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Response Inhibition in borderline personality disorder assessed with a gamified stop signal task

Nadine Barakat[1,2], Martin Dechant[3], Emmanuel Poulet[1,4], Lionel Cailhol[5,6,7,8], Jérôme Brunelin[1,2], Maximilian A. Friehs[9,10] & Cécilia Neige[1,2,11]✉

Borderline personality disorder (BPD) is characterized by pervasive difficulties with self-image, interpersonal relationships, emotion regulation and impulse control. Impulsive behaviors can be assessed using tasks such as the stop-signal task (SST). Traditional SSTs are repetitive and cognitively demanding, requiring sustained attention and effort over extended periods. This can be challenging, particularly for clinical populations who often experience difficulties with attention, emotional regulation, and frustration tolerance. In this study, we examined whether a gamified version of the SST (gSST) could effectively differentiate inhibitory control in patients with BPD compared to healthy controls (HC), and explored associations between behavioral performance and self-reported impulsivity. Fifty participants (25 BPD, 25 HC) completed the gSST and the UPPS-P impulsivity questionnaire. Patients with BPD showed significantly faster reaction times, more choice errors, and shorter stop-signal delays, indicating impairments in proactive inhibition. Evidence for reactive inhibition deficits was, however, inconclusive, as no significant group difference emerged for the primary measure, the stop-signal reaction time (SSRT). The SSRT correlated positively with self-reported positive urgency across the sample, suggesting a link between emotionally driven impulsivity and inhibitory control as assessed with a gSST. These findings highlight the potential of gamified cognitive tasks to provide sensitive, engaging, and ecologically valid measures of impulsivity, with implications for both clinical assessment and personalized intervention strategies in BPD.

Keywords Gamification, Impulsivity, Response inhibition, Motor control

Borderline personality disorder (BPD) is a severe and complex psychiatric condition characterised by pervasive instability in self-image, interpersonal relationships, emotion regulation and impulse control[1]. Among the abnormalities in impulse control, a hallmark feature of BPD is the tendency to engage in maladaptive or reckless behaviors during episodes of heightened emotional arousal, whether positive or negative, a phenomenon referred to as *urgency*. For instance, patients with BPD may exhibit substance abuse or self-harming behaviors triggered by intense emotional distress[2,3]. Accurate assessment of impulsivity in individuals with BPD is therefore critical, as it is also a predictor of both suicidal behavior and the lethality of suicide attempts[4,5].

Impulsivity in BPD

Impulsivity is commonly evaluated using self-report questionnaires, such as the Impulsive Behavior Scale (UPPS-P)[6] that assesses five dimensions of impulsivity: *negative urgency* (the tendency to act rashly when distressed), *positive urgency* (the tendency to act rashly when feeling positive emotion), *lack of perseverance* (failure to persist in tasks or obligations), *lack of premeditation* (tendency to act without considering consequences) and *sensation seeking* (preference for novel and thrilling experiences). It is worth mentioning that positive and

[1]Le Vinatier, Psychiatrie Universitaire Lyon Métropole, Bron 69500, France. [2]Centre National de la Recherche Scientifique, Université Claude Bernard Lyon 1, Institut National de la Santé et de la Recherche Médicale, Centre de Recherche en Neurosciences de Lyon U1028 UMR5292, PSYR2, Bron 69500, France. [3]Department of Clinical Educational Health Psychology (CEHP), University College London, London, UK. [4]Emergency Psychiatry Department, Edouard Herriot Hospital, Lyon 69003, France. [5]Department of Psychiatry and Addiction, University of Montreal, Montréal, QC, Canada. [6]CIUSSS de l'Est-de-l'Île-de-Montréal, Montréal, QC, Canada. [7]Research Center of the Montreal University Institute for Mental Health, Montréal, QC, Canada. [8]CERVO Research Center, Quebec, Canada. [9]Psychology of Conflict Risk and Safety, University of Twente, Enschede, The Netherlands. [10]School of Psychology, University College Dublin, Dublin, Ireland. [11]CH Le Vinatier, 95 Bd Pinel, PSYR2 team, Bat. 416, 1st floor, Bron 69500, France. ✉email: cecilia.neige@inserm.fr

negative *urgency* are the dimensions most diagnostically specific to BPD[7,8]. Impulsivity is also assessed using objective behavioral and cognitive tasks, which complement self-report measures by providing insight into automatic or implicit processes that may not be accurately captured through self-report alone. Among these behavioral measures, the Stop-Signal Task (SST) is considered a gold-standard paradigm to evaluate reactive inhibitory control[9] —the ability to cancel an already initiated action in response to a stop signal. This form of inhibitory control, known as reactive inhibition, is engaged in response to external signals that require action cancellation. It is distinct from proactive inhibition, which involves anticipatory slowing or withholding of responses based on contextual cues or goals[10].

Although some studies have reported inhibitory control abnormalities in individuals with BPD using such tasks, the literature remains inconsistent. In a recent meta-analysis of studies evaluating inhibitory control with the SST, we identified a small but statistically significant deficit in individuals with BPD compared to healthy controls[11]. This modest effect size raises important questions regarding the sensitivity and specificity of the SST for assessing impulsivity in patients with BPD. Furthermore, the absence of a significant correlation between self-reported impulsivity and SST performance[11] suggests considerable room for optimizing the task.

Traditional SSTs are repetitive and cognitively demanding, requiring sustained attention and effort over extended durations. These demands can be particularly challenging for patients with BPD, who often experience difficulties with attention, emotional regulation, and frustration tolerance[12,13]. As a result, disengagement during task performance is common, potentially compromising data quality and interpretability. Maintaining participant motivation and engagement is therefore critical, especially when assessing vulnerable clinical populations.

Gamification in cognitive assessment

One emerging strategy to address this challenge is the usage of playful design: On one side, the application of game design elements to enhance user engagement[14,15] which is referred as gamification. Gamified tasks incorporate features such as immersive visual designs, motivating narratives, and transparent feedback on performance and progress[16–19]. The goal of gamification is to promote sustained attention and intrinsic motivation without compromising the scientific rigor of the assessments. Empirical evidence supports the feasibility and utility of this approach. A systematic review by Lumsden et al. (2016) concluded that gamified cognitive tasks, including versions of the SST, can enhance participant motivation while maintaining measurement validity[14]. A more recent study comparing traditional and gamified SSTs have shown that a gamified version elicits behavioral performance comparable to a standard task, while significantly improving participant engagement[20]. Moreover, a correlation was observed between the impulsivity/hyperactivity subscale and performance in a gamified SST in children[21]. Collectively, these findings suggest that gamification can enhance behavioral measures of impulsivity, particularly in clinical populations where task compliance is often a concern. Notwithstanding its promise, gamification comes with concerns and challenges that warrant caution in its application[22]. For example, in a longitudinal web-based SST study, gamification did not reduce participant attrition[23]. Moreover, while gamified elements may initially boost engagement, they can divert attention from task-relevant cues, potentially degrading SST performance[24]. Taken together, these considerations should be explicitly weighed when designing and interpreting gamified cognitive tasks, including SST variants.

Objective and hypothesis

The present study builds on this emerging body of work by evaluating whether a gamified version of the SST (gSST) can effectively differentiate inhibitory control performance between patients with BPD and healthy controls (HC). Specifically, we examined group differences across a range of behavioral markers derived from the gSST, including the Stop Signal Reaction Time (SSRT), reaction times and response accuracy.

Our primary objective was to assess the gSST's sensitivity in detecting core inhibitory control deficits associated with BPD, using a format designed to increase immersion and motivation. While the task incorporates game-like elements that may improve engagement and ecological relevance, these assumptions were not directly tested in the present study. Accordingly, any potential advantages of the gamified format should be regarded as preliminary and inferred from the task's design rather than from an empirical comparison with a traditional SST.

We hypothesized that significant differences would emerge between the two groups, with patients with BPD exhibiting poorer inhibitory control. We also investigated the relationship between self-reported and behavioral measures of impulsivity, focusing on the association between the SSRT and the UPPS-P scores for positive and negative urgency subscales. Based on prior evidence linking urgency to deficits in inhibitory control, we expected significant correlations between these measures, such that individuals reporting higher levels of positive or negative urgency would exhibit poorer inhibitory control, as indicated by longer SSRT. Through this work, we aim to provide preliminary evidence supporting the use of gamified cognitive tasks in both research and clinical contexts, particularly for populations in which traditional assessment paradigms may fall short.

Materials and methods

Ethical approval

This cross-sectional study is embedded in a larger registered clinical trial in patients with BPD, pre-registered on ClinicalTrials.gov (ClinicalTrials.gov ID: NCT05942651, first posted on 08/01/2024) and approved by an ethics committee (CPP Ile de France X - N° ID-RCB: 2023-A00772-43). The study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants gave their written informed consent before their inclusion in the study.

Power analysis

An a priori power analysis was conducted using G*Power version 3.1.9.6 (Universitat Dusseldorf, Dusseldorf, Germany) to determine the required sample size for an independent samples t-test comparing patients and

controls. Assuming a medium effect size (Cohen's d = 0.6), a significance level of α = 0.05, and a statistical power of 0.80, the analysis indicated that 22 participants per group would be required to detect a statistically significant difference between groups. To account for potential data loss (10%), we recruited 25 participants per group, resulting in a total sample of 50 participants.

Participants

Twenty-five patients with BPD (22 females and 3 males) and 25 matched HC (22 females and 3 males) were recruited for this study (see Table 1). Expert psychiatrists included patients with BPD if they met the following inclusion criteria: 18 years or older, diagnosed according to the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-5) criteria. Exclusion criteria for patients were neurological disorders, current comorbid psychiatric disorders or substance abuse (except tobacco), benzodiazepines intake within 24 h prior to the experimental visit, pregnancy or being under a conservatorship or guardianship order. Exclusion criteria for the HC group were a lifetime history of neurological/psychiatric disorders and medication, pregnancy or being under a conservatorship or guardianship order.

Study procedure

All participants were tested individually in a quiet room at the research facility. They first completed a brief sociodemographic questionnaire and the UPPS-P impulsivity scale. They then received standardized instructions for the gSST and completed a short practice block to ensure task comprehension. The full gSST lasted approximately 20 min. Breaks were offered between each block (see Task design below) to ensure comfort and sustained attention. Although the task incorporated engaging visual and narrative elements, no quantitative post-task engagement or enjoyment ratings were collected, as the present study primarily aimed to evaluate feasibility and behavioral performance in a clinical context.

Self-reported measures of impulsivity

All participants completed the French version of UPPS-P 20-item questionnaire[25].

gSST design

The gSST was developed using Unity3D (version 2019.01) and designed to closely mirror the structure of the traditional SST while incorporating engaging game elements. The task began with a practice block, followed by four experimental blocks. Each block consisted of 56 trials, with 75% go-trials ($n = 42$) and 25% stop-trials ($n = 14$). Participants were given a 15-second break between blocks. During each trial, the Go-stimulus remained on screen for up to 1250 milliseconds or until a response was made. On stop trials, an auditory stop signal was delivered following a variable stop-signal delay (SSD), initially set at 250 milliseconds. This SSD was dynamically adjusted using a staircase method to maintain an approximate 50% inhibition success rate: it increased by 50 ms after successful inhibition and decreased by 50 ms following failed stops. Intertrial intervals were randomly jittered between 500 and 1500 milliseconds to reduce anticipatory responding.

The gSST featured a third-person view of an avatar running through a dark, procedurally generated forest (see Fig. 1). The storyline, which was integrated into the task instructions, described the player as being trapped in an enchanted forest by an evil witch and guided by a helpful fairy. On each trial, the fairy would indicate a direction—left or right—to help the player escape. However, when the fairy was revealed to be the witch (signaled by the auditory stop cue), participants were instructed to withhold their response to avoid being drawn deeper into the forest.

Following each decision, the avatar would move in the selected direction, regardless of correctness. If no response was made or the stop response was successfully withheld, the avatar continued running straight. Each trial occurred at a fork in the path, ensuring that both directional options were always available. Visual complexity was managed using stylized, low-polygon graphics to preserve aesthetic appeal while minimizing cognitive interference. Special attention was paid to the clarity of the pointing gesture to avoid misinterpretation due to motion artifacts. The task took approximately 20 min. For a full technical description of the gSST design, refer to Friehs et al. (2020)[20]. Participants completed the gSST in a standardized single-session format. The experimenter administering the task was blind to participants' UPPS-P scores. No other tasks were performed before the gSST, eliminating potential fatigue effects.

	BPD ($n = 25$)	HC ($n = 25$)
Age	25.1 ± 4.9	25.2 ± 8.3
Sex	22 F, 3 M	22 F, 3 M
Total UPPS-P	60.28 ± 4.88	44.48 ± 9.5
Negative urgency	12.76 ± 2.26	9.2 ± 3.58
Positive urgency	13.68 ± 1.97	10.68 ± 3.14
Sensation seeking	12.52 ± 2.53	10.64 ± 2.61
Lack of premeditation	9.84 ± 2.49	6.84 ± 2.39
Lack of perseverance	11.48 ± 2.50	7.12 ± 2.37

Table 1. Demographic information and self-reported measures of impulsivity for patients with BPD and HC participants. All data are presented in mean ± SD.

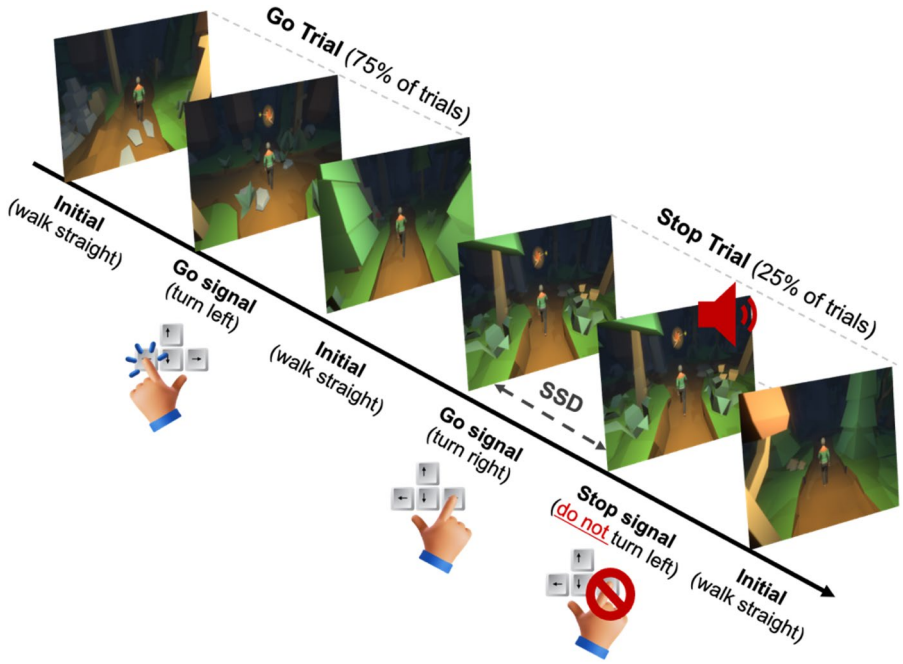

Fig. 1. Design of the gamified Stop-Signal Task with screenshots of the different types of trial.

	BPD ($n = 25$)	HC ($n = 25$)	Student/Mann-Whitney	p-value	FDR p-adj	Effect size
Go-trials RT (ms)	665.1 ± 133.9	763.9 ± 151.2	−2.454	0.018	0.002*	0.299
Stop-failure RT (ms)	589.6 ± 120.3	684.1 ± 141.6	−2.541	0.014	0.024*	0.301
p(respond|signal)	0.505 ± 0.06	0.467 ± 0.04	427	0.026	0.038*	0.366
Omission error	0.021 ± 0.05	0.025 ± 0.06	252	0.212	0.292	−0.194
Choice error	0.007 ± 0.008	0.001 ± 0.003	464	< 0.001	0.002*	0.485
SSD (ms)	270.63 ± 140.12	376.11 ± 145.45	−2.61	0.012	0.022*	0.302
SSRT (ms)	314.61 ± 35.14	315.12 ± 78.69	356	0.404	0.494	0.139

Table 2. Performances obtained by patients with BPD and HC participants in the gSST. All data are presented in mean ± SD. Effect sizes are presented as cohen's d for student's t-tests and rank-biserial correlation for U Mann-Whitney tests.

gSST outcomes

Based on previous similar studies[20,21,26] and guidelines[27], several behavioral outcomes were extracted and calculated. These include the *SSD* (in ms) and the *p(respond|signal)* reflecting the probability of making a response on stop trials. Other extracted variables were related to accuracy such as *choice errors* reflecting the probability of incorrect responses on go-trials and *omission errors* reflecting the probability of missed responses on go-trials. Other variables were related to the reaction times such as *go-trials RT* (reflecting the latency of correct responses on go-trials), and *stop-failure RT* (reflecting the latency of the responses on failed stop-signal trials).

To ensure reliable SSRT estimation, only data meeting three quality-control criteria were included: (1) the probability of responses on stop-signal trials exceeded 0.25 but was below 0.75, (2) the independent assumption of the horse-race model was satisfied, and (3) accuracy on go trials was at least 75%. This accuracy threshold followed established SST guidelines[27] to ensure valid model estimation and exclude unreliable data, rather than to constrain interindividual variability in impulsivity.

A paired samples t-test confirmed a significant difference between the mean go-trial RT and the mean stop-failure RT ($t(48) = 15.199$, $p < 0.001$), with stop-failure RTs being significantly faster than go-trial RTs, consistent with the independent race model assumptions[27]. All participants fulfilled these criteria, and no data were excluded from the SSRT analysis.

Finally, the *Stop-Signal Reaction Time (SSRT)*, the primary outcome measure of response inhibition performance in the SST, was computed using the integration method with replacement of go omissions[27].

Data analysis

All statistical analyses were performed using R (version 2022.12.0 + 353) and JASP (JASP Team, version 0.19.3; https://jasp-stats.org/), with the value of statistical significance set at $p < 0.05$ (two-tailed). The false discovery

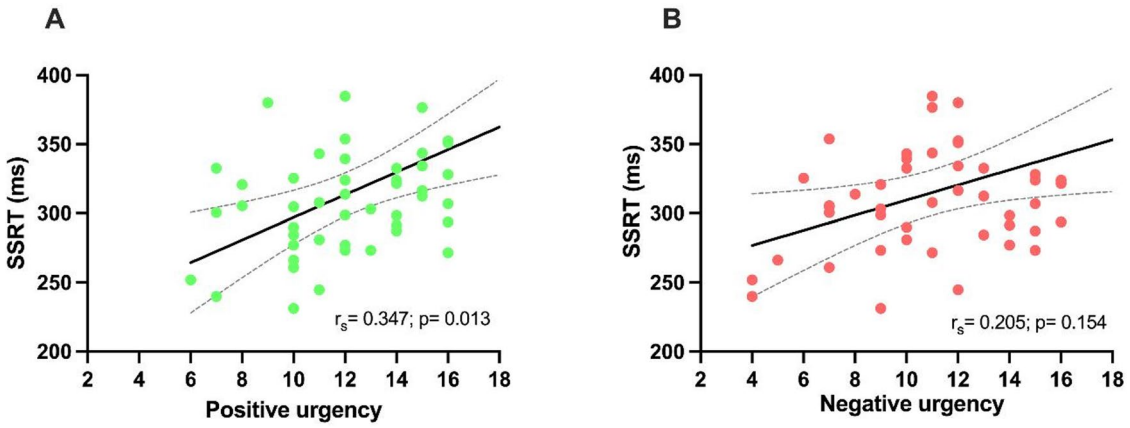

Fig. 2. Correlations between SSRT and self-reported UPPS positive (**A**) and negative (**B**) urgency scores. Dashed lines represent 95% CI. r_s: Spearman's rho.

rate (FDR) control was applied to address multiple-hypothesis testing and minimize the risk of type I (false positive) findings.

Assumptions of normality were assessed using the Shapiro-Wilk test. To compare performance between individuals with BPD and HC in the gSST, we conducted a series of independent-samples Student's *t*-tests or U Mann-Whitney tests on behavioral outcomes. Effect sizes are presented as rank-biserial correlation or Cohen's d.

In order to investigate the relationships between self-reported and behavioral measures of impulsivity, we calculated the correlation coefficients (Spearman's rho) between the SSRT derived from the gSST and the UPPS-P scores obtained from the positive and negative urgency subscales.

Results

Demographic characteristics

There were no significant differences between patients with BPD and HC in age (*Mann-Whitney* $U = 339$, *p*-adjusted = 0.612). However, patients with BPD scored significantly higher than HC on the negative urgency ($t(48) = 4.2$, *p*-adjusted = 0.02), positive urgency (*Mann-Whitney* $U = 509.5$, *p*-adjusted = 0.01), sensation seeking (*Mann-Whitney* $U = 427.5$, *p*-adjusted = 0.039), lack of premeditation ($t(48) = 4.34$, *p*-adjusted = 0.007), lack of perseverance (*Mann-Whitney* $U = 555$, *p*-adjusted = 0.005) subscales and total score ($t(48) = 7.39$, *p*-adjusted = 0.004) of the UPPS-P questionnaire, indicating elevated impulsivity across multiple dimensions (see Table 1).

Behavioral performance on the gSST

The performance data and statistical analysis from the gSST for both groups are presented in Table 2. First, there was no significant group difference in SSRT between BPD and HC (*Mann-Whitney* $U = 356$, *p*-adjusted = 0.404). However, patients with BPD showed significantly faster go-trials RT ($t(48) = -2.45$; *p*-adjusted = 0.002), and faster stop-failure RT ($t(48) = -2.541$, *p*-adjusted = 0.024). They also showed a lower p[response|signal] (*Mann-Whitney* $U = 427$, *p*-adjusted = 0.038) and committed significantly more choice errors than HC (*Mann-Whitney* $U = 464$, *p*-adjusted = 0.002). Additionally, the mean SSD was significantly shorter in patients with BPD compared to HC ($t(48) = -2.61$, *p*-adjusted = 0.022). No significant group difference was found for the proportion of omission errors (*Mann-Whitney* $U = 452$, *p*-adjusted = 0.212).

Association between self-reported and behavioral measures of impulsivity

Across participants, positive urgency showed a moderate positive correlation with SSRT ($\rho = 0.347$, $p = 0.013$), indicating that higher self-reported positive urgency was associated with longer SSRTs (see Fig. 2A). In contrast, the correlation between negative urgency and SSRT was not significant ($\rho = 0.205$, $p = 0.154$) (see Fig. 2B).

Discussion

This study examined the interest of a gamified Stop-Signal Task (gSST) to detect differences in inhibitory control between individuals with BPD and HC. Several gSST-derived measures, including faster reaction times, reduced stopping success, and more frequent choice errors, differentiated the two groups. Moreover, we found that higher self-reported positive urgency was associated with longer SSRTs. These findings highlight the potential of ecologically engaging paradigms to capture core impairments in impulsivity sensitively.

The gSST represents a valuable advancement in assessing impulsivity in BPD, a core component of the disorder. Traditional cognitive tasks, although methodologically sound, often lack the motivational appeal necessary to maintain engagement, especially in clinical populations prone to attentional difficulties[12,13]. The game-based format not only sustained engagement but also preserved sensitivity to between-group differences, reinforcing the robustness of inhibitory control impairments in BPD even in more immersive and enjoyable contexts. Notably, participants with BPD still showed faster responses, poorer stopping success, and significantly more choice errors, indicating persistent cognitive control difficulties despite the enhanced format. In addition,

after completing the task, the majority of patients spontaneously reported enjoying it more than the traditional neuropsychological tasks they typically complete during their standard course of care. However, the gSST should not be viewed as a diagnostic tool. Experimental tasks like the SST are typically designed to minimize individual variability in order to detect group-level effects. In contrast, diagnostic tools must reliably capture stable individual differences. While SSTs tend to show good internal consistency and are sensitive to experimental manipulations, they often suffer from poor test–retest reliability and were not originally designed to assess enduring traits[28].

One particularly striking result was the higher number of choice errors among patients with BPD, even within a task designed to be user-friendly and intuitive. This finding is consistent with our recent meta-analysis[11], suggesting that impairments in response accuracy and selection may be pervasive in BPD, transcending task format. Additionally, BPD patients exhibited significantly faster RT on both correct go-trials and failed stop-trials. Typically, slowing down go responses in anticipation of a potential stop signal reflects a top-down, endogenous regulatory mechanism that facilitates action withholding (i.e., proactive inhibition[29,30]. The combination of a lower stop success rate and shorter mean stop-signal delay further supports the notion of compromised reactive inhibition, echoing findings from traditional SST paradigms[31]. However, despite observing group differences in several gSST outcomes, we found no significant difference in our primary measure (SSRT), which primarily indexes reactive inhibition, contrary to our initial hypothesis. This finding may not be entirely unexpected, as previous studies report that motor components may not be uniformly impaired in BPD[32] and suggest that deficits may vary depending on task parameters[33].

Overall, our results tentatively suggest that proactive inhibition may be more compromised than reactive inhibition in BPD; however, this interpretation is post-hoc and should be confirmed in future studies. Alternatively, it is possible that compensatory neural mechanisms in BPD help preserve behavioral performance, thereby masking underlying impairments in inhibitory control[34,35].

Given the central role of impulsive behaviors in heightened emotional arousal, both positive and negative, the gSST may be more effective if affective components are explicitly incorporated into its design. Gamified tasks present an innovative and scalable studies should investigate how specific task features, such as reward contingencies, emotionally salient stimuli and adaptive difficulty, interact with BPD symptomatology. However, enhancing the gSST is not as simple as adding a narrative or customizing avatars (for a discussion, see[36]. While previous research suggests that personalized avatars can boost motivation, identification, and even task performance[37,38], introducing new elements can also have unintended consequences. Immersive features, though engaging, may become distracting and disrupt performance in unexpected ways[39].

Nevertheless, these features may also serve as valuable indicators for monitoring treatment response or identifying relapse risk. This is particularly relevant in light of our finding that positive urgency is significantly correlated with SSRT. Individuals who reported a stronger tendency to act impulsively during intense positive emotional states exhibited longer SSRTs, which suggests reduced inhibitory control in the gSST. Similarly, two previous studies in healthy participants found that, positive urgency predicted greater increase in risk taking on the Balloon Analogue Risk Task, a decision-making task used to assess risk-taking behavior[40] and was significantly related to poor performance on an anti-saccade task, a measure of prepotent response inhibition[41]. It is possible that certain features of the gSST (e.g., immersive visuals, feedback, narrative context) may have indirectly influenced participants' affective engagement. However, this interpretation remains speculative and was not directly measured in the present study. Given that positive urgency is implicated in real-world risky behaviors for patients with BPD (e.g., substance use and risky sex[42,43], the observed correlation with SSRT could inform personalized intervention strategies targeting emotionally driven impulsivity. For example, digital interventions or serious games could be designed to simulate emotionally charged decision-making scenarios and provide real-time feedback, helping individuals practice inhibitory control in affectively loaded contexts.

Although this correlation ($\rho = 0.35$) was moderate in size, it is noteworthy given the broader literature on impulsivity in BPD. Previous research has found weak or inconsistent associations between self-reported impulsivity traits and behavioral inhibition measures[44,45]. In this context, our result suggests that emotionally driven impulsivity—particularly under positive affect—may be more reliably captured in behavioral paradigms that are engaging, ecologically valid, and cognitively dynamic, such as the gSST. This adds support to the idea that task design and motivational salience play critical roles in detecting clinically meaningful patterns of impulsivity in BPD.

Schroeder et al., (2021) emphasize that game-like features, such as immediate feedback, progression systems, and immersive interfaces, can facilitate therapeutic engagement and foster psychological involvement, enhancing behavior change and cognitive learning. The potential of gamified tasks extends beyond engagement alone. Castellano-Tejedor & Cencerrado, (2024) underscore the importance of designing mental health tools that are personalized and user-driven to maximize motivational pull and clinical effectiveness[47]. This approach may be particularly relevant for populations like BPD, where emotional variability and motivational instability can hinder adherence to traditional interventions. Similarly, Damaševičius et al., (2023) highlight the role of adaptive and AI-driven gamification systems in tailoring challenge levels in real time—ensuring optimal difficulty, sustained engagement, and enhanced learning outcomes across diverse clinical profiles[48].

Still, gamification and digital games are not universal solutions. Lumsden et al., (2017), for instance, found that incorporating game-like features in a longitudinal SST did not significantly reduce participant attrition, challenging assumptions that gamification inherently improves long-term engagement[23]. Our study, while cross-sectional, did not directly test attrition or adherence, but the consistently positive subjective ratings suggest potential for greater acceptability in clinical research. A within-subjects comparison of traditional and gamified versions of the SST could have provided a more precise evaluation of the added value of the gSST for patients with BPD. While game-based elements may improve data consistency and reduce the time required to achieve

reliable measurements in some tasks[49], this advantage may not extend to paradigms like the SST, where a minimum number of trials is essential for accurate SSRT estimation[27].

A key limitation of the present study is the absence of a non-gamified control version of the task. Without such a comparison, it is not possible to determine whether the gamified format genuinely enhanced engagement or sensitivity relative to a traditional SST. The current findings should therefore be regarded as preliminary and hypothesis-generating regarding the potential benefits of gamification. Future studies should incorporate a direct within-subject comparison between gamified and traditional SSTs to quantify whether the gamified format indeed improves sensitivity, engagement, or ecological validity.

Together, these findings suggest that while gamified SSTs are not intended to be used as diagnostic tools, they may offer a more ecologically oriented approach to studying individual differences in impulsivity and inhibitory control. However, the ecological validity of the present design was inferred from task features rather than directly measured. By embedding well-established cognitive paradigms within engaging and intuitive formats, gamified tasks offer a promising bridge between experimental rigor and real-world relevance—opening new avenues for both research and clinical applications. In the future, it may be possible to combine multiple gamified tasks into a composite score, providing a more robust and multidimensional assessment of inhibitory control for clinical use.

Ultimately, by bridging the gap between traditional laboratory paradigms and real-world relevance[50,51], gamified tasks present an innovative and scalable approach for understanding -and potentially addressing- the complex nature of impulsivity in BPD. As this field moves forward, future studies should work toward enhancing the clinical usefulness of gamified cognitive tools by incorporating emotionally meaningful content, adapting task difficulty in real time, and offering tailored feedback. These refinements may help capture the subtle, moment-to-moment shifts in impulsivity that characterize BPD.

Longer-term, treatment-focused research will be essential to determine whether performance on gSSTs can reliably track behavioral change over time or identify early signs of relapse. By integrating experimental precision with ecologically grounded design, such tools may ultimately support more personalized and emotionally attuned care for individuals with BPD and related disorders.

Data availability

The datasets generated and analyzed during the current study and the code used to analyze the Stop-Signal data will be available in an Open Science Framework repository [https://osf.io/9khbv/](https:/osf.io/9khbv).

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Author contributions

N.B. conducted the investigation, data curation, formal analysis, and wrote the original draft. M.D., M.A.F., J.B., and C.N. contributed to conceptualization and methodology. L.C. contributed to the investigation. M.D. and M.A.F. developed the software. E.P., J.B. and C.N. provided supervision. All authors contributed to writing, review, and editing of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to C.N.