results. Besides these methodological shortcomings, this review suggests that gambling-related research is highly focused on the investigation of the reward-related processes, whereas gaming-related research is mostly focused on the altered aspects of more general information processing.

However, the described heterogeneity in methods can provide several insights and implications: (a) lack of clear guidelines and standardized procedures leads to having no recognizable measures capable to reliably discriminate or characterize the population susceptible to addictive behavior or being able to diagnose and monitor these disorders; (b) heterogeneity in methods indicates that different tools and instruments are being used to investigate the same research question which could lead to biases or limitations of reliability, validity or generalizability of the findings; (c) lack of consistency also makes it challenging to compare and synthesize the results of different studies, which highlights the importance of establishing guidelines or standardized protocols for conducting research in the field; (d) meta-analysis of the research findings could be a valuable approach to integrate the existing findings; however, careful consideration of the differences in the

experimental protocols and study samples provided in this review is required; (e) in order to establish methodological guidelines, the question of reproducibility should be addressed by attempting to replicate the findings using similar experimental paradigms, especially considering the tasks or ERPs measured only once – this could provide stronger evidence and help to identify any discrepancies or limitations in the original studies.

Considering the limitations discussed in this review, further research employing measures and experimental methods that could be compared and used across studies are necessary to shed light on the neurophysiological correlates of PG and IGD.

Conclusions

Lately, particular attention has been paid to the investigation of neurobiological mechanisms underlying problematic behavior disorders with a special focus on gambling and gaming. For most people high involvement in gaming or gambling does not necessarily mean problematic involvement; however, currently existing criteria for discrimination between problematic and non-problematic behavior receive criticism (Billieux et al., 2015; Dullur & Starcevic, 2018; Király et al., 2015). Electroencephalography (EEG) and Event-Related Potentials (ERPs) as considerably cheap and non-invasive technique, providing real-time measurement of brain activity (Bunge & Cognition, 2009) are broadly used in addiction-related research (Campanella et al., 2014; Houston & Schlienz, 2018). To our knowledge, no attempt was made so far to systematically overview the experimental paradigms and ERP components used in EEG research in the field of gaming and gambling. We aimed to review and systematize task-specific EEG protocols that are used to investigate the neurophysiological correlates of problematic gaming and gambling behavior, as well as the reported functional meaning of such correlates, to inform the selection of methods for further research in the field. To sum up, gambling-related research is highly focused on the investigation of the reward-related processes, whereas gaming-related research is mostly focused on the altered aspects of more general information processing. A vast heterogeneity regarding the ERP experimental paradigms being used, lack of clear guidelines and standardized procedures prevents identification of measures capable to reliably discriminate or characterize the population susceptible to addictive behavior or being able to diagnose and monitor these disorders.

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Authors and Affiliations

Dovile Simkute[1] · Artemisa R. Dores[2,3] · Fernando Barbosa[3] · Inga Griskova-Bulanova[1]

✉ Inga Griskova-Bulanova
inga.griskova-bulanova@gf.vu.lt; i.griskova@gmail.com

Dovile Simkute
dovile.simkute@gmc.vu.lt

Artemisa R. Dores
artemisa@ess.ipp.pt

Fernando Barbosa
fbarbosa@fpce.up.pt

[1] Life Sciences Center, Institute of Biosciences, Vilnius University, Sauletekio Ave. 7, 10257 Vilnius, Lithuania

[2] Escola Superior de Saúde, Politécnico Do Porto, Porto, Portugal

[3] Laboratory of Neuropsychophysiology, Faculty of Psychology and Education Sciences, University of Porto, Porto, Portugal