Self-Control Abilities in Specific Types of Problematic Usage of the Internet: Findings From Clinically Validated Samples With Neurocognitive Tasks

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Objective: Reduced cognitive functions are commonly associated with diminished self-control abilities. Research on cognitive functions in gaming disorder and other specific types of problematic usage of the Internet (PUI) remains rare. The aim of this study was to compare performance in different cognitive domains between clinically validated groups of individuals with and without specific PUI.

Methods: The data, from a large-scale multicenter study in Germany, were collected between October 2021 and August 2024. The study compared three groups: Internet users with pathological use (N=284), risky use (N=305), and nonproblematic use (N=424). Grouping was based on structured interviews for four types of specific PUI (gaming, buying-shopping, pornography use, social network use). All participants underwent extensive laboratory testing, including self-report scales and standard cognitive tasks: Modified Card Sorting Test, Stroop test, a logical reasoning test, Game of Dice Task, a delay discounting task, and a go/no-go task with Internet-related stimuli.

Results: The groups differed significantly regarding both behavioral (partial eta^2 ≤0.06) and self-report measures (partial eta^2 ≤0.14) of self-control abilities. The group with pathological use showed the weakest mean performance in all tasks. The groups with risky and nonproblematic use barely differed in behavioral measures but did differ in self-reported self-directedness and attentional impulsivity. Post hoc analyses revealed significant (interaction) effects of PUI type.

Conclusions: PUI is associated with deficits in general executive functions, decision making, and stimulus-specific inhibitory control that may evolve in later stages of addiction development. Potential PUI-specific differences should be considered when designing trainings and interventions that target improving self-control abilities.

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Global concern about problematic usage of the Internet (PUI) continues to grow. Specific manifestations of PUI comprise, among others, the addictive use of certain online services, including gaming, gambling, pornography, buying-shopping, or social network use, which we refer to as specific types of PUI here. PUI can be characterized by impaired control over the use of these services, resulting in functional impairment and/or significant distress in daily life activities. This is in accordance with the diagnostic criteria for disorders due to addictive behaviors proposed in ICD-11. ICD-11 lists gambling disorder and gaming disorder (updating the criteria proposed previously in DSM-5 section III) as distinct clinical diagnoses. For both disorders, ICD-11 provides specifiers for the respective behavior being performed predominantly offline or online, whereby the latter would represent a specific type of PUI. Given that there are sufficient theoretically and empirically based similarities to established addictive disorders, further specific types of PUI may be classified as "other specified disorders due to addictive behaviors." Currently, a broad consensus for further types of PUI that could be classified in this category exists for problematic pornography use, problematic buying-shopping, and problematic social network use (1, 2). ICD-11 currently considers problematic pornography use as a phenotype of compulsive sexual behavior disorder, categorized as impulse-control disorder, and compulsive buying-shopping disorder is considered an example of other specified impulse-control disorder. However, diagnostic criteria are very similar, and the debate about

classification is ongoing (e.g., 1, 3, 4). In this study, we focus on the online manifestations of these conditions and therefore use the term specific PUI, with gaming disorder (predominantly online) representing the prototype.

Diminished self-control has been considered an important factor in online behavioral addictions (5), and should principally relate to general cognitive functions. Deficits in cognitive functions—which are a set of executive control and decision-making skills relevant for controlling thoughts, emotions, and behavior—are prominent in many mental disorders (6), including substance use disorders (7) and gambling disorder (8). Dual-process models of addiction (e.g., 9, 10) and further integrations, such as the impaired response inhibition and salience attribution (iRISA) model (11) or the interaction of person-affect-cognition-execution (I-PACE) model (12), propose a decrease in the relative influence of "reflective"/"controlling" over "impulsive"/"driving" neural processes in the course of addiction development. Cognitive functions comprise different executive control and decision-making abilities, which may be domain-general or behavior-specific. The I-PACE model proposes general executive functions (more precisely, general inhibitory control) already to be relevant in the early stages of addiction development, as it enables control over temptations/urges to perform a certain behavior (e.g., to play online games). In later stages, additional stimulus-specific reductions in inhibitory control are assumed to occur and to be relevant for the development of habitualized behavioral patterns (12).

Self-control has been identified as a potential protective factor against developing gaming disorder (13). Results are based on self-report questionnaires, and the association between subjective self-control and objective measures of cognitive control in specific PUI remains unclear. At the same time, there is preliminary evidence for potential deficits in executive functions and decision making in the context of (unspecified) PUI (14, 15). However, most of the studies focused on gaming disorder, with inconsistently classified and predominantly male samples, or included a broad range of unspecified PUI. This also applies to initial neuroscientific studies indicating potential dysfunctions and alterations in (prefrontal) brain areas associated with executive control functioning in the context of gaming disorder (16, 17) and unspecified PUI (18). To date, studies on self-control abilities in specific PUI are scarce and report mixed findings, with classifications mainly based on self-report scales (15, 19). Evidence on deficits in general executive functions and decision making is absent for specific PUI beyond gaming disorder. Studies on stimulus-specific inhibitory control in PUI and other addictive behaviors also report mixed results and huge methodological variations in diverse samples (20).

Yet, there is a lack of research on cognitive functions in PUI, using clinical samples and including a broader range of specific PUI beyond gambling disorder and gaming disorder to better understand common cognitive mechanisms of PUI. Our aim in this study was to compare cognitive functions—namely, performance on standard neurocognitive tasks assessing general executive functions, decision making, and stimulus-specific inhibitory control abilities—between different PUI groups: individuals with pathological Internet use, with risky Internet use, or with nonproblematic Internet use (i.e., gaming, use of pornography, buying-shopping, and social network use). In contrast to previous work, we formed the groups based on standardized structured diagnostic interviews for specific PUI. We hypothesized weaker task performance in individuals with pathological Internet use compared to individuals with risky or nonproblematic use, with larger deficits in more advanced stages (i.e., pathological > risky > nonproblematic).

METHODS

Study Design and Procedure

The procedure applied is from a multicenter German Research Foundation–funded addiction research unit (FOR2974; for details, see reference 21). The overall study procedure of the research unit FOR2974 was preregistered at Open Science Framework (doi: 10.17605/OSF.IO/N5CD7), as was each of the projects involved. Participants were recruited from October 2021 through August 2024, at multiple sites in Germany (University of Duisburg-Essen, Otto-Friedrich University of Bamberg, LWL University Hospital of the Ruhr University Bochum, University of Lübeck, University of Siegen, Hannover Medical School, Justus Liebig University Giessen, and the Outpatient Clinic for Behavioral Addictions at the Johannes Gutenberg University Mainz). Each project recruited participants for specific target groups at treatment facilities (e.g., inpatient and outpatient clinics for psychosomatic medicine and psychotherapy) and via mailing lists, social media, and local advertisements at the investigating sites. Potential participants were prescreened by telephone for specific target behaviors/types of PUI, potential group assignment, and further inclusion and exclusion criteria. On-site, participants were classified into one of three groups (nonproblematic, risky, pathological) using an adapted version of the Structured Clinical Interview for Internet-Related Disorders (AICA-SKI:IBS) (22). The AICA-SKI:IBS is based on the criteria for gaming disorder as proposed in DSM-5 (23) and was supplemented by questions on functional impairment. This was done to consider the (somewhat stricter) ICD-11 criteria. The interviews were conducted by doctoral students in psychology, neuroscience, or medicine who received clinical-diagnostic training and regular supervision by experienced clinicians. Participants who fulfilled at least five criteria and reported functional impairments due to the respective online behavior were classified as being in the pathological use group. Those who fulfilled no more than one criterion without functional impairment were classified as being in the nonproblematic group. The remainder were classified as being in the risky group. All participants underwent the same diagnostic procedure and extensive laboratory testing, plus further project-specific measures that are not reported here (see the OSF preregistrations for details, including sampling plans). The data presented here focus on

behavioral tasks assessing different cognitive functions and complement the planned analyses of the comprehensive model testing (https://osf.io/6x93n/).

Measures

General executive functions.

Modified Card Sorting Test (MCST). We used a modification of the Wisconsin Card Sorting Test (24) in a computerized version for assessing executive functions (mainly rule detection, feedback processing, and cognitive flexibility). Participants were asked to sort cards, one after the other, into one of four decks. The cards display specific symbols that can be sorted according to one of three rules: shape, color, or number of displayed symbols. The rules are implicit and must be discerned based on the positive and negative feedback provided. Participants were informed when a rule changed. As outcome variables, the number of perseverative errors (i.e., incorrect sorting due to applying an old rule although a rule change was announced) and the total number of errors (i.e., perseverative plus further incorrect sorting) are counted. A higher number of errors indicates poorer executive functions.

Color-Word Interference Test (CWIT). Stroop's CWIT (25) is a classical measure of general interference control. Participants are required, first, to read color words printed in black (W card), second, to name the colors of solid squares (C card), and third, to name the colors of color words printed in an incongruent color (CW card) as fast as possible. Each card contained 72 items organized in three columns. As the main outcome measure, we used the time (in seconds) needed for identifying the CW card, as CW has been shown to produce large and reliable individual differences attributable to a person's "interference proneness" (26). Higher completion time is indicative of lower interference control.

Decision making.

Game of Dice Task. The computerized Game of Dice Task (27) was used to measure risky decision making. The task is to bet multiple times on the result of a virtual die roll by either betting on a single number or on different combinations of two, three, or four numbers. Betting on fewer numbers is associated with higher amounts of possible gains or losses, but also with a higher probability of losing. Choices are classified as either "high risk" (choices for one or two numbers) or "low risk" (choices for combinations of three or four numbers). The main outcome is the net score (low-risk minus high-risk choices), with negative values indicating disadvantageous decision making, that is, a preference for options that offer high risk for high potential gains but that are disadvantageous in the long term.

Delay discounting task. We used a computerized version of the five-trial adjusting delay discounting task by Koffarnus and Bickel (28) to assess individual discount rates in a timely manner. Participants are instructed to make a series of binary choices between hypothetical monetary rewards that are smaller (€500) and immediate or larger (€1,000) but delayed in time. The reward amounts remained stable while the delay intervals (ranging from 1 hour to 25 years) were increased or decreased depending on the previously made choices. The final choice results in an individual discount rate k (higher k indicates steeper discounting, i.e., stronger preference for smaller, sooner rewards over larger, later rewards), with log(k) being used in the analyses.

Stimulus-specific inhibitory control.

As a measure of stimulus-specific inhibitory control abilities, we used a go/no-go affective shifting task with Internet-related stimuli that has been used previously with food-related stimuli (29). For Internet-related stimuli, we used distal cues of the respective online behavior (e.g., two hands on a computer keyboard with the log-in for a gaming website displayed on the computer screen; for more details on the distal cues used in this research unit, see reference 30). As control cues, we used pictures also showing objects in two hands, but without any connection to digital devices (e.g., two hands holding an envelope). In 16 blocks with 20 trials each (320 trials in total), either the Internet-related pictures served as go cues (that should be reacted to) and neutral pictures as no-go cues (that should not be reacted to) or vice versa. Commission errors in no-go trials (i.e., reactions to Internet-related stimuli when the reaction should be restrained) served as the main measure for reduced stimulus-specific inhibitory control.

Logical reasoning.

We assessed logical reasoning skills with part 4 of the Leistungsprüfsystem (LPS4) (31), a German intelligence test battery. Participants were provided a sheet of paper with 40 logical sequences of characters. Each sequence contains exactly one character that does not fit into the logic, and this should be marked. Participants were instructed to solve as many sequences as possible in a time span of 8 minutes. The main outcome is the number of correctly solved sequences, with lower scores indicating poorer logical reasoning abilities.

Self-report measures.

The test battery additionally included various questionnaires (for more detailed descriptions and references, see https://doi.org/10.17605/OSF.IO/N5CD7), including a German 15-item version of the Barratt Impulsiveness Scale and the dimension "self-directedness" of the Temperament and Character Inventory as subjective measures of self-control. The Brief Symptom Inventory was used to identify self-reported clinically relevant symptoms of different dimensions, including depression, anxiety, and obsession-compulsion. In addition, sociodemographic variables, average usage times, and wish for treatment were surveyed.

Ethics

The study procedures were carried out in accordance with the Declaration of Helsinki. The local ethics committee of University of Duisburg-Essen approved the overall study protocol

for the main laboratory testing (ID: 1911APBM0457). In addition, all sites obtained the approval of the respective local ethics committee. Participants were informed about the study protocol and provided written informed consent prior to participation. For pseudonymization of the participant data across projects and to comply with the General Data Protection Regulation of the European Union, we used the encryption-based pseudonymization framework ALIIAS (doi: 10.1016/j.softx.2023.101522).

Statistical Analysis

For the hypothesis testing, we used multivariate analyses of variance with group (pathological, risky, nonproblematic) as between-subject factor (with and without PUI type [gaming, pornography use, buying-shopping, social network use], LPS4, age, and Brief Symptom Inventory subscores as covariates), and analysis of variance for testing group differences per measure. We used t tests (with Bonferroni correction, i.e., p values multiplied by number of group comparisons per outcome with a constant alpha level of 0.05) for post hoc pairwise comparisons between groups. A chi-square test of independence was used to analyze associations between group assignment and categorical variables.

RESULTS

Participants

In the study sample (N=1,119), we included participants of the first FOR2974 cohort who were recruited for one of four domains of specific PUI (gaming: 36.5%; social network use: 27.7%; buying-shopping: 23.7%; pornography use: 12.2%). We excluded 53 cases with missing data due to technical problems during task execution. Fifty-three further cases were excluded due to careless responding or not meeting inclusion criteria. The final sample consisted of 1,013 participants between ages 16 and 65 (mean age=26.71 years, SD=7.85) without missing data. The sample consisted of three groups: participants with pathological (N=284), risky (N=305), or nonproblematic (N=424) regular use of the respective online activity, classified on the basis of structured interviews. Table 1 summarizes the sample characteristics by group. With over 4 hours of daily use, on average, of the respective online behavior, individuals in the pathological group differed significantly from those in the risky group (almost 3 hours) and the nonproblematic group (about 1.5 hours). The groups also differed significantly regarding reported symptoms of depression, anxiety, and obsession-compulsion, with the highest ratings in the pathological group, as well as in logical reasoning abilities as measured by the LPS4 (see Table 1). Group differences in age were not statistically significant. Sex distributions did not vary overall ($\chi^2=0.18$, df=2, p=0.91) but differed between groups, as did PUI type distribution, origin, education, and treatment seeking (see Table 1). PUI type and sex were highly dependent ($\chi^2=630.91$, df=9, $p<0.001$), with 90.5% and 100% male participants in the domains of gaming and pornography use, respectively, and 88.8% and 81.5% female participants in the domains of shopping and social network use, respectively.

Group Differences in Behavioral Measures of Self-Control

The results on objective neurocognitive measures showed statistically significant differences between PUI groups ($F=7.86$, df=16, 2006, $p<0.001$, $\eta^2_p=0.059$, Wilks $\Lambda=0.886$). The groups differed significantly regarding all measures assessed; effect sizes were small (Table 2). Post hoc pairwise comparisons supported our hypotheses. More precisely, the group of individuals with pathological use, compared to the group of individuals with nonproblematic use, showed 1) significantly weaker performance in measures of interference control (i.e., CWIT [more time needed]), 2) less advantageous decision-making behavior (i.e., Game of Dice Task [lower net score], delay discounting task [higher k]), and 3) weaker stimulus-specific inhibitory control (i.e., go/no-go task [more errors toward Internet-related stimuli]). The group with pathological use performed significantly worse compared to the group with risky use on all measures except Game of Dice Task net score (Figure 1A). Against our expectations, the individuals with risky use did not differ significantly from individuals with nonproblematic use in any of the tasks except for MCST perseverative errors, where individuals with risky use made fewer errors than individuals with nonproblematic use (see Figure 1A).

The effect of PUI group on behavioral self-control measures remained similar when including PUI type (as four-level predictor), age, and LPS4 (as covariates) ($F=5.90$, df=16, 1984, $p<0.001$, $\eta^2_p=0.045$, Wilks $\Lambda=0.911$). The additional variables also had significant main effects, with the effect being large for LPS4 ($F=30.18$, df=8, 992, $p<0.001$, $\eta^2_p=0.196$, Wilks $\Lambda=0.804$), medium for PUI type ($F=10.06$, df=24, 2878, $p<0.001$, $\eta^2_p=0.075$, Wilks $\Lambda=0.792$), and small for age ($F=4.87$, df=8, 992, $p<0.001$, $\eta^2_p=0.038$, Wilks $\Lambda=0.962$). Furthermore, the interaction between the PUI group and PUI type had a small effect on behavioral measures of self-control ($F=1.82$, df=48, 4885, $p<0.001$, $\eta^2_p=0.014$, Wilks $\Lambda=0.792$).

The inclusion of Brief Symptom Inventory subscale scores as additional covariates showed no significant effects, either in depression ($F=1.41$, df=8, 989, p=0.187, $\eta^2_p=0.011$, Wilks $\Lambda=0.989$), obsession-compulsion ($F=1.13$, df=8, 989, p=0.339, $\eta^2_p=0.009$, Wilks $\Lambda=0.991$), or anxiety ($F=0.89$, df=8, 989, p=0.526, $\eta^2_p=0.007$, Wilks $\Lambda=0.993$). The group differences remained stable ($F=5.41$, df=16, 1978, $p<0.001$, $\eta^2_p=0.042$, Wilks $\Lambda=0.918$), as did the effects of LPS4 ($F=30.14$, df=8, 989, $p<0.001$, $\eta^2_p=0.196$, Wilks $\Lambda=0.804$), age ($F=4.31$, df=8, 989, $p<0.001$, $\eta^2_p=0.034$, Wilks $\Lambda=0.966$), PUI type ($F=9.88$, df=24, 2869, $p<0.001$, $\eta^2_p=0.074$, Wilks $\Lambda=0.794$), and group-by-PUI type interaction ($F=1.82$, df=48, 4870, $p<0.001$, $\eta^2_p=0.014$, Wilks $\Lambda=0.916$).

The effect of group on behavioral measures of self-control (overall) was largest in the buying-shopping and the pornography use samples; it was small in the gaming subsample,

TABLE 1. Descriptive statistics of the sample characteristics per PUI group[a]

Variable	PUI Group									Comparison		
	Pathological (N=284)			Risky (N=305)			Nonproblematic (N=424)					
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	F	p	Partial η^2
Age (years)	27.13	8.18	17–64	26.11	6.82	18–62	26.87	8.30	16–65	1.38	0.252	0.003
Mean daily use[b] (minutes)	249.89	153.02	0[c]–1,080	175.71	119.33	0–705	103.89	113.62	0–1,080	112.68	<0.001	182
Brief Symptom Inventory												
Depression	1.17	0.95	0.00–4.00	0.73	0.73	0.00–3.80	0.53	0.66	0.00–3.80	59.39	<0.001	0.105
Anxiety	0.85	0.64	0.00–3.17	0.57	0.48	0.00–2.50	0.47	0.45	0.00–2.83	47.38	<0.001	0.086
Obsession-compulsion	1.45	0.89	0.00–4.00	0.99	0.67	0.00–3.00	0.74	0.61	0.00–3.33	83.13	<0.001	0.141
LPS4	29.62	4.02	18–39	30.41	3.88	15–38	30.67	3.77	16–39	6.47	0.002	0.013
	N	%		N	%		N	%		χ^2	p	
Sex												
Male	108	38.0		196	64.3		217	51.2		42.79	<0.001	
Female	174	61.3		108	35.4		206	48.6				
Other	2	0.8		1	0.3		1	0.2				
Behaviors/PUI type												
Gaming	71	25.0		136	44.6		141	33.3		42.36	<0.001	
Shopping	62	21.8		62	20.3		117	27.6				
Pornography use	33	11.6		37	12.1		57	13.4				
Social network use	118	41.5		70	23.0		109	25.7				
Born in Germany	254	89.4		290	95.1		400	94.3		8.91	0.012	
Education: Qualification for university entrance	205	72.2		252	82.6		368	86.8		37.00	<0.001	
Occupation												
Employed full-time or part-time	73	25.7		57	18.6		91	21.5		28.38	0.056	
In vocational training or studying	176	62.0		226	74.1		298	70.3				
In a partnership	152	53.5		152	49.8		249	58.7		5.93	0.205	
Treatment-seeking	89[d]	31.4		20	6.5		4	0.9		170.12	<0.001	

[a] LPS4=Leistungsprüfsystem part 4 (logical reasoning); PUI=problematic usage of the Internet.
[b] Use time averaged over self-reported average use duration on a working day and nonworking day for the specific online activity (i.e., not general Internet use).
[c] One participant in the pathological group reported not performing the problem behavior (pornography use) on a daily basis, despite high symptom levels.
[d] Thirty of these participants stated that they had already started treatment.

and it was not statistically significant in the social network use subsample (see Table S2 in the online supplement).

Group Differences in Self-Report Measures of Self-Control

Regarding subjective self-report measures, the PUI groups also differed significantly, both overall ($F=22.84$, $df=8, 2014$, $p<0.001$, $\eta^2_p=0.083$, Wilks $\Lambda=0.841$) and in each single measure with small (Barratt Impulsiveness Scale motor and non-planning subscales) to medium (Temperament and Character Inventory self-directedness and Barratt Impulsiveness Scale attentional subscale) effect sizes (see Table 2). Individuals with pathological use showed lower levels of self-directedness and higher levels of motor impulsivity and attentional impulsivity compared to both other groups. The group with risky use reported lower levels of self-directedness as well as higher motor impulsivity and attentional impulsivity compared to the nonproblematic use group (Figure 1B).

The group differences in self-report measures remained similar ($F=18.67$, $df=8, 1992$, $p<0.001$, $\eta^2_p=0.070$, Wilks $\Lambda=0.865$) when controlling for PUI type, logical reasoning performance (LPS4), and age. These variables and the PUI type-by-group interaction had small effects (PUI type:

TABLE 2. Descriptive statistics and comparison of measures of cognitive functions between groups[a]

	PUI Group								
	Pathological (N=284)		Risky (N=305)		Nonproblematic (N=424)		Comparison		
Measure	Mean	SD	Mean	SD	Mean	SD	F	p	Partial η^2
Behavioral									
MCST									
Perseverative errors	2.67	3.65	1.83	2.41	2.32	2.66	6.24	0.002	0.012
Total errors	9.20	8.98	7.12	6.71	8.25	7.92	5.12	0.006	0.010
CWIT part 3 (seconds)	71.73	16.25	66.38	14.02	65.92	12.41	16.38	<0.001	0.031
Game of Dice Task net score	9.31	9.42	10.69	9.73	11.36	8.64	4.23	0.015	0.008
Delay discounting task, log(k)	−5.70	1.94	−6.40	1.37	−6.50	1.59	22.50	<0.001	0.043
Go/no-go task									
Commission errors, neutral trials	8.71	4.24	6.66	4.50	6.65	4.24	20.32	<0.001	0.039
Omission errors, PUI trials	3.49	3.84	2.53	2.83	2.47	2.71	10.43	<0.001	0.020
Reaction time, PUI trials (msec)	343.20	21.94	333.06	23.48	335.56	23.75	15.39	<0.001	0.030
Self-report									
TCI self-directedness	25.79	7.88	30.29	7.58	33.02	6.76	82.62	<0.001	0.141
Barratt Impulsiveness Scale									
Motor	11.77	3.32	11.05	3.01	10.63	2.52	13.09	<0.001	0.025
Non-planning	11.56	3.65	11.15	3.19	10.70	3.02	6.04	0.002	0.012
Attentional	11.37	2.97	10.26	2.73	9.61	2.57	35.04	<0.001	0.065

[a] CWIT=Color-Word Interference Test; MCST=Modified Card Sorting Test; PUI=problematic usage of the Internet; TCI=Temperament and Character Inventory.

F=3.72, df=12, 2635, p<0.001, η^2_p=0.015, Wilks Λ=0.957; age: F=7.10, df=4, 996, p<0.001, η^2_p=0.028, Wilks Λ=0.972; PUI type-by-group interaction: F=1.79, df=24, 3476, p=0.011, η^2_p=0.011, Wilks Λ=0.958). LPS4 did not have a main effect on self-report measures of self-control (F=1.07, df=4, 996, p=0.369, η^2_p=0.004, Wilks Λ=0.996).

The inclusion of Brief Symptom Inventory subscale scores as additional covariates showed statistically significant large effects of depression (F=60.52, df=4, 993, p<0.001, η^2_p=0.196, Wilks Λ=0.804), medium effects of obsession-compulsion (F=31.22, df=4, 993, p<0.001, η^2_p=0.112, Wilks Λ=0.982), and small effects of anxiety (F=4.55, df=4, 993, p=0.001, η^2_p=0.018, Wilks Λ=0.982). The group differences remained significant but were smaller in size (F=4.81, df=8, 1986, p<0.001, η^2_p=0.019, Wilks Λ=0.962). The same applied to the effects of age (F=4.37, df=4, 993, p=0.002, η^2_p=0.017, Wilks Λ=0.983) and PUI type (F=4.36, df=12, 2628, p<0.001, η^2_p=0.017, Wilks Λ=0.949). The effect of LPS4 remained insignificant (F=0.85, df=4, 993, p=0.494, η^2_p=0.003, Wilks Λ=0.997).

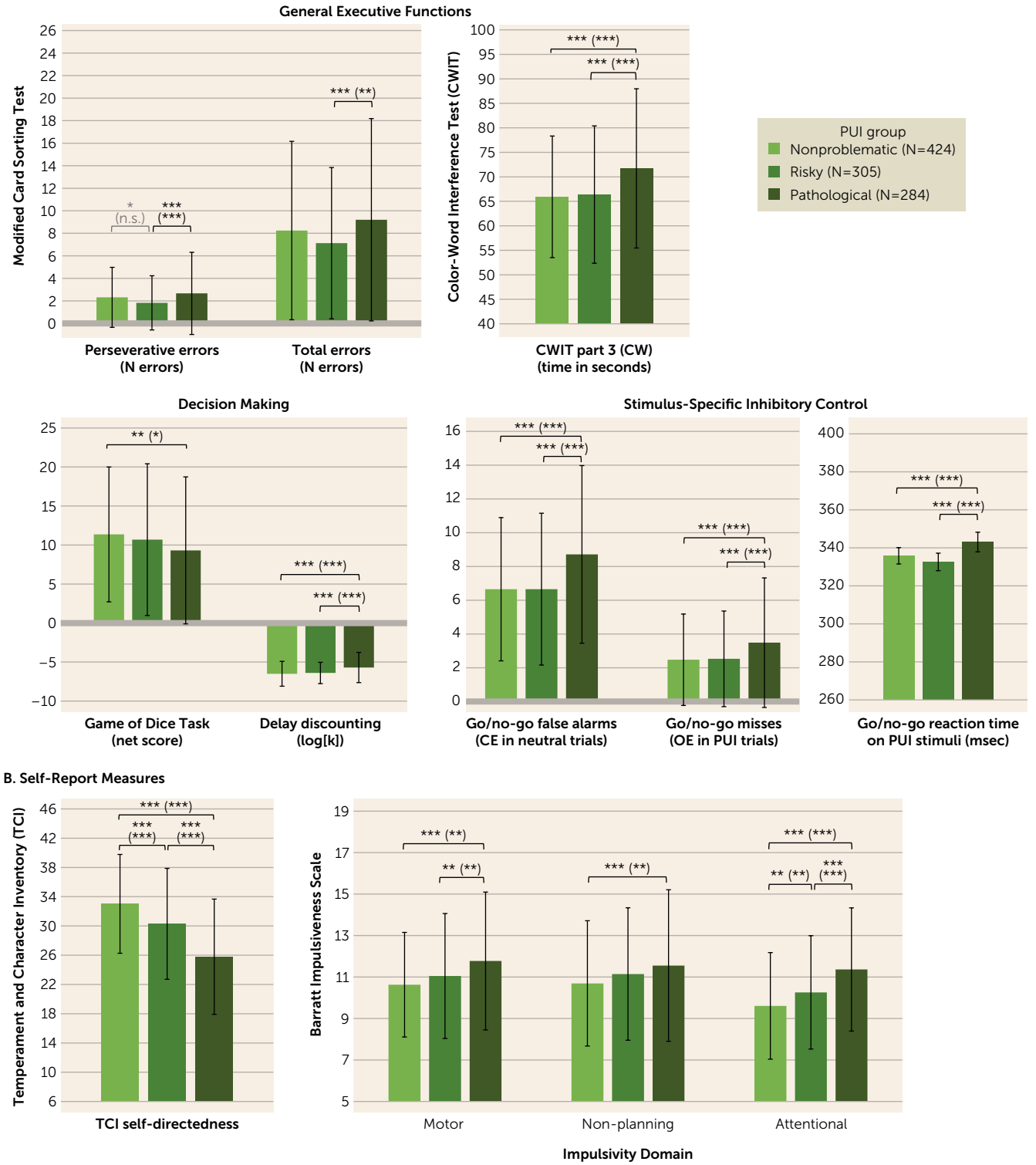
Group differences in self-report measures were consistent across PUI types. Descriptive statistics and results on group differences by PUI type are provided in the online supplement.

DISCUSSION

This study is, to our knowledge, the first to use a standardized classification procedure based on structured interviews to identify large groups (subsample Ns >250) of individuals with and without (potential) specific PUI, namely, individuals with pathological, risky, and nonproblematic use of specific online activities (i.e., gaming, pornography use, buying-shopping, social network use). All participants underwent the same highly standardized laboratory test procedure, including self-report scales and various cognitive tasks mirroring self-control abilities. The results confirm the hypothesized reductions in cognitive functions in individuals classified as having a specific type of PUI compared to those without. Contrary to expectations, individuals with risky use performed similar to those with nonproblematic use.

Individuals with pathological use (severe stage of specific PUI), compared to those without, showed lower self-control abilities, as indicated by results of self-report measures (especially self-directedness) and weaker performance in tasks assessing general executive functions (especially interference control), decision making, as well as stimulus-specific inhibitory control. Effect sizes were small (behavioral tasks) to medium (self-report measures), indicating slightly reduced self-control, not cognitive impairments. These results add to initial meta-analytical findings indicating (despite partly mixed results) deficits in cognitive control and decision making under risk in gaming disorder and other domains of problematic Internet use (e.g., 14, 15). This is in line with dual-process views and models of addiction that hold reductions in (prefrontal) cognitive functions responsible for impaired control over the behavior (5, 9, 11, 12). This corresponds with empirical findings on deficits in cognitive control and decision making in substance-use disorders and gambling disorder (7, 8) that have been attributed to impaired prefrontal cortex activity (32). The present findings complement recently reviewed fMRI studies indicating impaired executive functions in adolescents and young adults with unspecified problematic Internet use compared to those without (33). Stronger tendencies toward risky decision

FIGURE 1. Group differences in self-control abilities in behavioral neurocognitive measures and self-report measures[a]



[a] Bars show group means, and error bars indicate standard deviation. Asterisks indicate significant differences between PUI groups, uncorrected; asterisks in parentheses indicate significant differences after correction for three possible group comparisons. CE=commission errors; CW=color word; OE=omission errors; PUI=problematic usage of the Internet.
*p≤0.05. **p≤0.01. ***p≤0.001.

making and steeper discounting (as behavioral measures) may also reflect relevant temperamental features, such as heightened impulsivity and altered reward processing, commonly associated with addictive behaviors, including PUI (34).

Furthermore, this study indicates difficulties in stimulus-specific inhibitory control in individuals with specific PUI, as indicated by slower response times and more erroneous reactions to Internet-related stimuli in the go/no-go task. In accordance with the I-PACE model, reductions in stimulus-specific inhibitory control were evident only in the group of participants with pathological use representing later stages of addiction development (12). This contrasts with craving reactions (toward the same distal cues) that we have shown earlier (with a subsample of the same cohort) to differ already between nonproblematic and risky use in the context of gaming (30). The findings add an important piece of evidence to the current highly heterogeneous findings on stimulus-specific inhibitory control in behavioral addictions. In contrast to previous studies (for an overview, see reference 20), the present study investigated large groups including clinically relevant cases with the same tasks and a similar set of cues. By using distal instead of proximal cues, the differences found are all the more noteworthy. Effects might be more pronounced when using proximal cues (see reference 35).

The results point to reductions in general cognitive control abilities in later stages of PUI development. In all measures but the MCST, assessing various executive functions, the group with pathological use showed the weakest performance, but differences between the groups with risky and nonproblematic use were not statistically significant. The lack of differences between nonproblematic and risky use allows for assuming that self-control abilities do not decrease in a strictly linear fashion across different stages of addictive behaviors, but rather that there is a qualitative difference between individuals with pathological use (severe stage of specific PUI) and those without. The results seem to indicate that reduced cognitive functions develop or become relevant in pathological stages of PUI and may not exist or be relevant in earlier and preclinical stages. However, this does not indicate any causality in terms of reductions of self-control being the cause or the consequence of addictive behaviors. The question of causality is one of the most important topics in addiction research. At the same time, the question of causality is the most challenging to address, and longitudinal studies starting in childhood or early adolescence and lasting at least 10 years are required. The evidence discussed in the literature may indicate a cascade model of diminished executive control as a vulnerability factor (as a "cause"), which may decrease further in the addiction process when urges and desires become stronger (as a "consequence") (5). Based on the I-PACE model, general inhibitory control functions are assumed to moderate effects of craving on use behavior at early stages of addiction development already, whereas reductions in stimulus-specific inhibitory control are assumed to develop in later stages and may mediate the relationship between craving and behavior execution (12). This study did not include tasks that explicitly measure general (in contrast to stimulus-specific) inhibitory control. However, the present findings indicate that reductions in general executive control functions (e.g., interference susceptibility) may particularly characterize later stages of specific PUI. This does not address the question of causality, however (see below). Although the differences between groups are statistically significant, the effect sizes are rather small (and smaller than expected from, e.g., reference 14). On average, task performance of individuals in the group with pathological use lies within a normal range (e.g., in the MCST [36]). Accordingly, individuals at the pathological stage of specific PUI did not show cognitive impairments as severe as patients with neurological disorders, but rather they showed slight self-control deficits compared to individuals with nonproblematic or risky use. Severe cognitive impairments were an exclusion criterion in this study, which may leave a proportion of individuals with dual disorders unconsidered (e.g., reference 37).

As a limitation, it cannot be concluded from the present results whether reduced cognitive functions are the cause or the consequence of PUI symptoms (see above). To date, empirical evidence for cognitive functions predicting addiction severity is insufficient, especially concerning non–substance-related addictions (38). A longitudinal study by Kräplin and colleagues (39) reported that steeper delay discounting and lower loss aversion may be predictive of symptom severity of both substance-related and behavioral addictions. The planned follow-up assessments of the current ongoing cohort study will help expand our understanding of the role of different neurocognitive functions in the development and maintenance of PUI. Furthermore, future studies should investigate potential sex-/gender-related differences more systematically. The present results are confounded by unequal sex distributions across the investigated behaviors (e.g., the domains of gaming and pornography use consisted predominantly or exclusively of male participants; social network use and buying-shopping consisted predominantly of female participants), which is why the effects cannot be assigned clearly to one factor. We refrained from explicitly testing gender differences because we cannot make unbiased statements due to the noted confounding with PUI type. Also, types of behavior were not equally distributed across groups, and our results indicate interaction effects. More balanced samples (contrary to the natural occurrence) are needed to systematically investigate sex-/gender-related differences as well as potential specificities within specific types of PUI. Despite careful control, there may be other factors and comorbidities that may affect the results. Depression, anxiety, and obsessive-compulsive symptoms, for example, frequently co-occur with addictive disorders and other mental disorders and are considered both vulnerabilities and consequences of addictive behaviors, and it may be that only the combination of these symptoms contributes to the effects of reductions of self-control in specific PUI. The results of the present study

indicate that depression, anxiety, and obsessive-compulsive symptoms (included as covariates) may especially contribute to differences in subjectively perceived self-control but do not affect the group differences in objective neurocognitive measures of self-control. Beyond self-reported self-control and impulsivity, future studies may also more intensively address trait compulsivity as a potentially important transdiagnostic feature and to particularly capture the potential transition from more reward-oriented/impulsivity-related to more compulsivity-related addictive behaviors (5). Another limitation is that this study did not include the online manifestation of gambling disorder as another (increasingly emerging) main type of PUI. Lastly, the additional criteria for functional impairment that we used for classification supplement the DSM-5 proposed criteria in the sense of ICD-11. Given that the text revision of DSM-5 also mentions functional impairment as a general requirement for the proposed diagnosis of (Internet) gaming disorder, and given that the other ICD-11 criteria are also included in the DSM-5 proposed criteria, we have considered all possible indicators for classifying our groups as accurately as possible.

Self-control abilities and related cognitive functions are reduced in individuals with specific PUI. These reductions in cognitive functions become evident in later stages of PUI and may be a risk factor for or associated with the development of more severe symptoms and a chronic course. The results point to the relevance of self-control abilities in specific PUI and related cognitive functions that may be a promising target for training and intervention. Considering dual-process views of addiction, strengthening cognitive control should not, however, be regarded as the sole cure but as an augmentation of established psychotherapy approaches. Regarding the interplay between cognitive and affective/motivational processes, integrative training approaches that combine, for example, cognitive-behavioral therapy and cognitive bias modification might be more promising (see reference 40). Gaining a better understanding of underlying cognitive processes and potential deficits may help improve therapeutic intervention and trainings. Therefore, the longitudinal investigation of large clinical samples with the same standardized procedures offers a way to counteract the current methodological heterogeneity and to draw meaningful conclusions.

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