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Predicting moments of impaired control over addictive behaviors: Relevance of craving and inhibitory control measured in laboratory and ambulatory settings

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FULL-LENGTH REPORT

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ABSTRACT

Background and aims: Moments of impaired control are common in problematic gaming and pornography use. Previous research has mostly focused on general self-control deficits in laboratory or cross-sectional settings. As a novel approach, we examined craving and inhibitory control in daily life as dual mechanisms of moments of impaired control in the natural environment by combining laboratory tasks with ecological momentary assessment (EMA). *Methods:* In this pre-registered study, 118 participants (M = 26.16 years, SD = 7.72 years, 75 males, 42 females, 1 divers) with nonproblematic, risky or pathological pornography use or gaming (n_{gaming} = 74, $n_{pornography}$ = 44) based on a standardized diagnostic interview, completed a cue-reactivity paradigm, craving assessments, Stop-Signal Task, and seven days EMA of craving, behavior-specific inhibitory control, and moments of impaired control (July 2023–July 2025). *Results:* Average frequency of moments of impaired control was predicted by average craving intensity in real life. Intraindividual likelihood of experiencing a moment of impaired control was predicted by reduced behavior-specific inhibitory control in real life. Laboratory craving predicted real-life craving intensity which was linked to real-life behavior specific inhibitory control ratings. Findings generalized across both behavior groups. *Discussion and conclusions:* Craving emerged as an overall (between-person) risk factor, whereas behavior-specific inhibitory control as a situation-specific (within-person) mechanism in moments of impaired control in potentially addictive gaming or pornography use. Prevention, treatment, and future research should address within versus between-person processes and continue combining laboratory tasks with EMA to clarify how lab-indexed mechanisms translate into real-world impaired control.

KEYWORDS

behavioral addictions, I-PACE, ecological momentary assessment, inhibitory control, craving, multilevel SEM

The last sentence on p. 266 was corrected on 29 April 2026. The details of the correction can be found in the correction note https://doi.org/10.1556/2006.2025.11102.

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INTRODUCTION

With the increasing engagement in online-behaviors, potential harms of maladaptive engagement in behaviors such as gaming, buying/shopping, social network use, gambling, and pornography use need to be addressed. Some individuals engaging in these highly

rewarding behaviors may develop addictive symptoms such as an excessive and uncontrolled behavior engagement with the experience of negative consequences (Brand et al., 2020; Fineberg et al., 2022).

In the recent version of the International Classification of Diseases (ICD-11; World-Health-Organization, 2022), certain addictive behaviors have been categorized as disorders due to addictive behaviors, namely gaming disorder (GD) and gambling disorder. The experience of impaired control over the behavior is one key criterion both in the ICD-11 and the DSM-5 (American Psychiatric Association, 2022). Further symptoms in the ICD-11 are increasing priority of the behavior and continued engagement in the behavior despite experiencing negative consequences as well as marked distress and/or impaired functioning in different areas. Besides gaming and gambling, other behaviors have recently been discussed as potential disorders due to addictive behaviors (Brand et al., 2020). One of these is problematic pornography use (PPU) that has been allocated in the ICD-11 as a phenotype of compulsive sexual behavior disorders, classified as an impulse control disorder (World-Health-Organization, 2022). PPU is characterized by similar symptoms such as impaired control (Chen, Jiang, Luo, Kraus, & Bőthe, 2022), and underlying mechanisms involved in the development and maintenance (Antons & Brand, 2018; Brand, Snagowski, Laier, & Maderwald, 2016; Gola et al., 2017), which is why PPU is often discussed in the context of addiction models (Antons & Brand, 2021; Brand, Antons, Wegmann, & Potenza, 2019; Brand et al., 2020; Kraus et al., 2018; Kraus & Sweeney, 2019).

At a behavioral level, the symptom "impaired control" is reflected in single moments of impaired control in daily life. These moments may involve engaging in the behavior longer than originally planned despite other obligations or even despite negative consequences, for instance missing an important work meeting. While research has examined the underlying mechanisms leading to symptoms of impaired control in (potential) behavioral addictions such as GD and PPU (Chen et al., 2022; Kowalik, Baggio, King, & Delfabbro, 2025; Kowalik & Delfabbro, 2025), mechanisms that lead to moments of impaired control in everyday life have received little attention despite their relevance for developing and implementing effective treatment and prevention strategies.

In current theories and models that describe underlying mechanisms of different addictive behaviors (including GD and PPU), two competing processes have been highlighted: affective (e.g., cue reactivity and craving) and reflective processes (e.g., inhibitory control) (Bechara, 2005; Brand, 2022; Dong & Potenza, 2014; Everitt & Robbins, 2005, 2016). Cue reactivity refers to the attention of the brain's reward system towards reward-associated stimuli to which behavioral responses follow (Drummond, 2000) and is linked to craving which is characterized by intense affective and physiological desires towards a certain stimulus or behavior, that are difficult to resist (Antons, Trotzke, Wegmann, & Brand, 2019; Robinson & Berridge, 1993). According to the I-PACE model (Brand et al., 2025; Brand, Wegmann, et al., 2019), in later stages of addiction, heightened cue reactivity and craving as affective mechanisms diminish stimulus-specific inhibitory control over the behavior (the reflective mechanism), consequently increasing the likelihood of moments of impaired control. Craving intensity increases and craving quality might change from reward craving (gratifying craving) to relief craving (compensatory craving) (Antons, Müller, et al., 2025). Particularly when craving serves as compensation for negative states, inhibitory control becomes crucial to prevent moments of impaired control in everyday life, as impaired control reflects a failure of reflective regulation under dominant compensation motives. Craving is linked to higher symptom severity of behavioral addictions, behavior enactment, and relapse measured in laboratory as well as real-life settings (Antons, Müller, et al., 2025; Hawker, Merkouris, Youssef, & Dowling, 2021; López-Guerrero, Navas, Perales, Rivero, & Muela, 2023; A. Müller et al., 2025; Starcke, Antons, Trotzke, & Brand, 2018). Reduced self-control mechanisms over the behavior have been linked to pathological use and higher symptom severity (S. M. Müller et al., 2025). Evidence on the reflective mechanism of *behavior-specific* inhibitory control (BSIC) is inconsistent so far and predominantly based on cross-sectional studies (Antons, Müller, Neumann, Müller, & Steins-Loeber, 2023; Ioannidis, Hook, Wickham, Grant, & Chamberlain, 2019). Situational factors that are difficult to detect in laboratory settings might be responsible for mixed findings on BSIC. Depending on external regulating factors, such as actual opportunity to engage in the behavior and availability of devices to do so, BSIC may vary between different settings (Brand et al., 2025). In specific critical situations, for example with high craving (affective mechanism), BSIC might be especially crucial for keeping control over the behavior (Antons, Brand, & Potenza, 2020; Brand et al., 2025; Hawker et al., 2021). To our knowledge, the methods predominantly used so far—such as self-reports or laboratory studies with limited ecological validity—are only of limited use for understanding situation-specific BSIC. Knorr, Wegmann, Müller, Brand, and Antons (2025) identified clear knowledge gaps, as BSIC has not yet been investigated in natural environments in the context of behavioral addictions. Hence, we aim to illustrate the interplay of difficulties in controlling behavior with underlying mechanisms in current situations. To capture momentary mechanisms, ambulatory assessments offer a promising approach to collect longitudinal and real-life data.

Ambulatory assessments capture behavior and affect in real time and everyday contexts, thereby reducing recall bias (Naab, Karnowski, & Schlütz, 2019; Trull & Ebner-Priemer, 2013). Methods such as experience sampling, ecological momentary assessment, and daily diaries share key features: a focus on the individual, real-life settings, and repeated measures of current or recent states (Csikszentmihalyi & Larson, 1987; Stone & Shiffman, 1994; Trull & Ebner-Priemer, 2013).

Based on the described theoretical assumptions and evidence so far, craving and BSIC mechanisms are assumed as two underlying pathways of moments of impaired control in real-life. Cue reactivity and craving might function as an affective pathway, increasing the likelihood of behavior

engagement and inhibitory control might function as the cognitive, reflective pathway controlling behavior engagement. Investigating these two pathways in an ambulatory assessment combined with a laboratory assessment would provide a novel multi-method approach to gain insight into situation-specific mechanisms within individuals and context-independent mechanisms between individuals.

The present research

Our study aim was to investigate cue reactivity and craving and BSIC as predictors of moments of impaired control in real life over gaming and pornography use in a laboratory setting as well as situation-specific in the real-life environment. Despite differences in classification categories (as mentioned earlier), both GD and PPU are characterized by increased urges to engage in the behavior and impaired control. Compared to other types of online behaviors (e.g., social networking, online buying-shopping), GD and PPU also tend to exhibit more similar usage patterns – such as engagement primarily in non-public settings and longer usage durations per session. Since these patterns are particularly relevant for defining concrete moments of diminished control in everyday life, we focused on these two groups in the present study.

We aimed to explicitly identify moments of impaired control in the real-life environment and investigate the underlying mechanisms of cue reactivity and craving (the affective pathway) and inhibitory control (the cognitive pathway). We distinguish between two levels of analysis: level 1 (moment-to-moment, within-person fluctuations) and level 2 (stable, between-person differences in average craving and inhibitory control).

On the between-person level (level 2), we hypothesized that individuals with higher craving following a cue-reactivity paradigm show (H1) reduced BSIC in the laboratory assessment as well as (H2) higher average craving ratings and (H3) more pronounced average impairments in BSIC in the real-life environment. Individuals with lower BSIC in the laboratory experience lower average BSIC in the real-life environment (H4). Higher average craving ratings in the real-life environment predict average lower BSIC ratings (H5a). Individuals with average higher craving (H6a) and lower average BSIC in the real-life environment (H7a) experience more frequent moments of impaired control.

On the within-person level (level 1), we hypothesized that situations with higher craving predict lower BSIC (H5b) and the occurrence of a moment of impaired control (H6b). Lower BSIC in the real-life environment predict the occurrence of a moment of impaired control (H7b). No cross-level mediation was tested; mediations were tested separately for within- and between-person levels. These hypotheses are summarized in the depicted model in Fig. 1.

METHODS

Participants

Inclusion criteria were risky or pathological use of pornography or gaming, the experience of impaired self-control over gaming or pornography use in the last four weeks, and access to an Android or IOS Smartphone. The study was advertised in Germany via social networks (e.g., WhatsApp, Instagram, Facebook etc.), participants databases with analog flyers in local supermarkets, cafes etc., and cooperations with local addiction help centers. A time slot for the pre-screening via telephone was arranged via e-mail and appointment for the laboratory assessment was selected via an online calendar. Data collection was part of an overarching ongoing project. The present sample was collected between July, 2023, and July, 2025.

Procedure

The hypotheses and analysis plan are preregistered and available at OSF (DOI: 10.17605/OSF.IO/6NWCT) and the full procedure and test battery of the overarching project is preregistered and available at OSF (DOI: 10.17605/OSF.IO/MXYPW). Participants were screened regarding the inclusion and exclusion criteria during the telephone interview. Severity

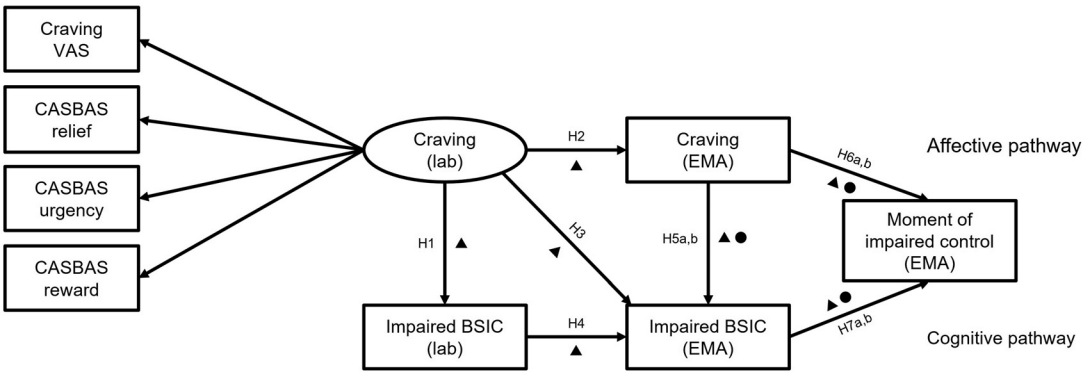

Fig. 1. Summary of the hypothesized structural equation model

Note. VAS = visual analogue scale; CASBAS = Craving Assessment Scale for Behavioral Addictions and Substance-use Disorders; lab = laboratory assessment; EMA = ecological momentary assessment; BSIC = behavior-specific inhibitory control; ▲ = level 2 (between-person); ● = level 1 (within-person); no cross-level mediation is hypothesized.

of the addictive behavior (9 yes/no items based on DSM-5 criteria for gaming disorder, e.g., "Have you noticed that other activities (apart from pornography use/gaming) have become increasingly less enjoyable than they used to, or that you are engaging in them less?") was determined during the telephone screening. Participants were allowed to fulfill criteria in both behavior domains and were assigned to the group corresponding to the behavior for which they met more criteria. If the number of fulfilled criteria was identical for both behavior domains, participants were allocated to the pornography group to increase its sample size and statistical power. The telephone screening criteria are available in the Supplementary material (S1).

The first part of the study was the laboratory assessment. Participants were instructed about the procedure and declared their consent. They answered questionnaires, were presented with a cue-reactivity paradigm, and participated in a behavior-specific Stop-Signal Task (besides other tasks not relevant for the current analysis, see preregistration). At the end of the laboratory session, participants were asked to plan their exact usage times for the following EMA period and to comply with them as best as possible to ensure a basic motivation for self-control and to enable the identification of moments of impaired control. Finally, the instructions for the EMA period were consulted. Participants were compensated with 10€/h for the laboratory assessment and with up to 70€ for the ambulatory assessment (based on their adherence rate). The procedure is visualized in Fig. 2.

Measures

Laboratory assessment

Structured Clinical Interview for specific problematic usage of the internet. A trained researcher conducted the Structured Clinical Interview for specific problematic usage of the internet (AICA-SKI:IBS; K. W. Müller, Beutel, & Wölfling, 2017), a standardized diagnostic interview based on DSM-5 criteria. The interview was adapted for problematic gaming or pornography-use and supplemented with six items concerning functional impairment. Based on the number of fulfilled DSM-5 criteria, participants were classified as individuals with nonproblematic use (0 criteria fulfilled), risky use (1–4 criteria fulfilled), or pathological use (5–9 criteria fulfilled & functional impairment in at least one area of life).

Assessment of criteria for specific internet-use disorders. Additionally to the diagnostic interview, we implemented the Assessment of Criteria for Specific Internet-Use Disorders (ACSID-11; S. M. Müller et al., 2022) as a symptom severity questionnaire. The questionnaire is based on the ICD-11 diagnostic criteria for gaming disorder and evaluates experiences of impaired control, increased priority, continuation or escalation, functional impairment, and significant distress over the past 12 months due to behavior engagement. Each of the 11 items is rated regarding frequency and severity and sum scores were computed separately for the frequency and intensity dimensions. In this sample, Cronbach's α was .87 for the frequency and α = .87 for the intensity scale across both behavior groups.

Imagery-based neutral/desire thinking paradigm. State craving towards gaming/pornography use was induced by presenting an auditive imagery-based (desire) thinking paradigm via headphones. The audio scripts were designed to evoke vivid mental imagery, sensory impressions, and affective states. The audio recording was 2.5 min long and contained a neutral scenario condition where teeth brushing should be imagined and an addiction-related condition where behavior engagement should be imagined. Before,

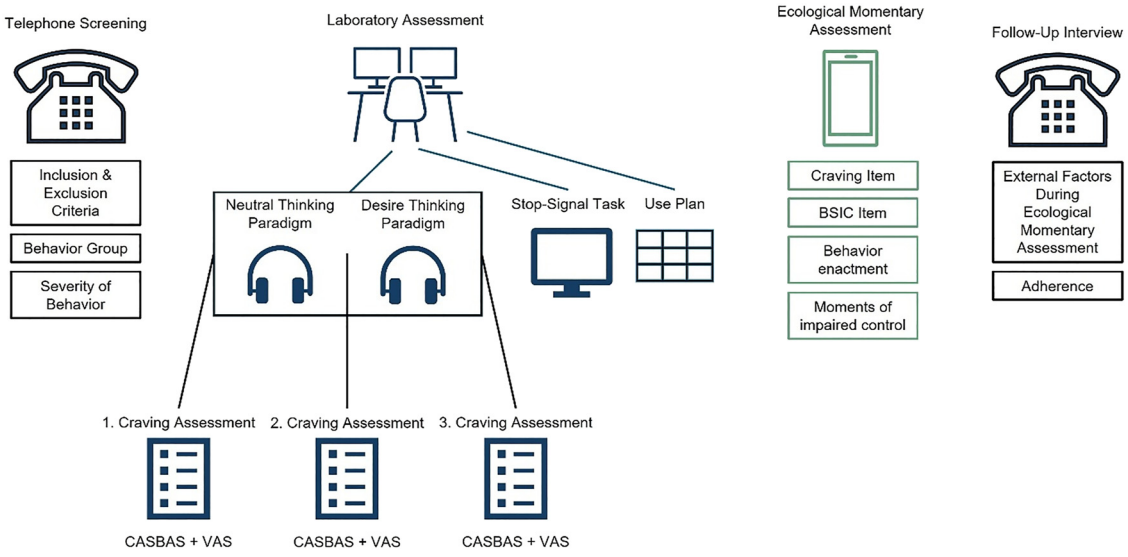

Fig. 2. Study procedure

Note. CASBAS = Craving Assessment Scale for Behavioral Addictions and Substance-use Disorders; VAS = visual analogue scale; BSIC = behavior-specific inhibitory control.

between, and after the two audio scripts, momentary craving was rated.

Visual analog scale (VAS). Participants were asked to rate their current desire to game/use pornography on a VAS (0–100) before and after the cue-reactivity paradigm. This single-item assessment is often used to assess craving; however, it bears the risk of mistaken different affective and physiological states as craving (e.g., excitement or anxiousness) (Antons et al., 2019; Rose, Field, Franken, & Munafo, 2013).

Craving assessment for behavioral addictions. Additionally to the VAS, the Craving Assessment Scale for Behavioral Addictions and Substance-use Disorders (CASBAS; Antons, Brandtner, et al., 2025; Antons et al., 2019) was presented as a self-report measurement for craving. The scale consists of nine items, however, only six were included in the CASBAS score, each answered on a 5-point Likert scale (completely disagree to completely agree). Three subscales assess aspects of craving: reward (e.g., "Gaming now would give me a sense of satisfaction."), urgency (e.g., "Using Internet-pornography now is something I wish so much that my heart beats faster."), and relief (e.g., "Using Internet-pornography now would ensure that I am less stressed"). A sum score was calculated and internal consistency in the current sample after the cue-reactivity paradigm was evaluated using inter-item correlations and Spearman–Brown reliabilities. The reward subscale showed an inter-item correlation of .62 and a Spearman-Brown reliability of .77, the relief subscale an inter-item correlation of .76 and a Spearman-Brown reliability of .86, and the urgency subscale an inter-item correlation of .58 and a Spearman-Brown reliability of .74.

Behavior-specific inhibitory control

A modified Stop-Signal Task (SST) was used (Casey et al., 2018; Verbruggen et al., 2019). The modification includes proximal behavior-related pictures (explicit gaming-/pornography-related pictures) that are randomized and presented in the background during the task (Antons & Brand, 2018, 2020). Images for the gaming condition were selected based on lists of the most popular games in June 2023 (e.g., Newzoo, 2023). Pornography images were chosen based on the 15 most popular categories on Pornhub in 2022 (Pornhub Insights, 2023). Stimuli included heterosexual and homosexual content (male–male, female–female), and participants could choose among the three sexual orientations. For each gaming or pornography category, three images were presented. After the SST, participants were randomly shown one image from each category and rated how strongly they associated it with their typical gaming or pornography use (0 = not at all - 10 = very strongly). The task consists of 270 go- and 90 stop-trials. In go-trials, an arrow pointing right or left indicates which button (left or right arrow button on the keyboard) should be pressed. In stop-trials, the go-signal (arrow) is followed by a stop-signal (red cross over the arrow) indicating that no button should be pressed at all. Individuals should try to stop their already initiated response on the go-signal and at best are able to stop the go response before pressing the key. They are instructed not to wait on the stop-signal. The stop-signal-reaction time (SSRT) as a measure for behavior-specific inhibitory control is estimated based on the horse-race model and the integration method (Casey et al., 2018; Verbruggen et al., 2019). Additionally, context independence was ensured by comparing reaction times on go-trials and failed stop-trials where the latter should not exceed the former.

EMA

The EMA was conducted with the *RealLifeExp* Application (LifeData, 2025) which is available in Android and Apple App-Stores. The EMA period was seven days long with four notification-initiated assessments (*random assessments* in morning, midday, afternoon, evening) per day, between 9am and 11pm. Notifications had to be answered within 30 min. Additionally, individuals were instructed to complete event-based assessments after they engaged in gaming/pornography use (*session assessment*) which were continuously available. Lastly, a user-initiated assessment (*temptation assessment*) was also continuously available, which was identical to the *random assessment*. Participants were instructed to complete it every time they experienced the urge to engage in the behavior. All EMA items are displayed in Table 1. Participants received 35€ for completing at least 50% of the notification-initiated assessments (= 14 prompts) and 70€ for completing at least 75% of the notification-initiated assessments (= 21 prompts). After the EMA week, a short follow-up interview via telephone was conducted.

Statistical analysis

Craving assessments before and after the cue-reactivity paradigm were compared with repeated-measures ANOVA using base R (Version 4.4.0; R Core Team, 2024) and the *emmeans* package (Lenth, 2024). Post-paradigm craving ratings as indicators of peak craving were included as predictors in the measurement model as individual peak craving was expected to predict average craving in everyday life. EMA random and temptation assessments were matched with subsequent session assessments based on session start times. If no use session occurred between two random/temptations assessments, moment of impaired control was defined as zero. If multiple use sessions occurred, only the first use session was retained. Use sessions without a preceding random or temptation assessment were excluded. A gap of >24 h between random/temptation assessment and use session meant that moment of impaired control was also defined as zero. The data matching procedure is visualized in Fig. 3.

A two-level SEM tested affective and cognitive pathways of moments of impaired control. The model incorporated both between-person (level 2) and within-person (level 1) variation across the EMA period and was estimated with *robust Maximum Likelihood (MLR)* and *Montecarlo integration* with the multilevel add-on in Mplus (Version 8.11; Muthén & Muthén, 1998–2017). Craving (latent factor

Table 1. EMA measures

Session	Variable	Item	Response format
Random & temptation assessment			
	Craving	Right now, how strong is your urge to game/use pornography?	(0) No urge at all – (100) very strong urge
	Conflict	Right now, is there a conflict between personal reasons not to game/use pornography and your desire to do so? (e.g., other commitments, a general goal to game/use less, the use plan you created, etc.)	(1) yes (2) no
	Motivation to regulate (**only presented if conflict = yes**)	Right now, are you motivated to regulate your gaming/pornography use?	(1) yes (2) no
	Behavior-specific inhibitory control (BISC, **only presented if conflict & motivation = yes**)	Right now, how difficult is it for you, to withhold from gaming/using pornography?	(0) Not at all – (100) very difficult (recoded for analyses, higher scores indicate higher BSIC)
	Situational constraints	Right now, would it be technically possible to game/use pornography (e.g., because device is available)?	(1) yes (2) no
Session assessment			
	Session start time	When did you start the session?	yyyy-mm-dd hh:mm:ss
	Session end time	When did you end the session?	yyyy-mm-dd hh:mm:ss
	Moment of impaired control	Did you game/use pornography longer or more intensely than you initially planned to? Did you game/use pornography even though you had other things to do/wanted to do other things? Did you game/use pornography even though this resulted in negative consequences for you?	(1) yes (2) no

modeled by CASBAS subscales and craving VAS) and BSIC in the EMA were mediators at both levels; moment of impaired control in EMA (binary: 0 = none, 1 = present) was the dependent variable. Between-person predictors were laboratory craving ratings and BSIC. The SSRT was logarithmized; the model was computed with random intercepts to reduce complexity and risk of misspecification given the sample size (Barr, Levy, Scheepers, & Tily, 2013). Level-1 predictors were person-mean centered and level-2 predictors were grand-mean centered (Brincks et al., 2017). Significance level was $\alpha = .05$. Effect size metrics were standardized beta coefficients (β) and *Odds Ratio* (*OR*). As conventional SEM fit indices were not applicable for two-level logistic SEM in Mplus, factor loadings for the latent modeling of craving were estimated separately in R with *lavaan* (Rosseel, 2012). Fit indices included *Root Mean Square Error of Approximation* (RMSEA; good fit ≤0.05, acceptable fit ≤0.10), *Root Mean Square Residual (*SMRS; good fit ≤0.05, acceptable fit ≤0.10), *Comparative Fit Index* CFI (good fit ≥0.97, acceptable fit ≥0.95) and a non-significant χ^2-test ($p > .05$) (Schermelleh-Engel, Moosbrugger, & Müller, 2003).

As the BSIC item was only presented following conflict endorsement and motivation to regulate behavior, BSIC data is missing by design for all non-conflict prompts (i.e., structural/conditional missingness). Therefore, we did not impute data. Only responses from the craving EMA items were included where participants also reported experiencing an inner conflict since a moment of impaired control can only occur when there is a reason to control the behavior. No listwise deletion was implemented in Mplus. If less than 3 observations were recorded on the EMA variables (level 1), those observations were recoded as missing to establish sufficient within-variance (Hox, Moerbeek, & Van De Schoot, 2017). Accordingly, responses on the dependent variable *moment of impaired control* were also recoded as missing in those cases.

We conducted sensitivity analyses by estimating path coefficients separately for the gaming and pornography-use group, as well as for male and female participants. Group differences were assessed in R using *z*-tests for independent estimates, with *p*-values corrected for multiple comparisons using the False Discovery Rate (Benjamini & Hochberg, 1995).

Ethics

The study procedures were carried out in accordance with the Declaration of Helsinki. The Institutional Review Board of the University of Duisburg-Essen [ID: 1911APBM0457] approved the study. All subjects were informed about the study and all provided informed consent. To ensure compliance with the European Union's General Data Protection Regulation (GDPR) and to enable pseudonymization across projects, the encryption-based pseudonymization framework ALIIAS was employed (Englert et al., 2023).

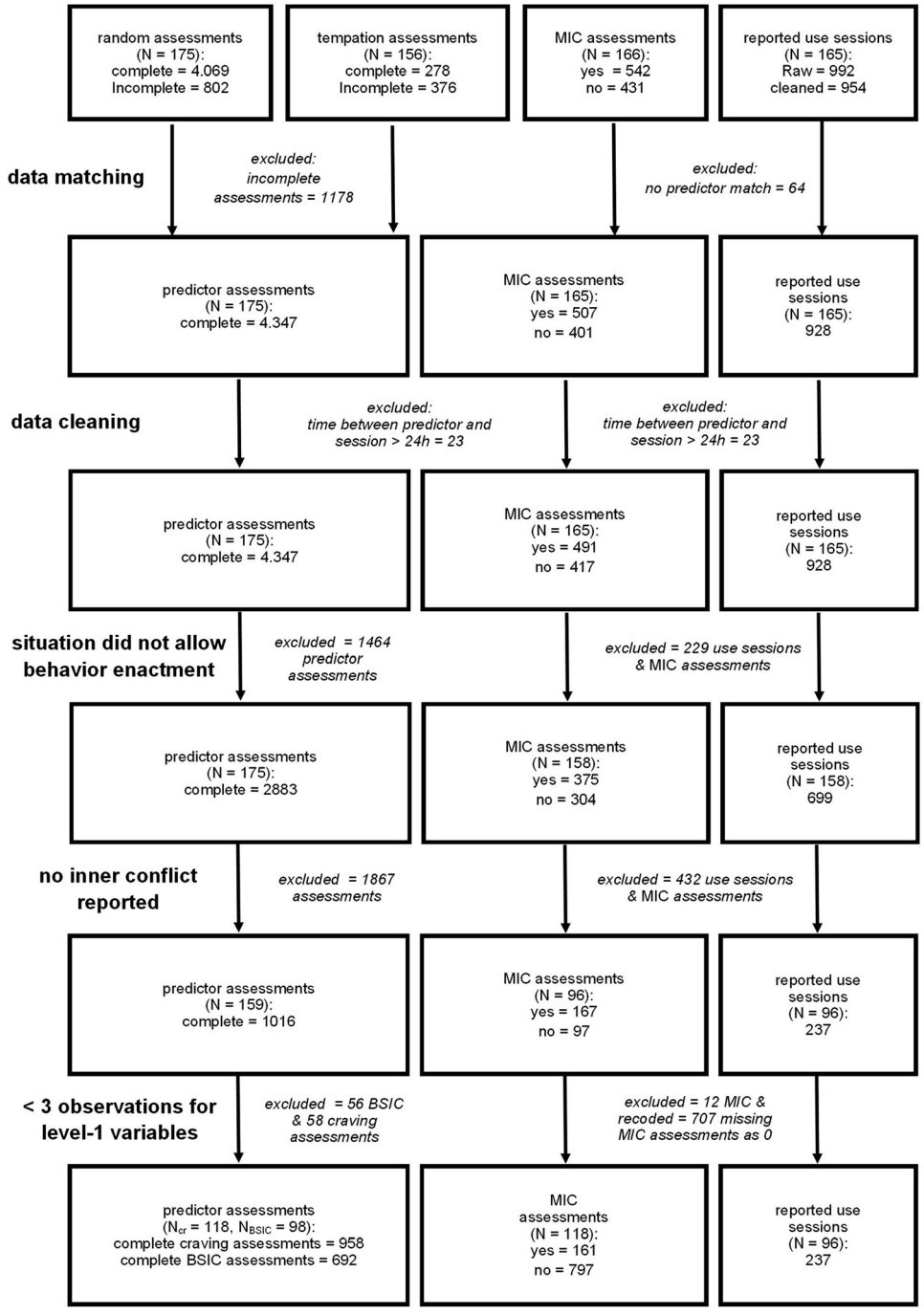

Fig. 3. Flow chart of EMA data handling

Note. Data matching = random and temptation assessments were matched to subsequent session assessments; data cleaning = if time between predictors and session assessment >24 h, moment of impaired control was defined as zero; MIC = moment of impaired control; BSIC = behavior-specific inhibitory control.

RESULTS

Descriptive statistics and craving induction

Overall, 175 individuals participated in this study, of which 118 were included in the analysis. Descriptive statistics of demographic and main variables are summarized in Table 2. Descriptive information about the complete sample is available in the Supplementary material (S2). The final sample included 75 male participants, 42 females and one diverse. In the gaming group, 74 individuals were included and 44 in the pornography group. Based on the diagnostic interview, 21 individuals were allocated to the nonproblematic-use group, 73 in the risky-use, and 24 in the pathological-use group, and n = 68 reported experiencing moments of impaired control in their daily lives across the time period of seven days.

Table 2. Descriptive statistics

Variable	*N* (Participants/observations)	*M*	$SD_{between}$	SD_{within}	*ICC*	*Min*	*Max*
Age	118	26.16	7.72	–	–	18.00	62.00
ACSID-11 frequency	118	15.33	7.06	–	–	0.00	31.00
ACSID-11 intensity	118	13.61	6.95	–	–	0.00	30.00
Craving VAS	118	44.97	27.50	–	–	0.00	100.00
CASBAS relief	118	1.90	0.91	–	–	0.33	3.67
CASBAS reward	118	2.34	0.79	–	–	0.33	3.67
CASBAS urgency	118	1.19	0.89	–	–	0.33	3.67
CASBAS sum score	118	13.31	6.98	–	–	0.00	30.00
Stop-Signal reaction time (in ms)	115	232.92	51.52	–	–	54.36	377.94
Craving (EMA)	118/958	42.08	18.65	25.17	.354	0.00	100.00
BSIC (EMA)	98/692	34.59	18.64	19.88	.463	0.00	100.00
MIC (EMA)	118/958	0.16	0.10	0.35	.101	0.00	1.00
Use time (min)	92/259	138.72	83.83	211.32	.136	1.00	1560

Note. ACSID11 = Assessment of Criteria for Specific Internet-Use Disorders; VAS = visual analogue scale; CASBAS = Craving Assessment Scale for Behavioral Addictions and Substance-use Disorders; ms = milliseconds; EMA = ecological momentary assessment; BSIC = behavior-specific inhibitory control; MIC = moment of impaired control; ICC = intraclass correlation.

Compliance rate for random assessments in the EMA across all 175 participants was 83.04% (~23 random assessments per person). There was no dropout and all participants finished the study with the brief follow-up telephone survey. Across all 175 participants, 4900 notifications were planned of which 9 were not sent due to technical issues. Average time latency from notification to answering the survey was 4.49 min. Mean time latency between random/temptation assessments and use session was 293min (~5 h).

Bivariate correlations among the EMA variables are displayed in Table 3. Multilevel correlations among EMA variables were calculated using the *misty::multilevel.cor* function in R (Yanagida, 2025), specifying clusters by participant. Pearson correlations were used for continuous variables, and correlations involving the binary outcome variable correspond to point-biserial correlations. As the correlation between craving (EMA) and BSIC (EMA) was moderate (r_{within} = .65) to strong ($r_{between}$ = .76), multicollinearity was evaluated using variance inflation factor (VIF) computed separately at the within- (person-mean centered) and between-person (person means) levels (Hox et al., 2017). With $VIF_{between}$ = 2.210 and VIF_{within} = 1.732, both well below common thresholds (e.g., 5 or 10; O'Brien, 2007), no problematic multicollinearity was indicated.

The CASBAS sum score after the cue-reactivity paradigm was significantly higher than before ($F(1, 117) = 7.36$, p = .020, η^2 = .05). For the VAS, ratings were also significantly higher after the cue-reactivity paradigm compared to before ($F(1, 117) = 72.28$, $p < .001$, η^2 = .34).

Individuals with higher symptom severity showed more frequent moments of impaired control (ACSID-11 frequency: r = .391, $p < .001$, ACSID-11 intensity: r = .421, $p < .001$).

Measurement model

Model estimates are depicted in Fig. 4. Odds ratio, standard errors, and confidence intervals are presented in Table 4. At the between-person level, latent modeling of craving was estimated separately and showed the following model fits: RMSEA = .123, SRMR = .019, CFI = .988, and $\chi^2(2)$ = 5.585 (p = .061). SRMR, CFI, and χ^2 indicated good model fit, RMSEA did not. Because SRMR and CFI are less susceptible to bias due to small degrees of freedom than RMSEA (Kenny, Kaniskan, & McCoach, 2015; Shi, Distefano, Maydeu-Olivares, & Lee, 2022), model fit is sufficient for the latent modeling of craving. The factor loading of the VAS was fixed to 1 for model identification. Standardized

Table 3. Bivariate correlations between EMA variables

Variables	*N* (Participants/observations)	*M*	1	2	3
1. Craving	118/958	42.08		0.74***	0.29
2. BSIC	98/692	34.59	0.65***		0.16
3. MIC	118/958	0.15	0.13**	0.13**	

Note. Lower triangle (grey) = within-person correlations, upper triangle (blue) = between-person correlations; BSIC = behavior-specific inhibitory control; MIC = moment of impaired control; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

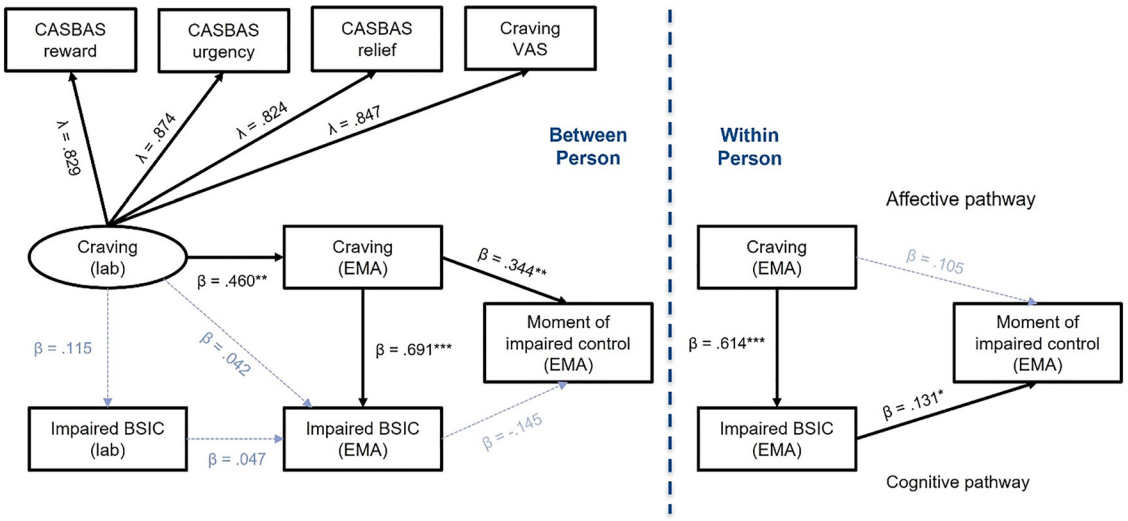

Fig. 4. Standardized measurement model

Note. λ = standardized factor loads; β = standardized path coefficient; VAS = visual analogue scale; CASBAS = Craving Assessment Scale for Behavioral Addictions and Substance-use Disorders; lab = laboratory assessment; EMA = ecological momentary assessment; BSIC = behavior-specific inhibitory control; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 4. Standardized effects for the hypothesized measurement model

Level	Predictor	Outcome	*OR* [95% CI]	*β*	SE	*z*	*p*
Within level							
	Craving (EMA)	MIC	1.008 [0.997, 1.020]	.105	0.073	1.439	.150
	BSIC (EMA)	MIC	1.013 [1.000, 1.026]	.131	0.065	2.028	**.043***
	Craving (EMA)	BSIC (EMA)		.614	0.048	12.804	**<.001*****
Indirect	Craving (EMA) → BSIC (EMA)	MIC		.08	0.040	1.991	**.046***
Between level							
	Craving (EMA)	MIC		.344	0.122	2.817	**.005****
	BSIC (EMA)	MIC		−.145	0.134	−1.078	.281
	Craving (EMA)	BSIC (EMA)		.691	0.098	7.048	**<.001*****
	Craving (lab) by	Craving VAS		.847	0.033	25.781	**<.001*****
		CASBAS reward		.829	0.032	25.613	**<.001*****
		CASBAS relief		.824	0.035	23.352	**<.001*****
		CASBAS urgency		.874	0.028	30.737	**<.001*****
	Craving (lab)	Craving (EMA)		.460	0.103	4.472	**<.001*****
	Craving (lab)	BSIC (EMA)		.042	0.083	.504	.614
	Craving (lab)	SSRT (lab)		.115	0.091	1.265	.206
	SSRT (lab)	BSIC (EMA)		.003	0.052	0.061	.951
Indirect	Craving (lab) → craving (EMA)	MIC		.178	0.078	2.282	.030
Indirect	Craving (lab) → BSIC (EMA)	MIC		−.005	0.014	−0.357	.608
Indirect	BSIC (lab) → BSIC (EMA)	MIC		.000	0.007	−0.060	.952

Note. EMA = ecological momentary assessment; BSIC = behavior-specific inhibitory control; MIC = moment of impaired control; VAS = visual analogue scale; CASBAS = Craving Assessment Scale for Behavioral Addictions and Substance-use Disorders; lab = laboratory assessment; SSRT = Stop-Signal reaction time; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

factor loadings were .847 for the VAS, .824 for the CASBA relief subscale, .829 for the reward subscale, and .874 for the urgency subscale. The standardized residual variances were .321 for the relief subscale, .313 for the reward subscale, .237 for the urgency subscale, and .283 for the VAS.

At the between-person level, higher craving in the laboratory did not significantly predict more difficulties with BSIC in the laboratory (H1) but predicted average craving ratings in the real-life environment (H2). Laboratory craving did not predict average difficulties with BSIC ratings in the real-life environment (H3). BSIC in the laboratory did not predict average difficulties with BSIC in the real-life environment (H4). Higher average craving in the EMA predicted more difficulties with BSIC in the EMA (H5a) and also more frequent moments of impaired control (H6a). Average difficulties with BSIC in the EMA did not predict frequency of moments of impaired control (H7a).

At the within-person level, higher momentary craving in real-life predicted concurrent difficulties with BSIC (H5b). In turn, momentary difficulties with BSIC predicted higher likelihood of experiencing a subsequent moment of impaired control (H7b). Momentary craving did not predict a subsequent moment of impaired control (H6b).

Overall, the affective pathway showed predominant effects at the between-person level, the cognitive pathway showed predominant effects on within-person level. Interestingly, craving was a significant predictor for moments of impaired control at the between-person level but not at the within-person level.

Sensitivity analyses comparing male and female participants and gaming vs. pornography-use group indicated that none of the path coefficients differed significantly between groups (z-tests, FDR-corrected p-values all >0.05; see Supplementary material S3–S4). Although some point estimates varied, these differences were within the range of sampling variability and not statistically reliable.

DISCUSSION

The current study showed that the occurrence of moments of impaired control in the real-life environment could be predicted by both affective and cognitive mechanisms: (1) moments of impaired control occurred more often in individuals with higher average degrees of craving in the real-life environment. However, (2) the occurrence of a moment of impaired control depended on the degree of control over the behavior in the specific situation and less on the craving experienced in the situation. Moreover, (3) in the natural environment, higher craving was related with reduced BSIC. These findings are based on a multimethod approach including a laboratory setting and an EMA as well as self-report measures and objective behavioral paradigms.

Relevance of affective and cognitive mechanisms for the occurrence of moments of impaired control

The observed underlying affective and cognitive mechanisms of moments of impaired control are consistent with dual process models of addictive behaviors (Bechara, 2005; Zilverstand & Goldstein, 2020) and current theories of the development and maintenance of problematic usage of the internet (Brand, 2022; Brand et al., 2025; Brand, Wegmann, et al., 2019). Craving in real life was a strong predictor of moments of impaired control in real life (between-level; H5a). These results support previous studies highlighting the role of craving in triggering behavioral engagement and relapse in behavioral addictions (López-Guerrero et al., 2023; Mallorquí-Bagué, Mestre-Bach, & Testa, 2023; Starcke et al., 2018). Moreover, craving measures in the laboratory could predict average experienced craving in daily life (between-person effect; H2), indicating that laboratory measures of craving are good indicators for average craving in real-life environments. This is a new finding that has not been explicitly examined in studies so far. On the within-person level, craving did not directly predict likelihood of experiencing a subsequent moment of impaired control (H6b). However, lower BSIC predicted a higher likelihood of a subsequent moment of impaired control (within-level; H7b), and the effect of craving was mediated by reduced BSIC. This mediation is consistent with the assumptions of the I-PACE model and empirical evidence (Antons et al., 2020; Mallorquí-Bagué et al., 2023). The interplay of affective and reflective mechanisms increase the risk of experiencing moments of impaired control which were defined as behavior engagement despite negative consequences, other obligations or personal reasons not to game/use pornography. These moments of impaired control were experienced by the majority of the participants and linked to higher symptom severity, emphasizing the clinical relevance of such moments of impaired control in potentially addictive behaviors.

Importance of inter- and intra-individual variations

The current results also indicate differences in mechanisms on inter- and intraindividual levels emphasizing the importance of multilevel approaches to avoid blurring inter- and intraindividual effects (Knorr et al., 2025). Specifically, the effect of BSIC on moments of impaired control was only significant within individuals but not on an overall (between-person) level (H7a,b). This difference of inter- vs. intra-individual mechanisms indicates that behavior- and situation-specific inhibitory control reductions are particularly crucial for moments of impaired control in specific situations, i.e. where craving and temptation is high and self-control is needed (Brand et al., 2025). Reducing overall craving in the daily life (e.g., by reducing availability of possible triggers) could be highly relevant for treatment and prevention strategies, while also addressing intraindividual and situation-specific variations in BSIC as a key factor for reducing moments of impaired control.

Impaired control as a facet of the craving construct

In the EMA, craving and BSIC were quite strongly related. Although the two items assessing each mechanism were planned to assess two distinct mechanisms (craving and BSIC), it is not surprising that responses on them were closely linked. The craving item asked specifically about an "urge" towards the behavior and the BSIC item about "difficulties to withhold" which could also be described as irresistibility of the urge. Considering craving definitions in the context of behavioral addictions, the mechanism is often defined as an *irresistible urge* towards the behavior or behavior-related stimuli (Antons et al., 2020; Brand, Young, Laier, Wölfling, & Potenza, 2016; Trotzke, Starcke, Müller, & Brand, 2019). Hence, both items might actually not measure two distinct mechanisms but rather two important aspects of the concept of craving itself. Based on our results, it could be argued that situation-specific irresistibility of craving is the determining factor for experiencing a subsequent moment of impaired control while the urge-component of craving is overall related to generally experiencing impaired control in the daily life.

Whether irresistibility reflects a motivational mechanism or rather a reward-driven (gratifying) or a relief-driven (compensating) mechanisms, should be further examined. Especially in the context of PPU, gratification and compensation have rarely been empirically investigated (Wegmann, Knorr, Antons, & Brand, 2025). Furthermore, how the different qualities of craving, namely reward-, relief- or urgency-driven craving (Antons, Müller, et al., 2025; Brand, Wegmann, et al., 2019), relate to moments of impaired control in the daily life, could be particularly interesting for future research. Hereby, considering differences in sexual cravings which occur in the context of PPU but also nonproblematic sexual behaviors and solely "problematic" craving, namely in the context of GD (Franken, 2023). To further enable distinct assessments of craving and BSIC in real-life settings, objective measures of inhibitory control (e.g., SST) could be implemented in future EMA studies (Lee et al., 2023).

Ecological validity of laboratory measures

While craving measures showed good reliability across assessment settings, this was not the case for BSIC measures and across different mechanisms. The SSRT, as a measure of inhibitory control ability, was unrelated to the momentary everyday ratings of BSIC (between-person effect; H4), highlighting fundamental differences in laboratory vs. real-life assessments of inhibitory control.

Low reliability and inconsistencies with inhibition tasks (such as the SST) have been reported in previous studies as well (Antons et al., 2023; Mestre-Bach & Potenza, 2024). One reason for the low reliability of the task in the current context might be that it measures motoric abilities to inhibit action as one facet of inhibitory control that is less relevant for behavior-specific inhibitory control in real-life situations. Furthermore, as discussed, BSIC is possibly only reduced in specific critical situations, for instance, when craving towards the behavior is high and behavior enactment is technically possible in that moment (Brand et al., 2025). While participants did report higher craving on the VAS after the cue-reactivity paradigm, actual behavior enactment was not possible in the laboratory settings contrary to the real-life setting.

Limitations

There are some noteworthy limitations. The current sample mostly contains individuals with risky use who occasionally experience moments of impaired control in their daily lives. Future studies should further investigate potential differences of situational mechanisms in individuals with pathological vs. risky use. Furthermore, the instruction to define a specific plan for behavior enactment could have potentially biased participants behavior regarding behavior enactment.

As discussed earlier, laboratory and ambulatory settings have advantages and disadvantages. Standardized procedures in combining the two settings are missing. Single items in the EMA might be less suitable to assess complex constructs such as craving and impaired control. Some individuals, especially those with addictive behaviors, might have reduced interoceptive abilities (Turel & Bechara, 2016). Cue reactivity might become more and more automatic and unconscious in later stages of behavioral addictions. Assessing intensity and quality of craving with objective (e.g., physiological measures) and self-report data could be helpful for assessing these unconscious facets of cue reactivity and craving.

Conclusion

Our findings emphasize the importance of EMA studies for understanding underlying mechanisms of moments of impaired control in everyday life in individuals with problematic/addictive behaviors. Furthermore, differences of within- versus between-person mechanisms need to be kept in mind and separately examined in multilevel-structured data. It seems that craving is a more stable and overall predictor for moments of impaired control in gaming and problematic pornography use, and BSIC is a key mechanism nested within specific risky situations of individuals. This knowledge is quite important when differentiating between overall prevention against behavioral addiction where craving could be a key risk factor and individual therapeutic strategies where improving BSIC could be a key factor.

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SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at https://doi.org/10.1556/2006.2025.00102.

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