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Date of secondary publication: 09.09.2025

Version of Record (Published Version), Article

Persistent identifier: urn:nbn:de:bvb:473-irb-110327x

Primary publication

Antons, Stephanie; Müller, Silke M.; Neumann, Paul; u. a. (2023): Stimuli-Specific Inhibitory Control in Disorders Due to Addictive Behaviours : a Review of Current Evidence and Discussion of Methodological Challenges, in: Current Addiction Reports, Cham: Springer Science and Business Media LLC, Vol. 10, Nr. 4, pp. 749–769, doi: 10.1007/s40429-023-00517-z.

Current Addiction Reports (2023) 10:749–769
https://doi.org/10.1007/s40429-023-00517-z

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Stimuli-Specific Inhibitory Control in Disorders Due to Addictive Behaviours: a Review of Current Evidence and Discussion of Methodological Challenges

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Accepted: 29 August 2023 / Published online: 16 October 2023

Abstract

Purpose of Review This systematic review focuses on stimuli-specific inhibitory control as measured with variations of Go/No-Go, Stroop, and Stop-Signal tasks including addiction-related cues. We aimed to identify whether individuals with tendencies towards behavioural addictions show stimulus-specific reductions in inhibitory control as assumed by recent theoretical models.

Recent Findings The systematic literature search yielded 31 studies eligible for inclusion. Most studies focused on gaming disorder and problematic social networks use. Variants of the Go/No-Go task were most frequently used measures of inhibitory control. Findings on stimuli-specific reductions in inhibitory control are mixed. The studies differ considerably regarding used measures, sample characteristics, and study designs.

Summary The large methodological heterogeneity across studies makes it almost impossible to draw any clear conclusions. Study designs, task characteristics, stimuli, and diagnostic instruments should be more standardised and used more consistently. We recommend to recruit clinical samples for studying stimuli-specific inhibitory control in behavioural addictions.

Keywords Behavioural addictions · Inhibitory control · Cue-reactivity · Impulsivity · Gaming

Introduction

Within the ICD-11, a new category of non-substance-related addictive disorders has been introduced: disorders due to addictive behaviours [1]. Two specific types of addictive behaviours are categorised under this section: online/offline gambling disorder and online/offline gaming disorder. In addition, the ICD-11 includes an "other specified disorders due to addictive behaviours" category (6C5Y), in which clinically relevant syndromes could be classified such as pornography-use disorder, buying-shopping disorder, and social-networks-use disorder because they share similar mechanisms with addictive behaviours including diminished control over the specific behaviour [2–4], although the inclusion of these behaviours remains controversial [5].

The Interaction of Person-Affect-Cognition-Execution (I-PACE) model [6••, 7] summarises psychological and neurobiological mechanisms that contribute to the development and maintenance of addictive behaviours. The diminished control over the behaviour is assumed to be the result of predisposing factors (e.g. genetics, early childhood experiences, psychopathology, specific motives or values) in interaction with affective and cognitive mechanisms that accelerate over the course of the disorder. One central mechanism is the development of cue-reactivity and craving. Cue-reactivity is assumed to be the result of the reinforcing and associative learning processes in later stages of the disorder, by which individuals more often or more robustly respond physiologically, emotionally, and cognitively to addiction-related stimuli (i.e. individuals with gaming disorder symptoms tend to show physiological responses towards gaming-related cues

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[8, 9]). One affective and cognitive response towards addiction-related stimuli is craving, defined as the strong desire or urge to engage in the specific behaviour [9]. Addiction-related cues can trigger this experience of an urge to engage in the behaviour [10, 11]. In addition, more conscious processes of desire thinking can be triggered by these cues [11]. Individuals with tendencies towards an addictive behaviour do not necessarily have to show a general reduced inhibitory control. In some contexts, they may even show good inhibitory control abilities; however, when being confronted with addiction-related cues, these individuals may show specific reductions in inhibitory control, probably due to an interaction with cue-reactivity and/or craving [12, 13]. Within the I-PACE model [6••], this type of inhibitory control is called "stimuli-specific inhibitory control". It is assumed that stimuli-specific inhibitory control may increasingly diminish in later stages of the disorder and thereby to be crucially involved in the development of habitual behaviours in these later stages where individuals engage in the behaviour despite experiencing negative consequences [14–16].

Inhibitory control is typically measured with experimental paradigms in which a motor response should be inhibited. The Go/No-Go Task and Stop-Signal Task (SST) are the most commonly used paradigms to assess inhibitory control [17–19]. In the Go/No-Go Task, participants must make a button press in response to one specific stimuli or group of stimuli (go-signal) and should not respond to a different type of stimuli (no-go signal). During each trial, only one type of signal (go or no-go) is presented [19]. In the SST, the stop-signal is always presented after the go-signal with a short delay between the go- and stop-signal. Stop-signals occur only in a minority of trials (25–33%) whereby a prepotent response tendency is implicated. The non-measurable time needed to inhibit the go-response (stop-signal reaction time, SSRT) can be calculated based on a mathematical model called "horse-race-model" [20]. Therefore, within the SST individuals have to inhibit a previously initiated response ("action cancellation"), while in the Go/No-Go task, the action might be inhibited before the go-signal has been initiated ("action restraint") [21]. A high proportion of go-signals (e.g. 75%) in Go/No-Go tasks could also induce a prepotent response tendency so that a go-response could be initiated before the more seldomly no-go signal occurs. Measures of inhibitory control are the no-go errors (commission errors) in the Go/No-Go Task and the SSRT in the SST. In addition, poor inhibitory control might be grounded in very fast go-responses, which is why the go-reaction times (go RT) in both tasks are further indicators of problems with inhibitory control. Tasks that measure stimuli-specific inhibitory control are typically modifications that include addiction-related stimuli (e.g. pictures, words, auditory tones). These stimuli can be included as task-irrelevant distractors (e.g. in the background of the task) or could serve as go- or no-go/stop-signals. Another task that is sometimes used as inhibitory control task is the Stroop task [22]. This task probably measures another type of inhibitory control namely "interference control" [23]. In the classic Stroop task, participants must name colours of colour-words (the word is written in blue, individuals should answer "blue"). In such an incompatible condition where the colour does not correspond to the colour-word, individuals must inhibit the prepotent response action of reading the word instead of naming its colour. This task has also been modified to measure stimuli-specific inhibitory control most commonly by writing addiction-related words in colours that should be named. It is assumed that in comparison to neutral words, these addiction-related words might interfere more with the process of naming the colour of the word. Accordingly, the measure of reaction-time bias (RT-bias, difference between response times in addiction-related conditions and non-addiction-related conditions) can serve as indicator for interference inhibition and the go RT as indicator for the go response [24]. However, this task should be interpreted independently from the more classic measures of inhibitory control.

The stimuli-specific inhibitory control has been investigated in laboratory settings with tasks that measure inhibitory control by requiring participants to inhibit a dominant motor response (i.e. SST, Go/No-Go task, Stroop task [18]) and at the same time include addiction-related stimuli such as images or words related to the specific behaviour. In the following, we first provide a systematic review of the current evidence on stimuli-specific inhibitory control in the context of addictive behaviours. Second, we describe systematically the methodological differences between the studies available and discuss methodological challenges for future research.

Methods

We followed a systematic review approach. The literature search was performed on PubMed and Scopus database. Studies were included if (1) published between January 2000 and end of June 2023; (2) written in English or German or contain an English translation; (3) investigated stimuli-specific inhibitory control in the context of specific (potential) behavioural addictions (including gaming disorder, gambling disorder, compulsive sexual behaviour disorder, problematic pornography use, compulsive buying-shopping disorder, social-networks-use disorder, or excessive smartphone use); (4) stimuli-specific inhibitory control has been operationalised through one of three highly standardised and often used inhibitory control tasks: Go/No-Go task, the SST, or the Stroop task that had been modified by including stimuli (e.g. pictures, sounds, words, videos) related to the specific addictive behaviour. Studies could have used between groups designs (pathological vs. control), within-between group designs, or correlational designs (associations between addictive behaviour symptom severity and stimuli-specific inhibitory control measures).

The search string was determined by consensus of the authors and was based on three subsections, which were combined with an AND condition: (1) inhibitory control tasks (e.g. “stop-signal”, “go/no-go”, “stroop”); (2) disordered behaviour (e.g. “addict*”, “disorder*”, “problematic”); (3) specific behaviour (e.g. “Internet”, “gaming”, “cybersex”). The full search string can be found in the supplementary material.

First, we screened the results of the systematic search for all articles that used one of the three inhibitory control tasks in the context of behavioural addictions (based on title and abstract). In case of uncertainty, we used the full-text to validate if the article is eligible. Second, we validated if the tasks were stimuli-specific (included stimuli related to the addictive behaviour). Third, we used reviews identified during the search process to validate if all studies on inhibitory control were identified [25–29]. Fourth, reference lists of all identified articles on stimuli-specific inhibitory control were screened. The initial screening of all search results was carried out by PN (trained student with a bachelor’s degree) and independently by SA. Search and screening were under the supervision of SA and SSL. Studies that did not appear to be suitable based on title and abstract screening were removed. All remaining studies were screened by SA based on full-texts. Reasons for exclusions were as follows: (1) no or non-addiction-related task manipulation (e.g. stress induction); (2) no inhibitory control assessment; (3) no assessment of symptom severity of the behavioural addiction. With the procedure, 121 articles could be identified that applied one of the inhibitory control tasks in the context of behavioural addictions. Within other reviews on inhibitory control in behavioural addictions [25–29], 51 studies applying the three inhibitory control tasks (stimuli-specific and stimuli-unspecific/classic tasks) were identified. Within our search, we identified 89% of these studies that were also included in previous reviews (6 studies were not identified), and two of these studies were on stimuli-specific inhibitory control and relevant for the current review. In contrast to these previous reviews, our search revealed 70 additional studies with inhibitory control tasks in the context of behavioural addictions (see supplementary material for full list). The final selection of full-text studies eligible for inclusion was reviewed and approved by all authors. Figure 1 shows the flowchart of the methodological procedure.

For the narrative synthesis, information on specific type of behavioural addiction, sample characteristics, experimental design, including task and stimuli, and main results were extracted. For the quantitative synthesis, effect sizes were extracted (correlation coefficients, *r*) or calculated (based on means and standard deviations, Hedges’ *g*). We focused on the most common task measures (see supplementary material). If relevant measures were not reported, the authors of the respective studies were contacted to provide the specific measures.

Results

Study Characteristics

Overall, 31 studies could be identified that investigated stimuli-specific inhibitory control with a Go/No-Go task, Stroop task, or SST in the context of behavioural addictions (Fig. 1). An overview of the studies is presented in Table 1. A more detailed description of studies can be found in the supplementary material (Table S4). The majority of studies was conducted in Europe (n=16, UK, Germany, Italy, the Netherlands, Portugal, Luxembourg, Spain) or Asia (n=13, China, Taiwan, South Korea). One study was conducted in Australia and one in North America (USA). Most studies used a within-between participants design (n=22). Some studies used a continuous design reporting correlations or regression analyses (n=8).

Empirical Results on Inhibitory Control and Go-Responses

Overall, results appear to be mixed (Table 1). Most studies could not identify significant results regarding stimuli-specific inhibitory control in addictive behaviours (n=12). Some studies (n=8) show that addictive behaviours are more strongly associated with impaired inhibitory control, and in other studies, addictive behaviours were associated with better stimuli-specific inhibitory control (n=3). Similarly, some studies showed worsened inhibitory control in individuals with addictive behaviours when addiction-related stimuli were present compared to non-addiction-related stimuli (n=2), one other study found improved inhibitory control. For the go-response, most studies could not identify significant associations between addictive behaviours and the go-responses (n=18). Some studies found faster go-responses to be associated with addictive behaviours (n=2), whereas in other studies, slower go-responses were associated with addictive behaviour (n=4). Some studies found faster go-responses to addiction-related stimuli compared to non-addiction-related stimuli in individuals with addictive behaviours (n=4); no study found slower go-responses.

Samples

Most studies were conducted in the context of gaming (n=10) and social networks use (n=5). Only few studies

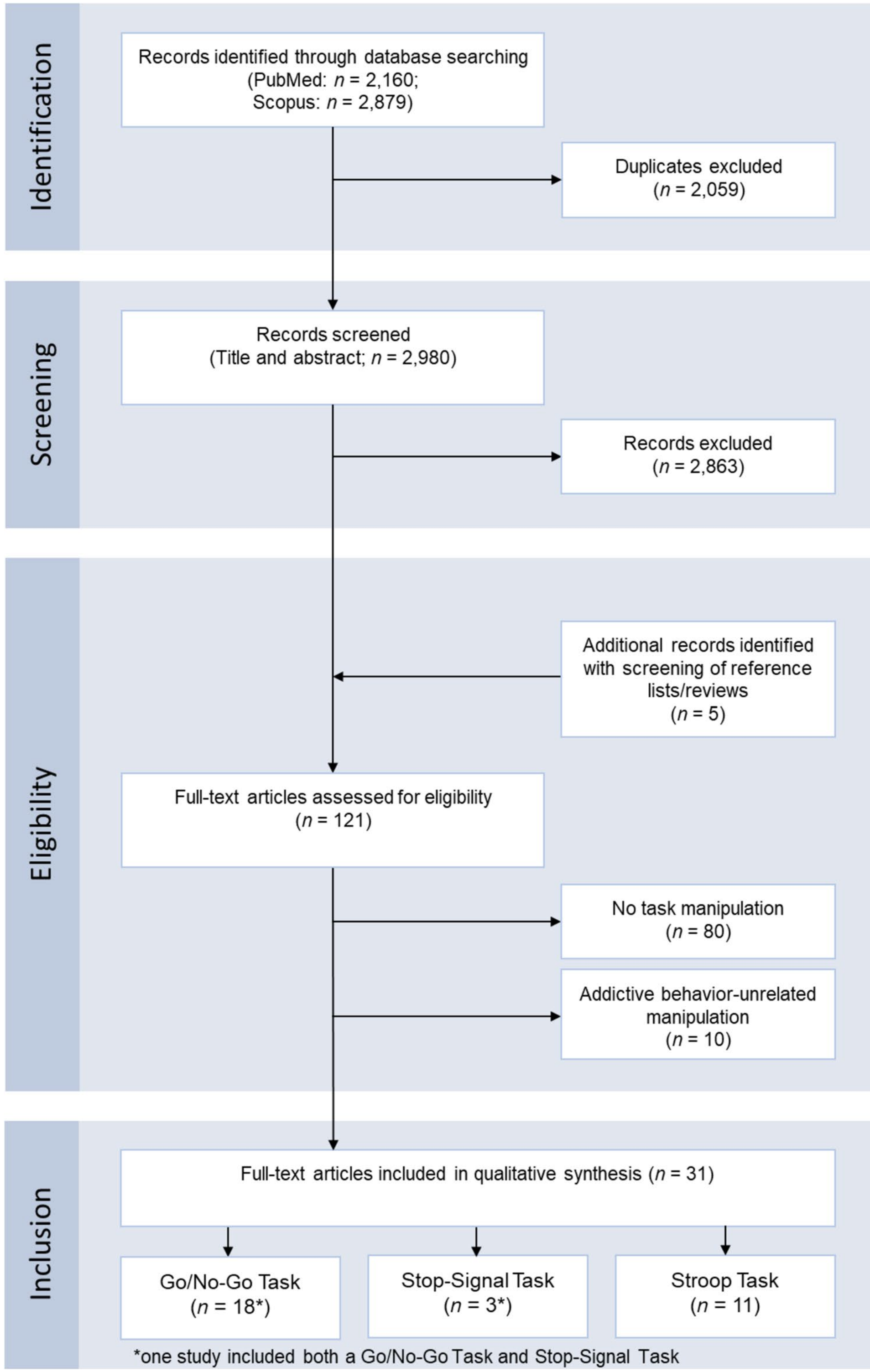

Fig. 1 Flowchart of the methodological procedure

focused on other specific addictive behaviours: sexual behaviour (*n*=3), pornography use (*n*=3), buying/shopping (*n*=4), gambling (*n*=2), or generalised use of the internet (*n*=3) or smartphones (*n*=2). Most studies recruited samples from the general community and from the university's context (non-clinical convenience samples). Only three studies indicated that they had recruited participants in a clinical context (clinical centres, outpatient groups) [45, 52, 53]. In addition, it is not always clear if all participants generally engage in the specific behaviour in the focus of the study. Accordingly, individuals might have participated in a study on a specific behavioural addiction although they might not

Table 1 Summary of studies and main results with focus on methodological characteristics

Reference	Sample					Task		Stimuli				Study procedure				Main results	
	Behaviour	Population	Screening instrument/group definition	Correction for comorbid disorders	Users/non-users	Task	% stop/no-go trials	Presentation of AR stimuli	Relevance of stimuli for task	Type of stimuli	Individualisation of stimuli	# tasks with AR-stimuli	Analysis	Lab/online	Add. methods	Inhibitory control (IC)	Go-response (GR)
Albery et al. [30], UK	SB	Non-clinical	SCS	No	All users	Stroop	NA	In blocks	Irrelevant	Words	No	One	Correlational	Lab	No	Higher AB worse IC, [r=.29]	-
Antons and Brand [31], Germany	PU	Non-clinical	sIATsex	No	All users	SST	20–33%	In blocks	Irrelevant	Pictures	Semi	One	Correlational	Lab	fMRI	Higher AB better IC, [r=−.52]	Non-sig.
Antons and Brand [32], Germany	PU	Non-clinical	sIATsex	No	All users	SST	20–33%	In blocks	Irrelevant	Pictures	Semi	One	Correlational	Lab	No	Non-sig.	Non-sig.
Balconi, Finocchiaro [33], Italy	IU	Non-clinical	IAT, extreme groups based on cut-off scores	Yes (exclusion criteria)	All users	Go/No-Go Task	20–33%	Randomised	Irrelevant	Pictures	No	One	Within-between	Lab	EEG	-	AB faster non-AB
Balconi et al. [34], Italy	IU	Non-clinical	IAT, cut-off score	Yes (exclusion criteria)	Unclear	Go/No-Go Task	20–33%	Randomised	Irrelevant	Pictures	No	One	Within-between	Lab	EEG	AB better non-AB	-
Carvalho et al. [35], Portugal	SB	Non-clinical	HDSI	No	Unclear	Go/No-Go Task	20–33%	Randomised	Irrelevant	Pictures	Semi	One	Correlational	Lab	Eye-tracking	Non-sig.	-
Cervigón-Carrasco et al. [36], Luxembourg and Spain	PU	Non-clinical	ISST	No	Unclear	Stroop	NA	In blocks	Irrelevant	Video	No	One	Correlational	Lab	No	-	Non-sig.
	GAM	Non-clinical	IGDT-10	No	Unclear	Stroop	NA	In blocks	Irrelevant	Video	No	One	Correlational	Lab	No	-	Non-sig.
Chen et al. [37], China	SP	Non-clinical	SPAI, extreme groups based on terciles	Yes (exclusion criteria)	All users[1]	Go/No-Go Task	20–33%	In blocks	Irrelevant	Pictures	No	One	Within-between	Lab	EEG	Non-sig.	-
Gao et al. [38], China	SP	Non-clinical	SAS-s, cut-off score	Yes (exclusion criteria)	All users[1]	Go/No-Go Task	20–33%	In blocks	Irrelevant	Pictures	No	One	Within-between	Lab	EEG	AB worse non-AB, [g=0.87], AR worse non-AR, [g=0.79], proximal stimuli, non-sig. distal stimuli	Non-sig.

Table 1 (continued)

Reference	Sample					Task		Stimuli				Study procedure				Main results	
	Behaviour	Population	Screening instrument/group definition	Correction for comorbid disorders	Users/non-users	Task	% stop/no-go trials	Presentation of AR stimuli	Relevance of stimuli for task	Type of stimuli	Individualisation of stimuli	# tasks with AR-stimuli	Analysis	Lab/online	Add. methods	Inhibitory control (IC)	Go-response (GR)
Gao et al. [39], China	SNU	Non-clinical	SNS-EU, extreme groups ($M\pm1.96*SD$)	Yes (exclusion criteria)	Unclear	Go/No-Go Task	20–33%	In blocks	Relevant (go/no-go stimuli)	Pictures	No	One	Within-between	Lab	EEG	Non-sig.	Non-sig.
Hague et al. [40], UK	BSh	Non-clinical	CBS, cut-off	No	All users[1]	Go/No-Go	20%	Randomised	Irrelevant	Pictures	No	One	Between	Lab	No	AB worse non-AB (all stimuli)	-
Jeromin et al. [41], Germany	GAM	Non-clinical	CIUS-WoW, AB: cut-off score, non-AB: non-gamers	No	No[2]	Stroop	NA	Randomised	Irrelevant	Words	No	Two (Go/No-Go Task and Visual Probe Task)	Within-between	Lab	No	-	Non-sig.
Jeromin et al. [42], (study 1) Germany	GAM	Non-clinical	CIUS, AB: cut-off score, non-AB: cut-off score and non-gamers or casual gamers	No	No[2]	Stroop	NA	Randomised	Irrelevant	Words	No	One	Within-between	Online	No	-	Non-sig.
Jeromin et al. [42], (study 2) Germany	GAM	Non-clinical	CIUS, B: cut-off score, non-AB: cut-off score and non-gamers or casual gamers	No	No[2]	Stroop	NA	In blocks	Irrelevant	Words	No	One	Within-between	Online	No	-	Non-sig.
Jiang et al. [43], China	BSh	Non-clinical	OSAS, extreme groups, upper/lower 27%	Yes (exclusion criteria)	All users[1]	Stroop	NA	Randomised	Irrelevant	Words	No	Two (Go/No-Go Task and Dot Probe Task)	Within-between	Lab	No	Non-sig.	AR faster non-AR
Liu et al. [44], Taiwan	GAM	Non-clinical	DCIA-C, cut-off score	Yes (exclusion criteria)	Unclear	Go/No-Go Task	50%	In blocks	Irrelevant	Pictures	No	One	Within-between	Lab	fMRI	AB worse non-AB [g=1.22], AR worse non-AR, [g=0.93]	-
Lorains et al. [45], Australia	GAB	Clinical	PGSI, treatment seeking, cut-off scores for each group	Yes (exclusion criteria)	All users	Stroop	NA	In blocks	Irrelevant	Words	No	One	Within-between	Lab	No	-	Non-sig.
Moretta, Buodo [46], Italy	SNU	Non-clinical	PFUS, AB: upper 25 percentile, non-AB: lower 50th percentile	No	Unclear	Go/No-Go Task	20–33%	Randomised	Irrelevant	Pictures	No	One	Within-between	Lab	EEG	Non-sig.	Non-sig.

Table 1 (continued)

Reference	Sample					Task		Stimuli				Study procedure				Main results	
	Behaviour	Population	Screening instrument/group definition	Correction for comorbid disorders	Users/non-users	Task	% stop/no-go trials	Presentation of AR stimuli	Relevance of stimuli for task	Type of stimuli	Individualisation of stimuli	# tasks with AR-stimuli	Analysis	Lab/online	Add. methods	Inhibitory control (IC)	Go-response (GR)
Nie et al. [47], China	IU	Non-clinical	CIAS, extreme groups, cut-off scores	Yes (exclusion criteria, control groups)	All users	SST (two-choice task)	40%	Randomised	Relevant (two choice task: verbs vs. nouns)	Words	No	Two (SST, 2-Back Task)	Within-between	Lab	No	-	AR faster non-AR, [g=−0.66]
Seok, Sohn [48], South Korea	SB	Non-clinical	SAST-R, HBI, clinical interview and cut-off scores	Yes (exclusion criteria)	Unclear	Go/No-Go Task	20–33%	Randomised	Irrelevant	Pictures	No	One	Within-between	Lab	fMRI	AB worse non-AB	-
Trotzke et al. [49], Germany	BSh	Non-clinical	PBS	No	Unclear	Go/No-Go Task	50%	Randomised	Relevant (go/no-go stimuli)	Pictures	Semi	Three (Go/No-Go Task, Dot-Probe Task, Implicit Association Test)	Correlational	Lab	No	Non-sig.	Non-sig.
Turel et al. [50], USA	SNU	Non-clinical	FAS	Yes (exclusion criteria)	All users	Go/No-Go Task	20–33%	In blocks	Irrelevant	Pictures	Individualised (Facebook)	One	Correlational	Lab	fMRI	Non-sig.	Non-sig.
van Holst et al. [51], Netherlands	GAM	Non-clinical	GAS, extreme groups, terciles (high, medium, low group)	No	All users	Stroop	NA	Randomised	Irrelevant	Words	No	Three (Go/No-Go Task, Stroop, Dot-Probe Task)	Within-between	Lab	No	Non-sig.	Non-sig.
						Go/No-Go Task	20–33%	In blocks	Relevant (go/no-go stimuli)	Pictures	No					Higher AB worse IC [r=.27]	Higher AB faster GR, [r=−.25]
van Holst et al. [52], Netherlands	GAB	Clinical	Clinical interview + SOGS, AB: patients, clinical interview, non-AB: played less than twice a year	Yes (exclusion criteria)	Unclear	Go/No-Go Task	29%	In blocks	Relevant (go-stimuli)	Pictures	No	One	Within-between	Lab	fMRI	-	AB slower non-AB [g=2.64] AR faster non-AR (sig for positive [g=−3.55], neutral [g=−3. 398]), non-sig for negative

Table 1 (continued)

Reference	Sample					Task		Stimuli				Study procedure				Main results	
	Behaviour	Population	Screening instrument/group definition	Correction for comorbid disorders	Users/non-users	Task	% stop/no-go trials	Presentation of AR stimuli	Relevance of stimuli for task	Type of stimuli	Individualisation of stimuli	# tasks with AR-stimuli	Analysis	Lab/online	Add. methods	Inhibitory control (IC)	Go-response (GR)
Vogel et al. [53], Germany	BSh	Clinical	PBS, AB: patients, clinical interview, cut-off score, non-AB: cut-off score	Yes (exclusion criteria)	All users	Go/No-Go Task	50%	Randomised	Relevant (go/no-go stimuli)	Pictures	Semi	Three (Go/No-Go Task, Dot-Probe Task, Implicit Association Test)	Within-between	Lab	No	Non-sig.	Non-sig.
Wang et al. [54], China	PU	Non-clinical	IPUS, extreme groups, upper/lower quartile	Yes (exclusion criteria)	Unclear	Stroop	NA	Randomised	Irrelevant	Pictures	No	One	Within-between	Lab	EEG	AB worse non-AB [g=0.58], higher AB - worse IC [r=.33]	AB slower non-AB [g=1.24], higher AB slower GR, [r=.45]
Wang et al. [55], China	GAM	Non-clinical	IAT + 9 of DSM-5 criteria for Gaming Disorder, cut-off scores	Yes (exclusion criteria)	All users (Game DOTA)	Stroop	NA	Randomised	Irrelevant	Words	Individualised (words related to game DOTA)	One	Within-between	Lab	fMRI	-	Non-sig.
Wegmann et al. [56], Germany	SNU	Non-clinical	sIAT-SNS	No	Unclear	Go/No-Go Task	50%	Randomised	Relevant (go/no-go stimuli)	Auditory tones	No	One	Correlational	Lab	No	Non-sig.	-
Yao et al. [57], China	GAM	Non-clinical	CIAS, extreme groups, cut-off scores	Yes (exclusion criteria)	Unclear (non-AB included non-gamers)	Go/No-Go Task	20–33%	Randomised	Relevant (AR stimuli were always go signals, non-AR stimuli were no-go signals)	Pictures	Individualised for AB group	One	Within-between	Lab	No	AB worse non-AB [g=0.90]	Higher AB slower GR, [r=.31]
Zhang et al. [58], China	GAM	Non-clinical	IAT + 9 of DSM-5 criteria for Gaming Disorder, cut-off score	Yes (exclusion criteria)	Unclear	Stroop	NA	Randomised	Irrelevant	Words	Individualised for AB group (words related to game DOTA)	One	Within-between	Lab	fMRI	-	Non-sig.

Table 1 (continued)

Reference	Sample					Task		Stimuli				Study procedure				Main results	
	Behaviour	Population	Screening instrument/group definition	Correction for comorbid disorders	Users/non-users	Task	% stop/no-go trials	Presentation of AR stimuli	Relevance of stimuli for task	Type of stimuli	Individualisation of stimuli	# tasks with AR-stimuli	Analysis	Lab/online	Add. methods	Inhibitory control (IC)	Go-response (GR)
Zhao et al. [59],	SNU	Non-clinical	BSMAS, cut-off score	Yes (exclusion criteria)	All users	Stroop	NA	Randomised	Irrelevant	Words	No	Two (Stroop, Dot Probe Task)	Within-between	Lab	No	Non-sig.	Non-sig.
Zhou et al. [60], China	GAM	Non-clinical	YDQ, AB: met criteria, non-AB: did not meet criteria + less than 2h on the internet per day	Yes (exclusion criteria)	Unclear[2]	Go/No-Go Task	50%	Randomised	Relevant (go/no-go stimuli)	Pictures	No	NA	Within-between	Lab	No	AB better non-AB [g=−1.09], AR better non-AR [g=−0.95]	AB slower non-AB [g=1.62], AR faster non-AR, [g=−3.06]

Note: *AB*, addictive behaviour group; *AR*, addiction-related stimuli condition; *BSh*, buying-shopping; *BSMAS*, Bergen Social Media Addiction Scale; *CIAS*, Chen Internet Addiction Scale; *CIUS*, Compulsive Internet Use Scale; *CIUS-WoW*, Compulsive Internet Use Scale for WoW; *DCIA-C*, Clinical interview, Diagnostic Criteria for Internet Addiction for College Students; *EEG*, electroencephalogram; *fMRI*, functional magnetic resonance imaging; *GAB*, gambling; *GAS*, Game Addiction Scale; *GAM*, gaming; *GR*, go-response; *FAS*, Facebook Addiction Scale; *HBI*, Hypersexual Behaviour Inventory; *HDSI*, Hypersexual Disorder Screening Inventory; *IC*, inhibitory control; *IAT*, Internet Addiction Test; *IGDT-10*, Internet Gaming Disorder Test; *IU*, Internet use; *IPUS*, Internet Pornography Use Scale; *ISST*, Internet Sex Screening Test; *non-AB*, non-addictive behaviour group; *non-AR*, non-addiction-related stimuli condition; *OSAS*, Online Shopping Addiction Scale; *PBS*, Pathological Buying Screener; *PFUS*, Problematic Facebook Use Scale; *PGSI*, Problem Gambling Severity Index; *PU*, pornography use; *SAS-s*, Smartphone Addiction Scale-Short; *SAST-R*, Structured interview, Sexual Addiction Screening Test-R; *SB*, sexual behaviour; *SCS*, Sexual Compulsivity Scale; *sIATsex*, Short Internet Addiction Test modified for sexual activities; *sIAT-SNS*, Short Internet Addiction Test modified for social-networking sites; *SNS-EU*, SNS Excessive Use Scale; *SNU*, social networks use *SP*, smartphone; *SPAI*, Smartphone Addiction Inventory; *SST*, Stop-Signal Task; *YDQ*, Modified Diagnostic Questionnaire for Internet Addiction. [1]Not explicitly stated but can be assumed. [2]Control group consisted (partly) of non-users engage in the behaviour in their daily life (e.g. non-gamers in studies on gaming disorder). Symptom severity was most often assessed with screening questionnaires and a classification of clinically relevant cases based on a cut-off score. Some studies used clinical interviews based on the proposed DSM-5 criteria for gaming disorder [42, 52, 55, 58] or for Compulsive Sexual Behaviour Disorder [48]. Seldomly the same instruments and criteria were used in multiple studies. Since inhibitory control performance has been associated with various psychopathological symptoms [61], a correction for comorbidities, e.g. as inclusion criteria is warranted. Most studies (*n*=19) screened for comorbidities such as depressive symptoms, anxiety, and other addictive behaviours. The gender distribution was often dependent on the addictive behaviour in focus. For example, most studies on sexual behaviour, pornography use, or gaming focused on male participants. Studies on social networks use and buying/shopping often included more female compared to male participants. Studies on unspecific Internet use or smartphone use were more balanced with regard to gender distribution.

No specific pattern of empirical results could be identified with regard to the sample characteristics (Table 2). Results for buying/shopping, gambling, and social networks use were non-significant. Results for gaming and smartphone use were mixed. For pornography use and sexual behaviours, a tendency towards worse inhibitory control and slower go-responses could be indicated by the empirical results. Results for the clinical samples were non-significant. And no specific pattern can be seen when differentiating between studies that corrected for comorbid disorders or that only included individuals who engage in the behaviour.

Tasks Used

Most studies (*n*=18) assessed stimuli-specific inhibitory control with variants of the Go/No-Go task. The SST was used in three studies. The Stroop task measuring interference inhibition was used in *n*=13 studies. For all three tasks, empirical results appeared to be mixed. It has been argued that tasks with equivocal proportions of go and no-go/stop signals require less of an inhibitory control response, but rather measure the decision to respond or not [17]. Although this view is of debate, we investigated empirical results separately for tasks with frequent go- and rare stop/no-go signals and for tasks with 50% of go- and no-go trials. Most studies (*n*=15) used a trial distribution with frequent go-signals that promote a prepotent response tendency. Five studies used equivocal trial distributions (e.g. in affective shifting tasks). Empirical results for both types of tasks are mixed. In some studies, addiction-related and non-addiction-related stimuli were presented in blocks (*n*=14). In other studies (*n*=20), addiction-related and non-addiction-related stimuli were presented randomly. Jeromin et al. [42] used two variants of the Stroop task within a web-based online study, one with addiction-related stimuli and non-addiction-related stimuli in separated blocks and one with a random presentation. In both versions of the Stroop task, no significant results were indicated. In the minority of studies (*n*=8), the addiction-related and non-related stimuli were relevant to execute the task (e.g. as indicators for go- or no-go signals). Results for ways of stimulus presentation and the relevance of stimuli for the task seem not to impact empirical results, which remain mixed (Table 2).

Type of Stimuli

Words (*n*=11), pictures (*n*=20), videos (*n*=1), and auditory tones (*n*=1) were used as stimuli. Most often, pictures were proximal cues with explicit content of the specific behaviour. For example, pictures showed explicit pornographic material or gaming content (e.g. [32, 44]) as well as words specific for certain games. Only one study included more distal cues showing smartphones with black screens instead of social-network-related contents [38]. Within this study, only the proximal images had an effect on inhibitory control in individuals with symptoms of smartphone use disorder, showing reduced inhibitory control when addiction-related stimuli were present. This effect was not shown for distal images. Most often, stimuli were not individualised (*n*=25); in some studies (*n*=5), stimuli were semi-individualised by showing preferred categories of shopping goods [53] or pornographic material according to the own sexual orientation [31, 32], and in four studies, stimuli were individualised showing specifically the preferred behaviour. When separating empirical results regarding the type or individualisation of stimuli results, inhibitory control and go-response remain heterogenous.

Study Procedure

Most studies focused on one task with addiction-related stimuli (*n*=23). In studies with multiple tasks that included addiction-related stimuli (two tasks: *n*=4, three tasks: *n*=4), empirical results seem to be predominantly non-significant. In some studies, it is reported that further indicators of cue-reactivity (e.g. subjective craving, arousal or valence ratings of images) were assessed [31, 32, 40, 46, 49, 52–54]. Overall, 14 studies used additional methods to assess physiological and neuroimaging correlates of stimuli-specific inhibitory control: functional magnetic resonance imaging [31, 44, 48, 50, 52, 55, 58], electroencephalogram (EEG)/event-related potentials (ERP) [33, 34, 37–39, 46, 54], eye-tracking [35]. One study was conducted as online study [42]. Results remained mixed when separating these results.

Table 2 Empirical results for methodological specificities

Methodological specificities	Inhibitory control (IC)						Go-response (GR)					
	Between groups		Within AB group		Correlation		Between groups		Within AB group		Correlation	
	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.
1. Sample												
1.1 Behaviour												
BSh		[53]		[53]		[49, 53] Stroop: [43]		[53] Stroop: [43]	*AR faster non-AR* Stroop: [43]	[53]		[49, 53]
GAB							*AB slower GR non-AB* 2.64 [52]	Stroop: [45]	*AR faster non-AR* −3.55 [52]	Stroop: [45]		
GAM	*AB worse IC non-AB* 1.22 [44], 0.90 [57] *AB better IC non-AB* 1.09 [60]	[51] Stroop: [51]	*AR worse IC non-AR* 0.93 [44] *AR better IC non-AR* 0.95 [60]		*Higher AB worse IC* .27 [51]	Stroop: [51]	*AB slower GR non-AB* 1.62 [60]	[51, 57] Stroop: [41, 42][1], [51, 55, 58]	*AR faster GR non-AR* −3.06 [60]	[51][2] Stroop: [41, 42][1], [51, 55, 58]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .31 [57]	Stroop: [36, 51]
IU	*AB better IC non-AB* [34]			[34]			*AB faster GR non-AB* [33]	[47]	*AR faster GR non-AR* −0.66 [47]	[33]		[47]
PU	*AB worse IC non-AB* Stroop: 0.58 [54]				*Higher AB worse IC* Stroop: .33 [54] *Higher AB better IC* −.52 [31]	[32]	*AB slower GR non-AB* Stroop: 1.24 [54]			Stroop: [54]	*Higher AB slower GR* Stroop: .45 [54]	[31, 32] Stroop: [36]
SB	*AB worse IC non-AB* [48]			[48]	*Higher AB worse IC* Stroop: .29 [30]	[35]						
SNU		[39, 46]		[39, 46]		[50, 56] Stroop: [59]		[39, 46] Stroop: [59]		[39, 46] Stroop: [59]		[50]
SP	*AB worse IC non-AB* 0.87 [38][2]	[37, 38][2]	*AR worse IC non-AR* 0.79 [38][2]	[37, 38][2]				[38]		[38]		
1.2 Population												
Clinical		[53]		[53]		[53]	*AB slower GR non-AB* 2.64 [52]	[53] Stroop: [45]	*AR faster non-AR* −3.55 [52]	[53] Stroop: [45]		[53]
Non-clinical	*AB worse IC non-AB* 0.87 [38][2], 1.22 [44, 48], 0.90 [57] Stroop: 0.58 [54] *AB better IC non-AB* [34], 1.09 [60]	[37, 38][2], [39, 46, 51] Stroop: [51]	*AR worse IC non-AR* 0.79 [38][2], 0.93 [44] *AR better IC non-AR* 0.95 [60]	[34, 37, 38][2], [39, 46, 48]	*Higher AB worse IC* .27 [51] Stroop: .29 [30], .33 [54] *Higher AB better IC* −.52 [31]	[32, 35, 49, 50, 56] Stroop: [43, 51, 59]	*AB slower GR non-AB* 1.62 [60] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 39, 46, 47, 51][2], [57] Stroop: [41, 42][1], [43, 51, 55, 58, 59]	AR faster non-AR −0.66 [47], −3.06 [60] Stroop: [43]	[33, 39, 46, 51] Stroop: [41, 42][1], [51], [54, 55, 58, 59]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .45 [54], .31 [57]	[31, 32, 47, 49, 50] Stroop: [36, 51]

Table 2 (continued)

Methodological specificities	Inhibitory control (IC)						Go-response (GR)					
	Between groups		Within AB group		Correlation		Between groups		Within AB group		Correlation	
	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.
1.3 Corrected for comorbid disorders												
Yes	*AB worse IC non-AB* 0.87 [38]^2, 1.22 [44, 48], 0.90 [57] Stroop: 0.58 [54] *AB better IC non-AB* [34], 1.09 [60]	[37, 39, 38]^2, [53]	*AR worse IC non-AR* 0.79 [38]^2, 0.93 [44] *AR better IC non-AR* 0.95 [60]	[34, 48, 39, 38]^2, [37, 53]	*Higher AB worse IC* Stroop: .33 [54]	[50, 53] Stroop: [43]	*AB slower GR non-AB* 2.64 [52], 1.62 [60] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 39, 47, 53, 57] Stroop: [43, 45]	*AR faster non-AR* −3.55 [52], −3.06 [60], −0.66 [47] Stroop: [43, 54]	[33, 38, 39, 53] Stroop: [45]	*Higher AB slower GR* .31 [57] Stroop: .45 [54]	[47, 50, 53]
No		[46, 51] Stroop: [51]		[46, [51]	*Higher AB worse IC* .27 [51] Stroop: .20 [30] *Higher AB better IC* −.52 [31]	[32, 35, 49, 56] Stroop: [51, 59]		[46, 51] Stroop: [41, 42, 51, 58, 59]		[46, 51] Stroop: [41, 42, 51, 58, 59]	*Higher AB faster GR* .25 [51]	[31, 32, 49, 56] Stroop: [36, 51]
1.4 Users												
All users	*AB worse IC non-AB* 0.87 [38]^2 *AB better IC non-AB* [34]	[37, 51, 53] Stroop: [51]	*AR worse IC non-AR* 0.79 [38]^2	[34, 37, 53]	*Higher AB worse IC* .27 [51] Stroop: .29 [30] *Higher AB better IC* −.52 [31]	[32, 50, 53] Stroop: [43, 51, 59]		[38, 47, 51, 53] Stroop: [43, 45, 51, 55, 59]	*AR faster non-AR* −0.66 [47] Stroop: [43]	[38, 51, 53] Stroop: [45, 51, 55, 59]	*Higher AB faster GR* .25 [51]	[31, 32, 47, 50, 53] Stroop: [51]
No/unclear	*AB worse IC non-AB* 1.22 [44, 48], 0.90 [57] Stroop: 0.58 [54] *AB better IC non-AB* 1.09 [60]	[38]^2, [39, 46]	*AR worse IC non-AR* 0.93 [44] *AR better IC non-AR* 0.95 [60]	[38]^2, [39, 46, 48]	Stroop: .33 [54]	[32, 35, 49, 56]	*AB slower GR non-AB* 2.64 [52] 1.62 [60] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[39, 46], [57] Stroop: [41, 42]^1, [58]	*AR faster non-AR* −3.55 [52], −3.06 [60]	[33, 39, 46] Stroop: [41, 42]^1, [54, 58]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .45 [54], .31 [57]	[49] Stroop: [36]
2 Task specificities												
2.1 Task												
Go/No-Go Task	*AB worse IC non-AB* 0.87 [38]^2, 1.22 [44, 48], 0.90 [57]	[37, 38]^2, [39, 46, 51, 53]	*AR worse IC non-AR* 0.79 [38]^2, 0.93 [44] *AR better IC non-AR* 0.95 [60]	[34, 37, 38]^2, [39, 46, 48, 53]	*Higher AB worse IC* .27 [51]	[35, 49, 50, 53, 56]	*AB slower GR non-AB* 2.64 [52], 1.62 [60] *AB faster GR non-AB* [33]	[38, 39, 46, 51]^2, [53, 57]	*AR faster non-AR* −3.55 [52], −3.06 [60]	[33, 38, 39, 46, 51]^2, [53]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .45 [54], .31 [57]	[49, 50, 53]
SST					*Higher AB better IC* −.52 [31]	[32]		[47]	*AR faster non-AR* −0.66 [47]			[31, 32, 47]

Table 2 (continued)

Methodological specificities	Inhibitory control (IC)						Go-response (GR)					
	Between groups		Within AB group		Correlation		Between groups		Within AB group		Correlation	
	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.
Stroop	*AB worse IC non-AB* 0.58 [54]	[51]			*Higher AB worse IC* .29 [30], .33 [54]	[43, 51, 59]	*AB slower GR non-AB* 1.24 [54]	[41, 42][1], [43, 45, 51, 55, 58, 59]	*AR faster non-AR* [43]	[41, 42][1], [45, 51, 54, 55, 58, 59]		[36, 51]
2.2 Proportion of stop/no-go trials												
20–33%	*AB worse IC non-AB* 0.87 [38, 48], 0.90 [57] *AB better IC non-AB* [34]	[37, 38][5], [39, 46, 51]	*AR worse IC non-AR* 0.79 [38][5]	[34, 37, 38][5,] [39, 46, 48]	*Higher AB worse IC* .27 [51][4] *Higher AB better IC* −.52 [31]	[32, 35, 50]	*AB slower GR non-AB* 2.64 [52] *AB faster GR non-AB* [33]	[38, 39, 46, 47, 51, 57]	*AR faster non-AR* −3.55 [52], −0.66 [47]	[33, 38, 39, 46, 51]	*Higher AB faster GR* .25 [51][4] *Higher AB slower GR* .45 [54] .31 [57]	[31, 32, 47, 50]
50%	*AB worse IC non-AB*1.22 [44] *AB better IC non-AB* 1.09 [60]	[53]	*AR worse IC non-AR* 0.93 [44] *AR better IC non-AR* 0.95 [60]	[53]		[49, 53, 56]	*AB slower GR non-AB* 1.62 [60]	[53]	*AR faster non-AR* −3.06 [60]	[53]		[49, 53]
2.3 Presentation of AR stimuli												
In blocks	*AB worse IC non-AB* 0.87 [38], 1.22 [44]	[37, 38][2] [39, 51]	*AR worse IC non-AR* 0.79 [38][2], 0.93 [44]	[37, 38][2,] [39],	*Higher AB worse IC* .27 [51] Stroop: .29 [30] *Higher AB better IC* −.52 [31]	[32, 50]	*AB slower GR non-AB* 2.64 [52]	[38, 39, 51] Stroop: [42, study 2, 45]	*AR faster non-AR* −3.55 [52]	[38, 39, 51] Stroop: [42, study 2, 45]		[31, 32, 50] Stroop: [36]
Randomised	*AB worse IC non-AB* [48], 0.90 [57] Stroop: 0.58 [54] *AB better IC non-AB* [34], 1.09 [60]	[46, 53] Stroop: [51]	*AR better IC non-AR* 0.95 [60]	[34, 46, 48, 53]	Stroop: .33 [54]	[35, 49, 53, 56] Stroop: [43, 51, 59]	*AB slower GR non-AB* 1.62 [60] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[46, 47, 53, 57] Stroop: [41, 42, Study 1, 43, 51, 55, 58, 59]	*AR faster non-AR* −0.66 [47], −3.06 [60] Stroop: [43]	[33, 46, 53] Stroop: [41, 42], Study 1, 51, 54, 55, 58, 59]	*Higher AB faster GR* .25 [51][4] *Higher AB slower GR* .45 [54], .31 [57]	[47, 49, 53] Stroop: [36, 51]
2.4 Relevance of stimuli for task												
Relevant	*AB worse IC non-AB*0.90 [57] *AB better IC non-AB* 1.09 [60]	[51, 53]	*AR better IC non-AR* 0.95 [60]	[39, 53]	*Higher AB worse IC* .27 [51]	[49, 53, 56]	*AB slower GR non-AB* 1.62 [60], 2.64 [52]	[39, 47, 51, 53, 57]	*AR faster non-AR* −0.66 [47], −3.06 [60], −3.55 [52]	[39, 51, 53]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .31 [57]	[47, 49, 53]
Irrelevant	*AB worse IC non-AB* 0.87 [38], 1.22 [44, 48] Stroop: 0.58 [54] *AB better IC non-AB* [34]	[37, 38][2], [39, 46] Stroop: [51]	*AR worse IC non-AR* 0.79 [38][5,] 0.93 [44]	[34, 37, 38][5], [46, 48]	Stroop: .29 [30], .33 [54] *Higher AB better IC* −.52 [31]	[32, 35, 50] Stroop: [43, 51, 59]	*AB slower GR non-AB* Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 46] Stroop: [41, 42][1], [43, 45, 51, 55, 58, 59]	*AR faster non-AR* Stroop: [43]	[33, 38, 46] Stroop: [41, 42][1], [45, 51, 54, 55, 58, 59]	*Higher AB slower GR* .45 [54]	[31, 32, 50] Stroop: [36, 51]

Table 2 (continued)

Methodological specificities	Inhibitory control (IC)						Go-response (GR)					
	Between groups		Within AB group		Correlation		Between groups		Within AB group		Correlation	
	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.
3 Stimuli												
3.1 Type of stimuli												
Pictures	*AB worse IC non-AB* 0.87 [38]^{2}, 1.22 [44, 48], 0.90 [57] *AB better IC non-AB* [34], 1.09 [60]	[37, 38]^{2}, [39, 46, 51, 53]	*AR worse IC non-AR* 0.79 [38]^{2}, 0.93 [44] *AR better IC non-AR* 0.95 [60]	[34, 37, 38]^{2}, [39, 46, 48, 53]	*Higher AB worse IC* .27 [51] Stroop: .29 [30], .33 [54] *Higher AB better IC* −.52 [31]	[32, 35, 49, 50, 53]	*AB slower GR non-AB* 1.62 [60], 2.64 [52] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 39, 46, 51, 53, 57]	*AR faster non-AR* −3.55 [52], −3.06 [60]	[33, 38, 39, 46, 51, 53]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .45 [54], .31 [57]	[31, 32, 49, 50, 53]
Words	*AB worse IC non-AB* 0.58 [54]	[51]			*Higher AB worse IC* .29 [30], .33 [54]	[43, 51, 59]	*AB slower GR non-AB* 1.24 [54]	[41, 42]^{1}, [43, 45, 47, 51, 55, 58, 59]	*AR faster non-AR* [43], −0.66 [47],	[41, 42]^{1}, [45, 51, 54, 55, 58, 59]		[36, 47, 51]
3.2 Individualisation of stimuli												
Individualised	*AB worse IC non-AB* 0.90 [57]					[50]		Stroop: [55, 58]		Stroop: [55]	*Higher AB slower GR* .31 [57]	[50]
Semi-individualised		[53]		[53]	*Higher AB better IC* −.52 [31]	[32, 35, 49, 53]		[53, 57]		[53] Stroop: [58]		[31, 32, 49, 53]
Non-individualised	*AB worse IC non-AB* 0.87 [38], 1.22 [44, 48] Stroop: 0.58 [54] *AB better IC non-AB* [34], 1.09 [60]	[37, 38]^{2}, [39, 46, 51] Stroop: [51]	*AR worse IC non-AR* 0.79 [38]^{2}, 0.93 [44] *AR better IC non-AR* 0.95 [60]	[34, 37, 38]^{2}, [39, 46, 48]	*Higher AB worse IC* .27 [51] Stroop: .29 [30], .33 [54]	[56] Stroop: [43, 51, 59]	*AB slower GR non-AB* 1.62 [60], 2.64 [52] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 39, 46, 47, 51] Stroop: [41, 42]^{1}, [43, 45, 51, 59]	*AR faster non-AR* −0.66 [47], −3.06 [60], −3.55 [52] Stroop: [43]	[33, 38, 39, 46, 51] Stroop: [41, 42]^{1}, [45, 51, 54, 59]	*Higher AB faster GR* .25 [51] *Higher AB slower GR* .45 [54]	[47] Stroop: [36, 51]
4 Procedure												
4.1 Number of tasks with AR-stimuli												
One	*AB worse IC non-AB* 0.87 [38]^{2}, 1.22 [44, 48], 0.90 [57] Stroop: 0.58 [54] *AB better IC non-AB* [34], 1.09 [60]	[37, 38]^{2}, [39, 46]	*AR worse IC non-AR* 0.79 [38]^{2}, 0.93 [44] *AR better IC non-AR* 0.95 [60]	[34, 37, 38]^{2}, [39, 46, 48]	Stroop: .29 [30], .33 [54] *Higher AB better IC* −.52 [31]	[32, 35, 50, 56]	*AB slower GR non-AB* 1.62 [60], 2.64 [52] Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 39, 46, 57] Stroop: [42]^{1}, [45, 55, 58]	*AR faster non-AR* −3.06 [60], −3.55 [52]	[33, 38, 39, 46] Stroop: [42]^{1}, [45, 54, 55, 58]	*Higher AB slower GR* .45 [54], .31 [57]	[31, 32, 47, 50] Stroop: [36]
Two						Stroop: [43]		[47] Stroop: [41, 43]	*AR faster non-AR* −0.66 [47] Stroop: [43]	Stroop: [41]		

Table 2 (continued)

Methodological specificities	Inhibitory control (IC)						Go-response (GR)					
	Between groups		Within AB group		Correlation		Between groups		Within AB group		Correlation	
	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.	Sig.	Non-sig.
Three		[51, 53] Stroop: [51]		[53]	*Higher AB worse IC* .27 [51]	[49, 53] Stroop: [51, 59]		[51, 53] Stroop: [51, 59]		[51, 53] Stroop: [51, 59]	*Higher AB faster GR* .25 [51]	[49, 53] Stroop: [51]
4.2 Further measures												
fMRI	*AB worse IC non-AB* 1.22 [44, 48]		*AR worse IC non-AR* 0.93 [44]	[48]	*Higher AB better IC* −.52 [31]	[50]	*AB slower GR non-AB* 2.64 [52]	Stroop: [55, 58]	*AR faster non-AR* −3.55 [52]	Stroop: [55, 58]		[31, 50]
EEG	*AB worse IC non-AB* 0.87 [38][2] Stroop: 0.58 [54] *AB better IC non-AB* [34]	[37, 38][2], [39]	*AR worse IC non-AR* 0.79 [38][2]	[34, 37, 38][2], [39]	*Higher AB worse IC* Stroop: .33 [54]		*AB slower GR non-AB* Stroop: 1.24 [54] *AB faster GR non-AB* [33]	[38, 39, 46]		[33, 38, 39, 46]		
Eye-tracking										Stroop: [54]		

Note: *GR*, go-response; *IC*, inhibitory control. [1]Results for study 1 (randomised AR-stimuli) and study 2 (AR stimuli in blocks). [2]Study [38] results were only significant for proximal cues, not for distal cues.

Additional data to calculate effect sizes were obtained from [49, 51, 54, 56, 57]

Discussion and Methodological Challenges

The results of our systematic review on experimental studies focusing on stimuli-specific inhibitory control in the context of addictive behaviours draw a heterogenous picture with mixed empirical results. Mixed findings may be explained by the high heterogeneity of the studies' methodologies. Heterogeneity in studies appeared particularly in four domains: (1) sample characteristics, (2) choice and design of inhibitory control task, (3) choice of addiction-related and non-addiction-related stimuli, and (4) study procedure.

First, the review indicates that the criteria to define addictive behaviour and non-addictive behaviour groups were very heterogenous across studies. Usually, questionnaires were used within the general populations to identify individuals below and above specific cut-offs. These cut-offs have often not been validated in clinical samples. In addition, the criteria assessed may not cover the criteria suggested by international diagnostic manuals (ICD-11 or DSM-5) for addictive behaviours [62–66]. In theories on the development of addictive behaviours such as the I-PACE model [6], it has been argued that stimuli-specific reductions in inhibitory control particularly evolve in later stages of the disorder when the behaviour becomes more compulsive/ habitual. Accordingly, it can be assumed that impairments in stimuli-specific inhibitory control are especially apparent in individuals with pathological symptoms and less in individuals in an at-risk state. However, empirical results of the two studies with clinical samples were non-significant, and results of one study with a clinical sample were significant [52]. Although it has to be stated that effects on inhibitory control might have been low due to the use of multiple tasks with addiction-related stimuli and an equivocal number of go- and stop-signals in the study by Vogel et al. [53] and the Stroop task with words as stimuli measuring interference inhibition in the study by Lorains et al. [45]. Thus, further methodological decisions may have driven these results. Overall with regard to the choice of the sample, it has to be considered that convenient samples, non-clinically validated cut-offs, and correlational designs may obfuscate potential developments of impaired stimuli-specific inhibitory control in later stages of addictive behaviours. Although those approaches are useful in other contexts, using clinical samples and patient populations might be more suitable for the investigation of stimuli-specific inhibitory control in the context of addictive behaviours.

One further confounding factor concerning sample characteristics is that comorbidities such as attention-deficit hyperactivity disorder (ADHD) or obsessive-compulsive disorder may explain associations between inhibitory control performance and symptom severity of addictive behaviours [61]. For example, an association between Stroop performance and social fear measures was found in the context of social-network-use disorder [59]. In addition, sample characteristics such as impulsivity but also age, gender, and educational level may moderate respective effects [67–70]. In multiple studies reported in the current review, groups not only differed in symptom severity of the addictive behaviour but (not surprisingly) also in symptoms of depressive disorders, anxiety disorders, and ADHD, as well as in impulsivity [38, 47, 53, 54, 57]. In other studies, it has been controlled for such conditions or groups were matched (e.g. age, educational level, yeas of engagement in the behaviour, IQ, impulsivity) [39, 42, 44–48, 51, 54, 55, 57–60]. When defining the control group, it should be considered that individuals at best only differ in the symptom severity of the addictive behaviour. Sociodemographic variables as well as experiences with the addictive behaviour should be similar, so that the symptom severity is the main factor differencing between groups (e.g. comparing recreational and pathological users). It is possible that the engagement in specific behaviours (e.g. gaming) may train inhibitory control skills [51, 58, 71]. Future studies on stimuli-specific inhibitory control in addictive behaviours should apply criteria and cut-off scores that have been validated in clinical samples and that cover the criteria proposed by international diagnostic systems. In addition, it should be controlled for symptoms of comorbid disorders (e.g. depression, ADHD, substance use disorders) and other individual characteristics that have been related to impairments in inhibitory control. Within-participant study designs could be used to assess an additional marker for general inhibitory control abilities (e.g. towards neutral stimuli) and could be used to control for effects of comorbidities on inhibitory control ability.

Second, although stimuli-specific inhibitory control was assessed with mainly three different but established inhibitory control tasks, there was a variance in the specific design of these tasks. For example, the number and proportion of go and no-go trials differed significantly between studies. These design-related differences might affect the evoke of prepotent motor activity and thus the reliability of the task to measure inhibitory control [72]. Overall, the stability and reliability of tasks should be considered, as it has been for example discussed for the Stroop task [59]. For the SST, guidelines have been published for a correct implementation of the task and to generate reliable inhibitory control measures [20]. Furthermore, tasks may measure different types of inhibitory control. Schachar et al. [21] argued that the Go/No-Go task measures "action restraint" while the SST measures "action cancellation" since the response is initiated before the stop-signal occurs. The Stroop task is considered to measure interference inhibition — another type of inhibitory control [23]. These different types of inhibitory control may be considered in future research. Furthermore, the task design modulates the general difficulty of the task. For example, the task difficulty may be increased by integrating dual-choice tasks vs. single choice tasks [46] or by integrating multiple distractors [44]. The mixed empirical results may indicate that inhibitory-control ability is only impaired in individuals with addictive behaviours when task difficulty is rather high. Accordingly, the use of tasks with higher difficulty might be helpful to identify inhibitory control deficits. Considering the choice and design of the task, researchers should be cautious with the design and modification of inhibitory control tasks. Modifications, such as the proportion of no-go trials in Go/No-Go tasks or stop-trials in SST, can significantly affect results. In addition, also the timing can confound inhibitory-control performance. Most importantly, all relevant design-features should be reported in publications.

Third, most studies used explicit contents as addiction-related-stimuli (e.g. pictures from game scenes, icons of social network sites, pictures of consumer goods). These images can be described as proximal and often show the rewarding content of the behaviour. On a mechanistic level, the use of such proximal addiction-related-stimuli is not very informative in terms of distinguishing effects resulting from cue-reactivity or reward processing [33, 73]. In the study by Gao et al. [38], proximal pictures (icons of social network sites) and more distal pictures (smartphone with blank screens) have been used in a Go/No-Go Task. Differences between groups could only be identified for the proximal images and not for the distal images. It is possible that in these early stages the same stimuli would not affect stimuli-specific inhibitory control as potential reductions occur later in addiction-development [6]. Furthermore, the content shown may represent different phases of engagement in the behaviour. For example, the blank screens on smartphones may represent the termination of smartphone use, which may elicit lower affective responses and cravings compared to pictures showing other phases of the behaviour such as the beginning [38]. It may be important to consider if the stimuli that are presented during the tasks are specifically relevant to the individual. In some studies, the stimuli have been semi-individualised (e.g. category of shopping goods) which may increase affective responses towards these goods [49, 53]. In the context of pornography use, the presentation of non-preferred stimuli (e.g. content differencing from own sexual orientation) may elicit altered affective or brain responses compared to preferred stimuli [74] which should be considered in research on stimuli-specific inhibitory control. Similar effects may appear if the stimuli are outdated (e.g. older versions of games). Similarly, for the often long and tedious inhibitory control tasks, stimuli that are more salient to individuals with addictive behaviours can result in higher attentive resources that may drift off in individuals for whom the stimuli are less salient [34]. Considerations such as whether to present stimuli in blocks of addiction-related stimuli and non-addiction-related stimuli or in random order [42, 46] or whether stimuli are relevant or irrelevant for the processing of the task may affect the result. However, Jeromin et al. [42] did not identify effects in neither task-option (block design vs. event-related) and effects of the relevance of stimuli within the task have not yet been investigated systematically. Taken together, the question if researchers aim to investigate interactions between inhibitory control and cue-reactivity or reward processing should guide the decision on whether to use proximal and distal stimuli types. The content of the stimuli such as the phase of engagement or if it is specifically relevant for and preferred by the individual may affect results; however, the heterogenous empirical results indicate that a systematic investigation of these factors is warranted. In addition, it is recommended to include a rating of the stimuli at the end of the study evaluating, for example arousal, valence, and urge elicited by the image (e.g. see [31, 32, 46, 49, 53, 54]) to identify potential confounding effects resulting from the choice of stimuli.

Fourth, the study design may be an additional confounding factor. Most studies focused on one task that included addiction-related stimuli, and other studies included multiple tasks with addiction-related stimuli. Although the latter methodology allows for an investigation of the interaction between multiple mechanisms during confrontation with addiction-related stimuli, ceiling effects might occur [49]. These ceiling effects may explain why lower effects/non-significant results were predominantly found in studies using multiple tasks with addiction-related stimuli. Furthermore, the use of neurophysiological methods such as electroencephalography and functional magnetic resonance imaging (fMRI) could alter inhibitory-control performance [31, 33]. For example, the situation of lying in an MRI scanner and the impression of being observed during an inhibitory control task that includes stimuli on a behaviour that is problematic for the individual might result in a higher motivation to perform well in the task. This may explain the improved inhibitory control in the study by Antons and Brand [31]. Jones et al. [75] argue that some parts of inhibitory control performance fluctuated due to situational circumstances. Following this argumentation, web-based assessments such as those applied by Jeromin et al. [42] should include questions describing the situation to control for these situational confounders.

Besides these methodological considerations, it is worth to explore the possibility that individuals with addictive behaviours may in fact do not show a deficit in stimuli-specific inhibitory control. A meta-analysis on effects of exposure to appetitive stimuli on inhibitory control only found effects for alcohol stimuli and not for food-related stimuli [76] and RCTs of inhibitory control training have also yielded null findings [77, 78]. Future studies should investigate which effects are specific for the development of addictive behaviours and how natural and secondary reinforcers differ.

The current review should be evaluated with regard to some limitations. First, the literature search has only been conducted in one data base. However, the standards that journals must have to be listed in PubMed are high so this can be seen as an additional indicator of the quality of studies. Second, no meta-analysis was applied to the data, as we regarded the studies as being very heterogeneous with regard to tasks and stimuli used as well as sample characteristics samples (addictive behaviour) and study design.

Conclusions

There are a number of studies that investigated stimuli-specific reductions in inhibitory control in addictive behaviours. However, findings are inconclusive. The studies vary considerably regarding sample characteristics, type and design of inhibitory control task, type of stimuli, and study procedure. The huge methodological heterogeneity across studies makes it difficult to draw clear conclusions about underlying processes. Most of the included studies were on gaming disorder while for other addictive behaviours (including gambling disorder) empirical studies on stimuli-specific inhibitory control are lacking. As all addictive behaviours mentioned in the current review have been associated with diminished control over the specific behaviour in daily life, it remains warranted to investigate stimuli-specific inhibitory control. We recommend to start with those methodological designs that probably would result in the highest effects. Accordingly, we would recommend to investigate clinical samples or samples screened based on clinically validated cut-off scores that are based on diagnostic criteria of the ICD-11 or DSM-5. The control group should be matched with regard to comorbid disorders and should engage in the addictive behaviour recreationally. The Go/No-Go task or SST with frequent go-signals should be the first-choice paradigms that induce a prepotent response tendency and thereby are suitable to measure inhibitory control ability. Addiction-related stimuli should be individualised or semi-individualised to trigger cue-reactivity and craving responses that are expected to interfere with inhibitory control processes. Proximal cues that have an additional rewarding effect might increase this interference effect. To avoid ceiling effects, no further tasks or only with longer breaks in between should be used. The use of neuroimaging or psychophysiological measures can be informative, but may additionally effect results. Considering these recommendations could be a starting point of a systematic investigation of stimuli-specific inhibitory control in addictive behaviours. Despite these methodological challenges, some more general considerations should be taken into account. Up to now, given the mixed results of present studies, it is unclear whether individuals with addictive behaviours show stimuli-specific reductions in inhibitory control and if yes, whether it is a consequence of the development of the disorder and related to later stages of this process. Furthermore, stimuli-specific inhibitory control may only be relevant for specific individuals (e.g. those with high impulsivity) [32, 56] or in specific situations (e.g. when under stress, or showing a high attentional bias) [49]. These interaction-effects between trait and state variables as well as those between different state variables should be systematically investigated in future research to enhance our understanding of underlying processes. At present, findings are far too heterogeneous to draw any clear conclusions.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40429-023-00517-z.

Funding Open Access funding enabled and organized by Projekt DEAL. The work of all authors was conducted in the context of the Research Unit ACSID, FOR2974, funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 411232260.

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance

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