Response Monitoring of Aggressive Behavior in Impulsive Individuals: Threat Sensitivity or Response Inhibition

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Abstract

Reactive monitoring of aggressive behavior is dynamic, process-oriented cognitive control that involves two processes: threat detection and response inhibition. Previous research has shown that threats can trigger aggressive behavior in impulsive individuals, but whether impulsive individuals impair reactive monitoring by enhancing sensitivity to threat stimuli or by acting on the response inhibition process, as well as the moderating role of cognitive load, constitutes an important question for investigation. This study designed two experiments to investigate this issue. Experiment 1 employed a flanker-stop-signal combined task to verify whether impulsivity can influence threat detection and response inhibition in reactive monitoring; Experiment 2 examined the impact of cognitive load on reactive monitoring in impulsive individuals by adding cognitive load and expanding threat types based on Experiment 1. The results of Experiment 1 showed no significant differences between high- and low-impulsivity individuals in threat sensitivity and response inhibition ability; aggressive threats impaired the response inhibition capacity of impulsive individuals. The results of Experiment 2 revealed that the impairing effect of cognitive load on response inhibition in impulsive individuals varied with threat type, and cognitive load had a greater impairing effect on symbolic threats than on realistic threats. Low-impulsivity individuals exhibited enhanced ability to filter out irrelevant information, and cognitive load modulated the processing of symbolic and realistic threats in both high- and low-impulsivity individuals, such that cognitive load enhanced high-impulsivity individuals' capacity to resist reputation threats while diminishing low-impulsivity individuals' capacity to resist reputation threats. Overall, this series of experiments demonstrates that in the process of reactive monitoring of aggressive behavior, impulsivity primarily impairs reactive monitoring of aggressive behavior by weakening response inhibition capacity, with the key mechanism being the impairment of reactive monitoring of aggressive behavior through attentional resource depletion.

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Performance Monitoring of Aggressive Behavior in Impulsive Individuals: Threat Sensitivity or Response Inhibition

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Abstract

Performance monitoring of aggressive behavior represents a dynamic, process-oriented form of cognitive control involving both threat detection and response inhibition. While previous research has demonstrated that threat can trigger aggressive behavior in impulsive individuals, a critical unresolved question concerns whether impulsive individuals impair performance monitoring by enhancing sensitivity to threatening stimuli or by compromising response inhibition processes, and how cognitive load might moderate these mechanisms. The present study addressed this issue through two experiments. Experiment 1 employed a flanker-stop-signal combined task to examine whether impulsivity influences threat detection and response inhibition within performance monitoring. Experiment 2 built upon Experiment 1 by introducing a cognitive load manipulation and expanding the range of threat types to investigate how cognitive load and threat type jointly modulate performance monitoring in impulsive individuals.

The results of Experiment 1 revealed no significant differences between high- and low-impulsivity individuals in threat sensitivity or response inhibition ability; however, aggressive threats specifically impaired response inhibition in impulsive individuals. Experiment 2 demonstrated that the detrimental effect of cognitive load on impulsive individuals' response inhibition varied across threat types, with symbolic threats showing greater vulnerability to cognitive load than realistic threats. Low-impulsivity individuals exhibited enhanced ability to filter out irrelevant information, and cognitive load differentially modulated the processing of symbolic versus realistic threats in high- and low-impulsivity groups. Specifically, cognitive load enhanced high-impulsivity individuals' capacity to defend against reputational threats while diminishing low-impulsivity individuals' capacity to defend against reputational threats.

Overall, this series of experiments indicates that in the performance monitoring of aggressive behavior, impulsivity primarily undermines monitoring capacity by weakening response inhibition, with the key mechanism involving attentional resource depletion that compromises performance monitoring of aggressive behavior.

Keywords: aggressive behavior; threat sensitivity; performance monitoring;

response inhibition; flanker-stop-signal joint task

Aggressive behavior is defined as actions intended to cause harm to others or groups (Tsuyuki et al., 2020). Such behavior poses numerous challenges to individuals and society, including reduced life satisfaction and deteriorating psychological and physical health (Tsuyuki et al., 2020), making it a prominent concern across sociology, psychology, management, and public health disciplines. Performance monitoring refers to the capacity for continuous monitoring of problematic behaviors and plays a critical role in behavior correction, serving as the psychological foundation for changing and intervening in aggressive behavior (Krämer et al., 2007). Impulsivity is a personality trait associated with risky decision-making, poor planning, premature expression, and rapid thinking, representing a key psychological factor that leads individuals to engage in aggressive behavior (Miller & Racine, 2022). Effective performance monitoring is essential for impulsive individuals to avoid aggressive behavior (Carli et al., 2014). Therefore, investigating the mechanisms underlying performance monitoring of aggressive behavior in impulsive individuals is crucial, holding significant theoretical and practical implications for reducing and curbing aggressive behavior.

Performance monitoring typically involves two distinct processing components: threat detection (threat sensitivity) and response inhibition. Threat sensitivity refers to the degree of sensitivity in evaluating, perceiving, and responding to threats (Kramer et al., 2020). From a cognitive perspective, threat sensitivity also encompasses attentional and interpretive biases toward threat information—namely, threat vigilance (Kramer et al., 2020). From a physiological perspective, threat sensitivity is defined as the level of physiological, emotional, and behavioral responses when confronting threats (Carver, 2009; Kramer et al., 2020). The error-related negativity (ERN) may reflect the degree of threat sensitivity (Traxler et al., 2022). Research indicates that this monitoring process is continuously active, requires minimal cognitive resources, and operates below conscious awareness (Nieuwenhuis et al., 2010).

Impulsive personality and threat type represent important moderating factors of threat sensitivity (张禹 et al., 2014; Syfers et al., 2023). Some studies show that individuals with high impulsivity are less sensitive to threats, exhibiting reduced ERN amplitudes (Heffer, 2022). Impulsive individuals may fail in performance monitoring due to over-interpretation of threatening stimuli (primarily angry faces and weapons) (Black et al., 2012; Carli et al., 2012; Kashyap et al., 2012). In aggressive contexts, threats generally include aggressive threats, realistic threats, and symbolic threats. Generally, symbolic threats appear more likely than realistic threats to lead to dehumanization and moral exclusion, reducing empathy toward outgroups (Jetten et al., 2002; Vaes & Wicklund, 2002). Symbolic threats may also elicit the most vicious behavioral responses toward outgroups, such as genocide, torture, and mutilation. However, previous research has only examined the impact of impulsivity on perception of biological threats or emotional faces, leaving uninvestigated the perception of different threat types in aggressive contexts. Based on this gap, the present study aims to examine how impulsivity influences sensitivity to different types of threats in aggressive behavior.

Response inhibition refers to the ability to stop or cancel inappropriate responses, automatic impulses, and habits (Gupta & Singh, 2021). It is a resource-dependent regulatory component that overrides inappropriate response tendencies, playing a vital role in maintaining rational cognition, stable emotions, and behavioral control (Bari & Robbins, 2013). The Go/No-go paradigm is suitable for objectively assessing response inhibition (Gillespie et al., 2022). In Go/No-go tasks, two ERP components serve as electrophysiological measures of response inhibition: No-go-N2 and No-go-P3. No-go-N2 is considered fundamental to various cognitive control processes in response inhibition, including response activation (Li et al., 2023), premotor inhibition (Falkenstein et al., 1999), and conflict monitoring (Nieuwenhuis et al., 2003). In contrast, No-go-P3 primarily reflects the inhibition process itself (Li et al., 2023). Additionally, P2 is believed to reflect early attentional processes (Li et al., 2023), with P2 amplitude associated with evaluation of task-relevant stimuli (Cavanagh & Frank, 2014). Enhanced frontal P2 as a more efficient processing mechanism facilitates inhibition of irrelevant stimuli and helps participants attend to relevant stimuli (Knežević, 2018). Existing research has established that impulsivity is associated with response inhibition deficits (Chambers, 2010). However, evidence for the relationship between response inhibition and impulsivity remains weak and inconsistent (Skippen et al., 2019).

Some researchers have used the stop-signal task to measure response inhibition and examine the role of impulsivity, finding that high-impulsivity individuals cannot suppress motor responses (Moeller et al., 2001). Studies with non-clinical populations also show that higher scores on impulsivity questionnaires correlate with longer stop-signal reaction times (SSRT) (Logan et al., 1997) and lower inhibition rates (Lijffijt et al., 2004). Conversely, other studies have not found reliable relationships between impulsivity and SSRT (Cheung et al., 2004; Lijffijt et al., 2004) or inhibition rates (Horn et al., 2003). In Lijffijt et al. (2004), no differences in SSRT were observed between low- and high-impulsivity groups. Electrophysiological findings have similarly yielded inconsistent conclusions. For instance, Dimoska and Johnstone (2007) found that high-impulsivity individuals showed larger frontal P3 amplitudes during successful inhibition trials compared to low-impulsivity individuals. Lansbergen et al. (2007) also found larger P3 amplitudes in high-impulsivity individuals, suggesting that they require greater inhibitory control effort to achieve equivalent stopping performance (Dimoska & Johnstone, 2007; Lansbergen et al., 2007). Contrary to Lansbergen et al. (2007), some studies using visual Go/No-go tasks reported reduced P3 amplitudes in high-impulsivity individuals compared to low-impulsivity individuals, reflecting lower levels of response inhibition (Justus et al., 2001). Ruchsow et al. (2008) found similar results, with reduced P3 amplitudes in high-impulsivity individuals. Whether P3 amplitudes are reduced or enhanced in high-impulsivity individuals remains an open question. In summary, the relationship between impulsivity and response inhibition warrants further investigation (Shen et al., 2014).

Regarding the relationship between cognitive load and performance monitoring, processing of threats is considered relatively unconscious and requires minimal cognitive resources (Lojowska et al., 2019). Therefore, the relationship between cognitive load and performance monitoring primarily manifests in response inhibition. Some studies have found that low working memory capacity leads to reduced response inhibition (Arce & Sanisteban, 2006), while effective working memory training can enhance individuals' response inhibition (Bickel et al., 2011). However, other similar experiments have not observed such effects (Franco-Watkins et al., 2006). These divergent findings may result from employing different working memory cognitive loads (Franco-Watkins et al., 2006; Hinson et al., 2003). Working memory load leads to more impulsive behavior and is believed to play an important role in response inhibition failure across many social problem behaviors (Nagin & Pogarsky, 2004). Thus, response inhibition deficits in impulsive individuals may stem from insufficient capacity of actual cognitive load in working memory (Whitney et al., 2004).

Therefore, this study employed two experiments to investigate the influence of impulsivity on performance monitoring of aggressive behavior and the moderating role of cognitive load. Given that the standard flanker task combined with an embedded stop-signal task is used to examine performance monitoring in general cognitive domains (Krämer et al., 2007), Experiment 1 utilized a flanker-stop-signal combined task to investigate how impulsivity affects performance monitoring of aggressive behavior. While Experiment 1 results may demonstrate that high-impulsivity individuals have lower threat sensitivity than low-impulsivity individuals and weaker response inhibition ability, they cannot reveal whether cognitive load affects threat sensitivity or response inhibition in impulsive individuals. Based on Experiment 1 results, Experiment 2 incorporated threat type variables and added a cognitive load task to the flanker-stop-signal combined task, integrating event-related potential (ERP) technology to further examine the moderating effects of threat type and cognitive load on performance monitoring of aggressive behavior in impulsive individuals. Experiment 2 results may show that cognitive load does not exhibit a moderating effect on threat sensitivity, but in terms of response inhibition, cognitive load impairs impulsive individuals' response inhibition ability, with effects varying across threat types.

Experiment 1

Experiment 1 recruited 120 college students. Before the experiment began, all participants completed a brief demographic questionnaire and the Brazilian Version of the Barratt Impulsiveness Scale (BIS-11). Participants scoring in the top 25% (high impulsivity) or bottom 25% (low impulsivity) on the impulsivity scale were selected to form high- and low-impulsivity groups (Shen et al., 2014), comprising 21 low-impulsivity participants (M = 30.12, SD = 4.29) and 21 high-impulsivity participants ($M = 49.33$, $SD = 5.19$). An independent samples t-test on impulsivity scores between the two groups revealed significant differences, $t(40) = -13.06$, $p < 0.001$, Cohen's $d = 1.97$, 95% CI = [-26.21, -19.85].

Experiment 2

Experiment 2 recruited 300 college students, with the same selection procedure as Experiment 1. The sample included 49 low-impulsivity participants ($M = 38.82$, $SD = 5.23$) and 51 high-impulsivity participants ($M = 56.32$, $SD = 5.17$). An independent samples t-test confirmed significant differences between groups, $t(98) = 11.86$, $p < 0.001$, Cohen's $d = 1.77$, 95% CI = [-24.26, -18.89]. High- and low-impulsivity participants were randomly assigned to either a cognitive load condition or a control (no cognitive load) condition, as shown in Table 1 .

Sample size was calculated using G*Power 3.1, with maximum effect size set at $f = 0.6$ and $\alpha = 0.05$. Experiment 1 employed a 2 × 2 mixed design with 2 groups and 1 degree of freedom, yielding a required sample size of 39 participants. The study obtained 42 valid participants, meeting the sample size requirement. Experiment 2 used a 2 × 2 × 4 mixed design with 4 groups and 3 degrees of freedom, requiring 52 participants. The study obtained 100 valid participants, satisfying the sample size requirement.

All participants were right-handed with no history of psychiatric disorders, substance dependence, mental illness, or brain injury. They had normal or corrected-to-normal vision and no color blindness. Participants received compensation after completing the experiment and provided informed consent. The study was approved by the Ethics Committee of Nantong University Affiliated Hospital.

Measures and Materials

Trait Impulsivity Questionnaire The Chinese version of the Barratt Impulsiveness Scale (BIS-II), revised by Li Xianyun et al. (2011), was used to assess trait impulsivity. The scale comprises three subscales: non-planning, motor impulsivity, and cognitive impulsivity. The total scale and subscales demonstrate good internal consistency (Cronbach's $\alpha = 0.77$–0.89) and test-retest reliability ($r = 0.68$–0.89), indicating satisfactory reliability and validity.

Threat Stimulus Materials (Pictures and Words) Two research assistants created threat pictures based on threat content. Flanking words (selected from Sun, 2011; Banse et al., 2015) included three categories: threatening words (e.g., "punch," "defeat"), safe words (e.g., "negotiate," "coordinate"), and neutral words (e.g., "man," "woman").

Pictures were rated for threat type and intensity. First, 40 undergraduate psychology students classified pictures by threat type into realistic, symbolic, and aggressive threats. Results showed 18 pictures classified as aggressive threats, 18 as realistic threats, 18 as symbolic threats, and 4 as neutral materials. Subsequently, 200 college students rated the threat level of 58 pictures via an online survey.

Material inclusion criteria followed Powell et al. (2002): For neutral materials, average neutrality ratings had to fall within one standard deviation of the scale midpoint (e.g., for a 9-point scale, mean ratings between 5 $\pm$ 1SD). For threat materials, average ratings had to meet or exceed the moderate score.

Table 2 presents descriptive statistics for different threat types (M $\pm$ SD): 8.00 $\pm$ 0.49, 6.90 $\pm$ 0.67, 6.58 $\pm$ 0.69, 2.08 $\pm$ 0.39.

Flanker-Stop-Signal Combined Paradigm Experiment 1 used a modified Eriksen flanker task (Eriksen & Eriksen, 1974) with triads of stimuli (central picture with words above and below). Participants responded to the consistency between the central picture and the threatening nature of the flanking words. The task included 33.3% congruent trials, 50% incongruent trials, and 16.6% No-go trials embedded as a variant of the stop-signal paradigm (Band et al., 2003). In these trials, a delay period varied randomly; when the border of the central green arrow picture turned red, participants were required to withhold their response. The stop-signal delay was set at 140 ms.

Figure 1 [Figure 1: see original paper] illustrates the flanker-stop-signal combined paradigm procedure.

Cognitive Load Task Participants performed a digit-string retention task (Hinson et al., 2003). In the working memory load condition, participants were presented with a five-digit string and required to recall a specific digit at a particular position at a designated time. After completing 10 trials of the flanker-stop-signal task, participants recalled the digit at the specified position and responded using the numeric keypad. This cycle repeated throughout the task.

Experimental Design

Experiment 1 employed a 2 (impulsivity: high vs. low) $\times$ 2 (threat type: aggressive vs. neutral) mixed design, with impulsivity as a between-subjects variable and threat type as a within-subjects variable. Dependent variables included reaction times in the flanker task, No-go trial inhibition rates, and stop-signal reaction times in the Go/No-go task.

Experiment 2 used a 2 (impulsivity: high vs. low) $\times$ 2 (working memory load: high vs. low) $\times$ 4 (threat type: realistic vs. symbolic vs. aggressive vs. neutral) mixed design. Dependent variables included reaction times in the flanker task, No-go trial inhibition rates, stop-signal reaction times, and ERP components including ERN, N2, and P2.

Procedure and EEG Recording

The study consisted of two experiments. Stimuli and procedures for Experiment 1 are shown in Figure 1. In Experiment 1, a fixation cross "+" appeared for 500 ms, followed by a gray screen for 500 ms. The picture stimulus (central picture with flanking words) then appeared for 500 ms. Participants judged the consistency between the picture and words: if the picture and words were congruent in threat level, they pressed the "D" key (indicating aggressive action); if incongruent, they pressed the "K" key (indicating non-aggression or compromise). If the picture border turned red (stop signal, appearing in both congruent and incongruent trials), participants withheld their response. A white screen then appeared for 500 ms before the next trial (see Figure 3 [Figure 3: see original paper]-1). Trials and blocks were fully randomized. The formal experiment comprised 8 blocks of 40 trials each (40 trials per condition being sufficient), with each trial lasting approximately 5 seconds, totaling 320 trials. Participants rested for 20 seconds after every 4 blocks, with total duration approximately 28 minutes.

EEG data were recorded using a Neuroscan system (Scan 4.5) with a 64-channel electrode cap. The reference electrode was placed on the left mastoid, with offline re-referencing to the average of left and right mastoids. GND was grounded. Horizontal and vertical electrooculograms were recorded. The sampling rate was 500 Hz per channel, with scalp impedance maintained below 5 kΩ. Behavioral data (accuracy and reaction time) were recorded simultaneously. Offline analysis merged behavioral data with epochs from 200 ms pre-stimulus to 1000 ms post-stimulus, using the 200 ms pre-stimulus interval as baseline. The bandpass filter was set at AC = 0.05–100 Hz, with automatic correction of blink artifacts. ERP grand-average waveforms were obtained by averaging correct-response trials.

Electrodes were placed according to the international 10–20 system. Nine electrode sites were selected for statistical analysis: Fz, Cz, Pz; F3, C3, P3; F4, C4, P4. Peak amplitudes and latencies were measured for ERN (0–80 ms), N2 (130–200 ms), and P2 (80–130 ms). Repeated measures ANOVA was used to examine effects of impulsivity, threat type, and cognitive load on performance monitoring of aggressive behavior. Data were analyzed using SPSS 19.0, with Greenhouse-Geisser correction applied when sphericity assumptions were violated. Effect sizes are reported as d for t-tests (small: d = 0.2, medium: d = 0.5, large: d = 0.8) and partial ^{2} for F-tests (weak: $^2 < 0.06$, moderate: $0.06 < {}^2 < 0.14$, strong: $^2 > 0.14$).

Results

Experiment 1 Results

Flanker Task Reaction Times A 2 (impulsivity: high vs. low) × 2 (congruency: congruent vs. incongruent) × 2 (threat level: high vs. low) repeated measures ANOVA on reaction times revealed a significant main effect of threat, with slower responses in neutral conditions (M = 1428.15, SD = 575.36) compared to aggressive threat conditions (M = 1266.86, SD = 681.80), $F(1, 38) = 3.354$, $p < 0.05$, partial $^2 = 0.077$. The congruency × impulsivity interaction was significant: under congruent conditions, low-impulsivity participants showed slower reaction times (M = 1412.13, SD = 578.75) than high-impulsivity participants (M = 1341.13, SD = 673.67), whereas under incongruent conditions, low-impulsivity participants showed faster reaction times (M = 1283.71, SD = 630.89) than high-impulsivity participants (M = 1481.78, SD = 726.54), $F(1, 40) = 7.071$, $p < 0.05$, partial $^2 = 0.150$.

Figure 2 [Figure 2: see original paper] illustrates the impulsivity × congruency interaction.

Go/No-go Task Performance A 2 (impulsivity: high vs. low) × 2 (threat type: aggressive vs. neutral) repeated measures ANOVA on No-go trial inhibition rates and stop-signal reaction times showed no significant effect of impulsivity. Only the main effect of threat type was significant: successful inhibition rates were higher in neutral threat conditions (M = 0.432, SD = 0.102) than in aggressive threat conditions (M = 0.43, SD = 0.13), $F(1, 38) = 3.06$, $p < 0.05$, partial $^2 = 0.071$. Stop-signal reaction times were shorter in neutral threat conditions (M = 1089.82, SD = 344.90) than in aggressive threat conditions (M = 1268.52, SD = 397.15), $F(1, 38) = 9.55$, $p < 0.001$, partial $^2 = 0.193$. These results indicate that aggressive threats impair response inhibition ability.

Experiment 2 Results

Flanker Task Reaction Times A 2 (impulsivity: high vs. low) × 2 (cognitive load: present vs. absent) × 2 (congruency: congruent vs. incongruent) × 4 (threat type: realistic vs. symbolic vs. aggressive vs. neutral) repeated measures ANOVA revealed a significant main effect of threat type. Reaction times were slowest for realistic threats (M = 1372.33, SD = 522.09), followed by symbolic threats (M = 1318.21, SD = 508.22), neutral threats (M = 1279.71, SD = 468.09), and fastest for aggressive threats (M = 1200.48, SD = 475.67), $F(3, 288) = 7.680$, $p < 0.001$, partial $^2 = 0.197$.

The threat type × cognitive load interaction was significant. Simple effects analysis showed that without cognitive load, reaction times were slowest for symbolic threats (M = 1357.08, SD = 403.70), followed by realistic threats (M = 1325.92, SD = 393.88), neutral threats (M = 1205.78, SD = 387.63), and fastest for aggressive threats (M = 1189.94, SD = 325.03). With cognitive load, reaction times were slowest for realistic threats (M = 1418.74, SD = 650.30), followed by neutral threats (M = 1353.65, SD = 548.55), symbolic threats (M = 1279.35, SD = 612.74), and fastest for aggressive threats (M = 1211.03, SD = 626.31), $F(3, 288) = 3.315$, $p < 0.05$, partial $^2 = 0.033$.

The congruency × cognitive load × impulsivity interaction was significant. Simple effects analysis revealed that with cognitive load, high-impulsivity participants showed slower reaction times in congruent trials (M = 1330.30, SD = 353.00) compared to low-impulsivity participants (M = 1231.49, SD = 401.57). Without cognitive load, high-impulsivity participants showed slower reaction times in incongruent trials (M = 1379.59, SD = 674.74) compared to low-impulsivity participants (M = 1268.59, SD = 596.98), $F(1, 96) = 5.219$, $p < 0.05$, partial $^{2} = 0.052$.

Figures 3 and 4 [Figure 4: see original paper] illustrate the threat type × cognitive load and congruency × cognitive load × impulsivity interactions.

Go/No-go Task Performance A 2 (impulsivity: high vs. low) × 2 (cognitive load: present vs. absent) × 4 (threat type: aggressive vs. realistic vs. symbolic vs. neutral) repeated measures ANOVA on No-go trial inhibition rates and stop-signal reaction times showed only a significant main effect of threat type. Inhibition rates were lowest for aggressive threats (M = 0.56, SD = 0.30), followed by symbolic threats (M = 0.57, SD = 0.30), realistic threats (M = 0.59, SD = 0.30), and highest for neutral threats (M = 0.60, SD = 0.31), $F(3, 288) = 5.685$, $p < 0.001$, partial $^{2} = 0.056$. Stop-signal reaction times were shortest for neutral threats (M = 957.30, SD = 516.04), followed by aggressive threats (M = 1141.05, SD = 650.49), realistic threats (M = 1159.23, SD = 593.26), and longest for symbolic threats (M = 1168.15, SD = 608.73), $F(3, 288) = 6.598$, $p < 0.001$, partial $^{2} = 0.174$.

The threat type × cognitive load interaction was significant for stop-signal reaction times. Without cognitive load, neutral threats yielded significantly shorter stop-signal reaction times (M = 574.92, SD = 643.54) than realistic threats (M = 1017.98, SD = 755.37), symbolic threats (M = 1042.03, SD = 817.48), and aggressive threats (M = 1097.99, SD = 963.56). With cognitive load, aggressive threats produced shorter stop-signal reaction times (M = 1184.12, SD = 337.42) than symbolic threats (M = 1294.27, SD = 399.98), realistic threats (M = 1300.47, SD = 431.16), and neutral threats (M = 1339.68, SD = 388.55), $F(3, 288) = 10.710$, $p < 0.001$, partial $^{2} = 0.255$.

Figure 5 [Figure 5: see original paper] illustrates the cognitive load × threat type interaction.

ERP Results A 2 (impulsivity: high vs. low) × 2 (cognitive load: present vs. absent) × 4 (threat type: aggressive vs. realistic vs. symbolic vs. neutral) × 2 (trial type: go vs. No-go) × 9 (electrode site: C3/4 vs. Cz vs. P3/4 vs. Pz vs. F3/4 vs. Fz) repeated measures ANOVA was conducted on ERN, N2, and P2 amplitudes.

ERN Results. The ANOVA revealed a significant main effect of threat type, with aggressive threats eliciting more negative ERN amplitudes (-0.98 V ± 4.30) than symbolic threats (-0.77 V ± 3.22), realistic threats (-0.35 V ± 4.39), and neutral threats (-0.29 V ± 3.27), $F(3, 477) = 7.242$, $p < 0.001$, partial $^{2} = 0.015$. Electrode site also showed a significant main effect, with P4 showing the most negative ERN amplitude (-1.22 V ± 3.41), followed by P3 (-1.11 V ± 3.14), Pz (-0.65 V ± 3.93), F4 (-0.29 V ± 4.40), Cz (-0.212 V ± 4.11), C4 (-0.42 V ± 3.83), C3 (-0.187 V ± 3.77), F3 (-0.052 V ± 3.58), and Fz (-0.12 V ± 4.69), $F(3, 479) = 2.049$, $p < 0.05$, partial $^{2} = 0.045$.

N2 Results. The ANOVA on N2 amplitudes revealed significant main effects of threat type and electrode site. Realistic threats elicited the most negative N2 amplitudes (-1.23 V ± 5.47), followed by symbolic threats (-1.06 V ± 5.18), aggressive threats (0.13 V ± 5.17), and neutral threats (0.88 V ± 5.88), $F(3, 3105) = 105.677$, $p < 0.001$, partial $^{2} = 0.235$. For electrode sites, F4 showed the most negative N2 amplitude (-1.62 V ± 5.77), followed by Fz (-1.54 V ± 6.04), F3 (-1.24 V ± 5.87), Cz (-0.97 V ± 5.26), C4 (-0.42 V ± 4.84), C3 (-0.12 V ± 4.69), Pz (0.24 V ± 5.65), P4 (1.27 V ± 5.23), and P3 (1.53 V ± 4.82), $F(8, 1035) = 12.502$, $p < 0.05$, partial $^{2} = 0.088$.

The threat type × impulsivity interaction was significant. Simple effects analysis showed that for high-impulsivity participants, realistic threats elicited more negative N2 amplitudes (-1.41 V ± 5.08) than symbolic threats (-1.02 V ± 5.52), aggressive threats (0.31 V ± 5.29), and neutral threats (1.01 V ± 5.65). For low-impulsivity participants, symbolic threats elicited more negative N2 amplitudes (-1.11 V ± 4.84) than realistic threats (-1.05 V ± 5.86), aggressive threats (-0.04 V ± 5.04), and neutral threats (0.76 V ± 5.52), $F(3, 3105) = 2.808$, $p < 0.05$, partial $^{2} = 0.008$.

The threat type × cognitive load × impulsivity interaction was significant. With cognitive load, high-impulsivity participants showed more negative N2 amplitudes for realistic threats (-1.75 V ± 4.73) than symbolic threats (-0.62 V ± 6.05), aggressive threats (0.98 V ± 4.55), and neutral threats (1.61 V ± 4.59). Low-impulsivity participants showed more negative N2 amplitudes for symbolic threats (-0.29 V ± 5.35) than realistic threats (-0.15 V ± 6.25), aggressive threats (0.50 V ± 5.04), and neutral threats (1.23 V ± 5.49). Without cognitive load, high-impulsivity participants showed more negative N2 amplitudes for symbolic threats (-1.42 V ± 4.99) than realistic threats (-1.07 V ± 5.43), aggressive threats (-0.35 V ± 6.03), and neutral threats (0.42 V ± 6.72). Low-impulsivity participants showed more negative N2 amplitudes for realistic threats (-1.95 V ± 5.48) than symbolic threats (-1.93 V ± 4.33), aggressive threats (-0.59 V ± 5.04), and neutral threats (0.30 V ± 5.56), $F(3, 3105) = 11.601$, $p < 0.001$, partial $^{2} = 0.033$.

P2 Results. The ANOVA on P2 amplitudes revealed significant main effects of threat type and electrode site. Neutral threats elicited the most positive P2 amplitudes (3.14 V ± 6.29), followed by aggressive threats (1.83 V ± 6.09), symbolic threats (0.49 V ± 6.27), and realistic threats (0.23 V ± 6.08), $F(3, 3132) = 111.278$, $p < 0.001$, partial $^{2} = 0.243$. For electrode sites, P4 showed the most positive P2 amplitude (3.81 V ± 5.46), followed by P3 (3.65 V ± 5.24), Pz (2.82 V ± 6.04), C4 (1.99 V ± 5.73), C3 (1.54 V ± 5.63), Cz (1.19 V ± 6.18), F4 (-0.68 V ± 7.13), F3 (-0.75 V ± 6.98), and Fz (-0.78 V ± 7.25), $F(8, 1044) = 22.150$, $p < 0.001$, partial $^{2} = 0.145$.

The threat type × cognitive load × impulsivity interaction was significant. With cognitive load, high-impulsivity participants showed more positive P2 amplitudes for neutral threats (4.49 V ± 5.36) than aggressive threats (2.43 V ± 5.47), symbolic threats (0.65 V ± 6.36), and realistic threats (-0.42 V ± 5.88). Low-impulsivity participants showed more positive P2 amplitudes for neutral threats (3.78 V ± 6.07) than aggressive threats (2.40 V ± 5.86), realistic threats (1.86 V ± 7.01), and symbolic threats (1.64 V ± 6.69). Without cognitive load, high-impulsivity participants showed more positive P2 amplitudes for neutral threats (1.16 V ± 6.02) than aggressive threats (0.36 V ± 7.19), realistic threats (-0.78 V ± 5.19), and symbolic threats (-1.49 V ± 6.63). Low-impulsivity participants showed more positive P2 amplitudes for neutral threats (3.14 V ± 7.70) than aggressive threats (2.13 V ± 5.84), symbolic threats (1.15 V ± 5.40), and realistic threats (0.24 V ± 6.25), $F(3, 3132) = 12.997$, $p < 0.001$, partial $^{2} = 0.036$. Waveforms are shown in Figure 6 [Figure 6: see original paper].

Discussion

This study investigated impulsivity's influence on performance monitoring of aggressive behavior and the moderating roles of cognitive load and threat type using a flanker-stop-signal combined task and threat Go/No-go paradigm. Both behavioral and ERP results indicated that, compared to low-impulsivity individuals, high-impulsivity individuals exhibited higher threat sensitivity, consistent with previous research (Black et al., 2012; Carli et al., 2012; Kashyap et al., 2012; Ruchsow et al., 2005). This suggests that higher impulsivity is associated with greater threat sensitivity (Ruchsow et al., 2005). ERN amplitude is typically reduced by impulsive personality traits (Ruchsow et al., 2005), with high-impulsivity individuals showing diminished ERN (Ruchsow et al., 2005). Differences in threat sensitivity between high- and low-impulsivity individuals were primarily observed in the processing of symbolic and aggressive threats, suggesting that impulsive individuals may be more sensitive to implicit threats, whereas high-impulsivity individuals' rapid responding may manifest as sensitivity to explicit threats but weaker sensitivity to implicit threats.

Furthermore, results indicated that threat sensitivity varies by threat type, with reaction times slowest for realistic threats, followed by symbolic threats, and fastest for aggressive threats. This suggests that individuals are most sensitive to aggressive threats, followed by symbolic threats, and least sensitive to realistic threats. This pattern aligns with Maslow's hierarchy of needs: as basic material needs are satisfied and safety concerns remain paramount, spiritual needs become more salient than material needs. Consequently, individuals show greater sensitivity to symbolic than realistic threats, with symbolic threats more likely to lead to dehumanization, moral exclusion, and aggressive behavior (Jetten et al., 2002; Vaes & Wicklund, 2002). Overall, these findings converge with research conceptualizing threat as a negative emotional state (Moser et al., 2005), where negative emotions signal potential environmental threats, prompting increased effort to detect and avoid danger. We infer that different threat types may enhance threat sensitivity through affective states, with the heightened threat sensitivity effect primarily resulting from impulsive individuals' altered processing of threat signals themselves.

Regarding response inhibition, Experiment 1 found no significant differences between impulsivity groups in No-go trials, consistent with previous research (Logan et al., 1997; Cheung et al., 2004; Lijffijt et al., 2004; Horn et al., 2003; Shen et al., 2014). Prior research examining relationships between self-reported impulsivity and inhibitory control in normal populations found that high trait impulsivity was not associated with inhibitory control deficits (Shen et al., 2014). The absence of significant differences between high- and low-impulsivity groups in response inhibition suggests that while high-impulsivity individuals may detect threat-related signals more quickly, they may need to expend more cognitive resources to achieve comparable behavioral performance on cognitive control tasks.

Moreover, across different threat contexts, response inhibition ability was highest under neutral threats, followed by symbolic threats, then realistic threats, and lowest under aggressive threats. This indicates that threat stimuli consume cognitive resources and impair stop-signal processing, demonstrating that threat information weakens response inhibition ability. The impairing effect of aggressive threats on response inhibition was greater than that of realistic threats, which in turn was greater than that of symbolic threats. Therefore, Experiment 2 examined how cognitive load affects impulsive individuals' performance monitoring and how threat type moderates this relationship.

For threat sensitivity, neither the cognitive load × threat type interaction nor the cognitive load × impulsivity interaction reached significance, consistent with the characteristic that threat processing requires minimal cognitive resources and operates below conscious awareness (Nieuwenhuis et al., 2010).

For response inhibition, behavioral results showed a significant threat type × cognitive load interaction for stop-signal reaction times. Without cognitive load, neutral threats produced significantly shorter stop-signal reaction times than realistic, symbolic, and aggressive threats. With cognitive load, aggressive threats yielded shorter stop-signal reaction times than symbolic, realistic, and neutral threats. These findings indicate that cognitive load attenuates the impact of threat information on response inhibition ability. Under cognitive load, competitive processing between threat stimuli and stop signals becomes more intense, with individuals showing attentional bias toward aggressive threats, consuming cognitive resources in the order of aggressive > symbolic > realistic threats.

Electrophysiological data revealed a significant threat type × impulsivity interaction. High-impulsivity individuals showed more negative N2 amplitudes for realistic threats than symbolic, aggressive, and neutral threats. Low-impulsivity individuals showed more negative N2 amplitudes for symbolic threats than realistic, aggressive, and neutral threats. This suggests that low-impulsivity individuals are more vigilant, with enhanced ability to filter out irrelevant information, and this vigilance varies by threat type, showing greater alertness to implicit than explicit threats.

Furthermore, the threat type × cognitive load × impulsivity interaction was significant. With cognitive load, high-impulsivity individuals showed more negative N2 amplitudes for realistic threats than symbolic, aggressive, and neutral threats, while low-impulsivity individuals showed more negative N2 amplitudes for symbolic threats than realistic, aggressive, and neutral threats. Without cognitive load, high-impulsivity individuals showed more negative N2 amplitudes for symbolic threats than realistic, aggressive, and neutral threats, while low-impulsivity individuals showed more negative N2 amplitudes for realistic threats than symbolic, aggressive, and neutral threats. This suggests that despite consuming some resources, cognitive load actually increased low-impulsivity individuals' vigilance toward implicit threat stimuli.

Regarding inhibition of irrelevant stimuli (with threat stimuli treated as irrelevant), cognitive load moderated high-impulsivity individuals' processing of symbolic (reputation) and realistic (material) threats. With cognitive load, high-impulsivity individuals showed more positive P2 amplitudes for symbolic threats than realistic threats; without cognitive load, they showed more positive P2 amplitudes for realistic threats than symbolic threats. This indicates that cognitive load moderated high-impulsivity individuals' processing of symbolic (reputation) and realistic (material) threats, reducing their attentional bias toward reputation. Similarly, cognitive load moderated low-impulsivity individuals' processing of symbolic and realistic threats: with cognitive load, low-impulsivity individuals showed more positive P2 amplitudes for realistic threats than symbolic threats; without cognitive load, they showed more positive P2 amplitudes for symbolic threats than realistic threats. This demonstrates that cognitive load enhanced low-impulsivity individuals' ability to resist economic temptation.

In summary, this study demonstrates through two experiments that in the process of performance monitoring of aggressive behavior, high-impulsivity individuals develop attentional bias toward threat information, with threat-related signals attracting more attentional resources, weakening stop-signal monitoring and thereby compromising cognitive control. By manipulating a digit-string task, we further verified that cognitive load can impair individuals' cognitive control ability. The impairing effect of aggressive threats on response inhibition was greater than that of realistic threats, which was greater than that of symbolic threats. Shorter reaction times to threat-related signals indicate faster detection of threat-related information. Additionally, cognitive load had a moderating effect on monitoring of threat stimuli, primarily manifested for realistic and symbolic threats. Under no cognitive load, individuals showed greater monitoring capacity for reputation than for economic concerns; under cognitive load, they showed greater monitoring capacity for economic concerns than for reputation. This suggests that individuals are more cautious without cognitive load, and that cognitive load impairs conflict monitoring ability. Cognitive load moderated high-impulsivity individuals' processing of symbolic (reputation) and realistic (material) threats, reducing their attentional bias toward reputation while enhancing low-impulsivity individuals' ability to resist economic temptation.

Based on these findings, our results suggest that impulsive individuals' performance monitoring of aggressive behavior can be improved by reducing attentional bias toward threat information, regulating attentional resource allocation, and enhancing monitoring of relevant target stimuli to further improve cognitive control.

The present findings on mechanisms for enhancing performance monitoring in impulsive individuals also provide new perspectives and insights for future research on threat and cognitive control in impulsive populations. Future work should not only examine processing mechanisms of different threat types in threat-cognitive control interactions but also attend to individual differences in signal monitoring and conflict control interactions with threat.

Building on our finding that threat can impair individuals' ability to inhibit responses to stop signals, subsequent research could develop targeted training and intervention programs for monitoring and control functions to achieve effective enhancement of cognitive control abilities.

The present results demonstrate that in a flanker-stop-signal combined paradigm, impulsive individuals' attentional bias toward threat information can impair stop-signal processing, indicating that impulsive individuals are more sensitive to threats and have weaker response inhibition ability, with threat weakening cognitive control. To further examine effects of cognitive load and threat type on impulsive individuals' performance monitoring, we expanded threat types and inserted a digit-string cognitive load task. Results showed that sensitivity to aggressive threats was higher than to symbolic threats, which was higher than to realistic threats. Differences between high- and low-impulsivity individuals primarily manifested in processing symbolic and aggressive threats, suggesting that impulsive individuals are more sensitive to implicit threats, while high-impulsivity individuals' rapid responding may reflect sensitivity to explicit threats but weaker sensitivity to implicit threats.

High-impulsivity individuals may need to expend more cognitive resources, indicating that cognitive load can impair individuals' cognitive control ability. The impairing effect of aggressive threats on response inhibition was greater than that of realistic threats, which was greater than that of symbolic threats. Shorter reaction times to threat-related signals indicate faster detection of threat information. Additionally, cognitive load had a moderating effect on monitoring of threat stimuli, primarily for realistic and symbolic threats. Under no cognitive load, individuals showed greater monitoring capacity for reputation than for economic concerns; under cognitive load, they showed greater monitoring capacity for economic concerns than for reputation. This indicates that individuals are more cautious without cognitive load, and that cognitive load impairs conflict monitoring ability. Cognitive load moderated high-impulsivity individuals' processing of symbolic (reputation) and realistic (material) threats, reducing their attentional bias toward reputation and enhancing low-impulsivity individuals' ability to resist economic temptation.

Based on these results, we conclude that impulsive individuals' performance monitoring of aggressive behavior can be enhanced by reducing attentional bias toward threat information and regulating attentional resource allocation to improve monitoring of relevant targets and cognitive control.

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Note: Figure translations are in progress. See original paper for figures.