Characterizing the role of impulsivity in costly, reactive aggression using a novel paradigm

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Abstract

Lack of self-control has long been theorized to predict an individual's likelihood to engage in antisocial behaviors. This idea is also key to several neurobiological theories of aggression, which argue for a coupling of heightened limbic reactivity and impaired PFC-driven inhibitory control when an individual experiences provocation. However, existing definitions of self-control encompass multiple psychological constructs. We introduce a novel paradigm, the Retaliate or Carry-on: Reactive AGgression Experiment (RC-RAGE) which includes an immediate retaliation option and a financial cost to retaliating, placing high demands on self-control. The current study tests to what extent dispositional impulsivity, self-control, aggression, and state anger contribute to aggression upon provocation where self-control is needed most. Results showed that costly retaliation on this task was related to trait aggression and being in an angry emotional state, but not related to social desirability. Importantly, we show that the tendency to act impulsively is a better predictor of costly retaliation than other forms of self-control, such as the ability to delay gratification, resist temptation, or plan ahead. Going forward, this task provides a tool for the future investigation of reactive aggression in a variety of experimental settings.

The relationship between self-control and violence has been observed for decades and generated several theoretical accounts of aggression, beginning with Gottfred & Hirschi's General Theory of Crime (Gottfredson & Hirschi, 1990) and more recently described by the general aggression model (DeWall et al., 2011) and the I^3 theory, (Finkel et al., 2012), among others. Despite dissimilarities in what specific, mechanistic role self-control plays in preventing reactive aggressive behavior, these theories generally agree on a common sequence of events. First, some sort of provocation occurs, which triggers the desire to aggress or retaliate. If the provoked individual has sufficient self-control, they will successfully inhibit this desire, and if their self-control is impaired or insufficient to inhibit the aggressive response, they will retaliate (Denson et al., 2012). This type of impulsive aggression upon provocation is referred to as reactive aggression, which is often distinguished from premeditated, proactive aggression (Barratt et al., 1999; Walters, 2008; cf. Bushman & Anderson, 2001).

Some of the most compelling evidence for this link comes from a recent meta-analysis of 99 observational studies which demonstrated a robust correlation between self-control and deviant or criminal behavior (Vazsonyi et al., 2017). Importantly, there are key environmental influences which lead to lower self-control and similar psychological processes. Research demonstrates that chronic stress, unemployment, resource scarcity, environmental instability, and other stressors can have a significant influence on self-control (Lovallo, 2013; Sheehy-Skeffington, 2020). Thus, the relationship between self-control and aggression is likely a complex interaction between dispositional and environmental factors.

The notion of self-control is colloquially defined as "willpower" but is used by researchers to describe a number of psychological processes that allow individuals to regulate behavior. As such, self-control does not have a single agreed upon operational or conceptual definition. In Gottfredson & Hirschi's (1990) original definition, self-control is a trait-level construct associated with characteristics such as the ability to: delay gratification, be persistent, exert caution, and inhibit aggressive responses when frustrated. Other research describes self-control as a conscious effort to control one's behavior in the moment when presented with two competing or conflicting goals, and is therefore treated more as a decision-making process that is influenced by both dispositional and situational/environmental factors (Berkman et al., 2017; Hofmann et al., 2009; Inzlicht et al., 2021; Inzlicht & Schmeichel, 2012). Finally, self-control is also conceptualized as the process of choosing a cognitively-demanding, context-dependent mode of responding over a more automatic, habit-based or heuristic mode (Boureau et al., 2015).

However, in the extant literature, poor self-control is also described as high impulsivity or poor self-regulation, despite evidence that these may reflect separable psychological processes (Inzlicht et al., 2021). A recent data-driven factor analysis demonstrated that the higher order self-control construct could actually be broken into two dominant clusters of related behaviors - one most related to impulsivity, reward sensitivity, goal-directedness and mindfulness, and the other loading onto longer-term attitudes surrounding goals, such as grit or will-power (Eisenberg et al., 2019). Indeed, many researchers specifically focus on the link between impulsivity and aggression (Barratt et al., 1999; García-Forero et al., 2009) rather than self-control more broadly.

A predominant neurobiological model of aggression is based on the idea that reactive aggression is more likely to occur when individuals have heightened limbic reactivity to provocation and insufficient inhibitory control from prefrontal cortical (PFC) regions (da Cunha-Bang et al., 2017; Nelson & Trainor, 2007; Siever, 2008). This framework of aggression is also described as reflecting a mismatch between a heightened "drive" and an insufficient "brake" when provocation occurs. Evidence for this comes from observed functional and structural abnormalities of the prefrontal cortex and limbic regions such as the amygdala and anterior cingulate cortex in those with a history of aggressive, antisocial behaviors (Best et al., 2002; Raine, 2008; Siever, 2008). However, it remains unclear what the relative importance of self-control (broadly reflecting delayed gratification, resisting temptation, perseverance, etc.; Eisenberg, 2019) and impulsivity (i.e. an impaired drive/brake system) are for preventing an aggressive response upon provocation.

One caveat of the work linking self-control impairments and impulsivity to aggression, crime, and violent behaviors is that it has primarily been conducted using observational studies, rather than empirical tests. As evidence mounts for a robust link between self-control/impulsivity and reactive aggression based on this work, an important next step is to empirically identify the most important trait-level (i.e., self-control, impulsivity) and state-level (i.e., situational/ environmental cues, emotional state) predictors. Given the ethical and logistical issues that arise when attempting to measure a laboratory-based measure of aggression, this is no simple task and existing measures of retaliatory aggression are somewhat limited (Lobbestael, 2015; McCarthy & Elson, 2018; Ritter & Eslea, 2005; Tedeschi & Quigley, 1996). While these paradigms may be effective in many contexts, they are not suited to examine aggression where self-control is needed most: where there is an explicit conflict between a desired response (react aggressively) and the correct response (ignore provocation).

For example, these paradigms often elicit aggressive behavior in a context where there may be either explicit or implicit permissibility and encouragement to act aggressively (i.e., Teacher/Learner paradigm; Buss, 1961). While the often-used Competitive Reaction Time Task (Taylor, 1967) does measure reactive aggression upon provocation, this task is embedded within a competitive context where acting aggressively may, in fact, imbue a tactical advantage (Tedeschi & Quigley, 1996). At a minimum, the Competitive Reaction Time Task creates a context where the desired aggressive response is not discouraged. By imbuing a potential incentive or advantage to aggressing, tasks of this nature are not well suited to studying aggression where self-control or inhibition of an impulsive response is needed, as there is no conflict between what is the “right” choice and what is the “desired” response.

In contrast, other paradigms such as the Point-Subtraction Aggression Paradigm, or PSAP (Cherek et al., 1996), are able to evaluate aggression upon provocation that has a cost involved, but it does not allow for the examination of impulsive aggression. In the typical PSAP and its close variants, participants press a button to gain money and an opponent will occasionally steal some of their earnings. Depending on the specific version used, participants can subtract points from their opponent, ignore their opponent's actions, or protect their money. While this paradigm has been shown to distinguish between participants with and without a history of violence (Cherek et al., 2000; Cherek et al., 1996), it is not ideally suited to study impulsive, reactive aggressive responses as the participant cannot retaliate against their opponent immediately. If participants are provoked while pressing the key used to earn money, they must wait until they've finished that round of key presses before retaliating. Thus, there is a temporal delay between the time that a person experiences provocation and when they are actually able to retaliate. Consistent with this limitation, a study found that participants high on impulsive, reactive aggression do not retaliate more on the PSAP, but rather, work harder to earn money (Gan et al., 2016).

When studied in non-clinical samples, individual differences in self-control, impulsivity, aggression, and history of violence are determined by questionnaire measures or tasks in which participants may underreport these tendencies due to social desirability (Saunders, 1991). It has been proposed that in many cases, social desirability may explain low correlations between self-reported aggression and behavioral measures of aggression (Lobbestael, 2015; Vigil-Colet et al., 2012). Therefore, to study reactive aggression in a neurotypical sample in an experimental setting, an ideal task would elicit aggression even if participants are motivated to act in a socially desirable manner.

To fill this methodological gap and allow for an empirical test of the link between impulsivity, self-control, trait-level aggression, and costly, reactive aggression, we designed a new paradigm, called the Retaliate or Carry on - Reactive AGgression Experiment, or RC-RAGE. The RC-RAGE differs from the PSAP in that provocations are more visually salient and prolonged (thereby putting more pressure on self-control), and retaliations are very easy, immediate, and more visually violent. However, as in the PSAP (but not in the Competitive Reaction Time Task), there is a financial cost to retaliating, which creates the conflict that requires self-control. Our task diverges from standard lab-based paradigms where there is an ostensible other person being harmed directly or indirectly, due to concerns over the beliefs regarding deception/cover stories (McCarthy & Elson, 2018) and due to a desire to increase the contexts in which the task can be used (e.g., outside of the lab). We propose that our task can provide a proxy for impulsive, reactive aggression that allows greater use-case flexibility. Evidence that this a proxy for real-world aggression would be bolstered by a positive relationship between costly retaliation on the RC-RAGE and trait-level aggression, which is something we examine here. Additionally, given concerns about the flexible measures used in quantifying aggression in paradigms such as the Competitive Reaction Time Task (Elson, 2016; Elson et al., 2014), we preregistered our experiment, measurement approach, and confirmatory analyses.

We hypothesized that participants who reported higher trait aggression, higher trait impulsivity, and poorer trait self-control would show higher levels of costly retaliation in this paradigm. Additionally, based on research linking aggression and state-level anger (Denson et al., 2009; Harmon-Jones & Sigelman, 2001), we hypothesized that negative affective states, particularly feelings of hostility, would be associated with costly retaliation. Lastly, we hypothesized that retaliation in this task would provide a measure of impulsive, costly aggression that is less affected or unaffected by participants' desires to "look good" (i.e, social desirability) relative to self-report measures. All three of these hypotheses were generated after conducting the exploratory study and were pre-registered at https://osf.io/czn43 before conducting the confirmatory study.

Consistent with the pre-registered hypotheses, we find that more costly retaliation is strongly linked to dispositional aggression, the tendency to act impulsively, and angry state affect, and not underestimated due to social desirability. However, we did not find strong evidence that it was related to other forms of self-control (e.g., delayed gratification, the tendency towards planning ahead). This selectivity is consistent with recent evidence for the separable nature of multiple self-control-related constructs (Eisenberg et al., 2019; Inzlicht et al., 2021). The strong relationship between costly retaliation and the tendency to act impulsively is consistent with neurobiological models of aggression (Nelson & Trainor, 2007; Siever, 2008), where there is a heightened "drive" and insufficient "brake" to stop one from impulsively responding to provocation with aggression. Therefore, this neurobiological model may be especially applicable to scenarios where there is a strong conflict between the desired retaliation response and the optimal, but less appealing, inhibition of this aggressive response. Together, these results suggest that the RC-RAGE task provides a robust measure of impulsive, costly aggression that can be used to better elucidate the factors that lead to impulsive aggression even when there is a clear incentive to ignore provocation and carry on.

Results

Behavioral Task and Hypotheses

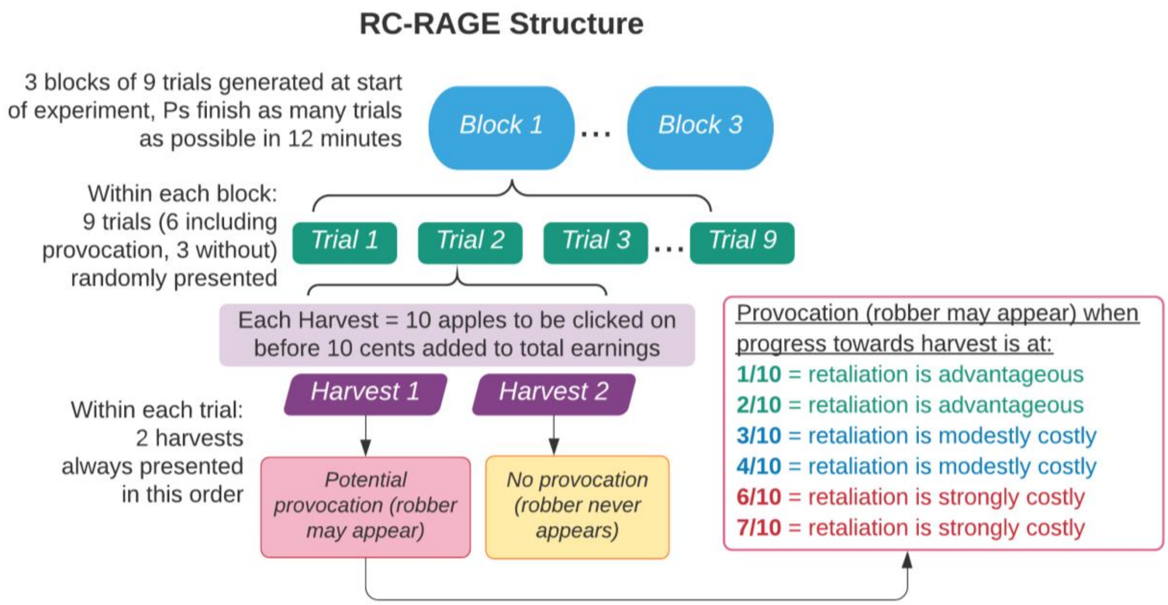
To examine whether retaliation on this novel task: 1) corresponds to individual differences in dispositional aggression, impulsivity, and self-control, and 2) provides a measure costly reactive aggression unaffected by social desirability, we had participants complete a number of questionnaires either before or after completing the RC-RAGE. The order was counterbalanced so that one half of participants would complete the questionnaires first and the other half would complete the RC-RAGE first. To see 3) whether costly retaliation on our task was also sensitive to current emotional state, particularly feelings of anger, all participants completed a state affect assessment directly before performing the RC-RAGE. The pre-registration can be accessed at https://osf.io/czn43 and the data and analysis scripts at: https://osf.io/796rs/. Task code can be found at https://github.com/kywch/RC-RAGE_jsPsych and a working demo of the task is available: https://kywch.github.io/RC-RAGE_jsPsych/rc-rage-demo.html.

In the RC-RAGE, participants were asked to maximize their earnings in 12 minutes by clicking on green dots (referred to as apples) moving the screen. Once participants clicked on 10 apples in a row (i.e., a harvest), they were able to cash out and 10 cents was added to their total earnings. Occasionally, an opponent (referred to as the "robber") would appear on the screen, steal 5 cents of their money, and remain there for some period of time. Participants could retaliate against the robber and get 3 cents back by shooting him twice to destroy him, but when they did so, they would lose their progress towards their harvest. (See **Figure 1** for RC-RAGE participant interface examples). For example, if a participant clicked on 7 apples in a row, their current progress towards the harvest would be 7/10, and if the robber appeared at this point and the participant retaliated, they would get 3 cents back but their progress towards the harvest would return to 0/10 (i.e., when they retaliate they lose progress on the current harvest, but get some money back from their banked total earnings). The robber always disappeared before participants could complete their progress towards the 10 apples, and after he disappeared, they would lose their chance to get 3 cents back. Thus, the robber forced participants to continuously choose between whether to retaliate and lose progress or to ignore him and carry on.

Figure 1. Example Screenshots from RC-RAGE with event descriptors

The time at which the robber appeared was manipulated so that, depending on how much progress the participant had made towards the harvest of 10 apples, the cost associated with retaliation was varied. To quantify the extent to which retaliation was more or less costly, we calculated the monetary value of each mouse click during the task and compared the value of mouse clicks across conditions. When the robber appears at the 1/10 progress, the value of each click is slightly higher with retaliation than self-restraint (ignoring the robber and carrying on) and when the robber appears at the 2/10 progress, the value of click is the same between retaliation and self-restraint. However, when the robber appears at the 3+/10 progress, the value of click is lower with retaliation than self-restraint.

Figure 2. Structure of the full RC-RAGE

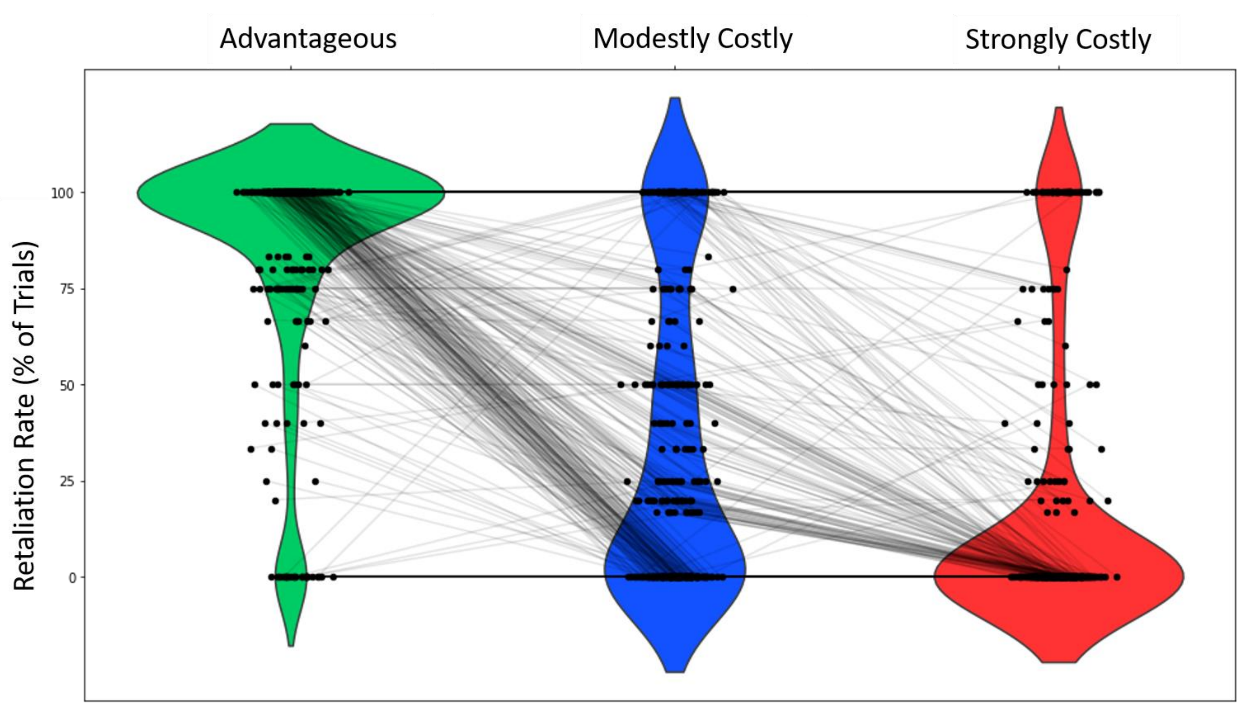


We operationally define retaliation at 1-or-2 clicks in as advantageous, retaliation at 3-or-4 clicks in as modestly costly, and 6-or-7 clicks in as strongly costly. These 3 conditions were created based on what participants were explicitly told (i.e., it was financially best to retaliate if progress is at 1 or 2 clicks in but not if they've made progress greater than 2/10 clicks) and with the goal of keeping the number of trial types per condition consistent (i.e., combining trials where progress was 3-or-4, 6-or-7). For each condition (advantageous, modestly costly, strongly costly), retaliation rate was calculated as the (#retaliations in condition / #trials in condition). Raincloud plots showing the distribution of retaliation rates for each type of aggression across all 354 participants are shown in **Figure 3**. The percentage of participants who retaliated at least once for each type can be found in **Table 1**.

Table 1. Percent of participations retaliating at least once in each situation split by gender and order

		Gender			Order	
	Overall (N=354)	Female (N=174)	Male (N=174)	Other (N=6)	Survey 1st (N=176)	Task 1st (N=178)
Advantageous						
Did not retaliate	27 (7.6%)	12 (6.9%)	14 (8.0%)	1 (16.7%)	10 (5.7%)	17 (9.6%)
Retaliated	327 (92.4%)	162 (93.1%)	160 (92.0%)	5 (83.3%)	166 (94.3%)	161 (90.4%)
Modestly Costly						
Did not retaliate	153 (43.2%)	76 (43.7%)	73 (42.0%)	4 (66.7%)	86 (48.9%)	67 (37.6%)
Retaliated	201 (56.8%)	98 (56.3%)	101 (58.0%)	2 (33.3%)	90 (51.1%)	111 (62.4%)
Strongly Costly						
Did not retaliate	264 (74.6%)	134 (77.0%)	127 (73.0%)	3 (50.0%)	140 (79.5%)	124 (69.7%)
Retaliated	90 (25.4%)	40 (23.0%)	47 (27.0%)	3 (50.0%)	36 (20.5%)	54 (30.3%)

Figure 3. Distributions of Retaliation Rates by Condition. Raincloud plot shows retaliation rates (0% = never retaliated in condition, 100% always retaliated in condition) across all 354 participants for each condition with jittered dots representing individual participants



Results

Confirmatory Correlation Results

<u>*Relationship Between Costly Retaliation & Trait Aggression, Impulsivity, and Self-control*</u>

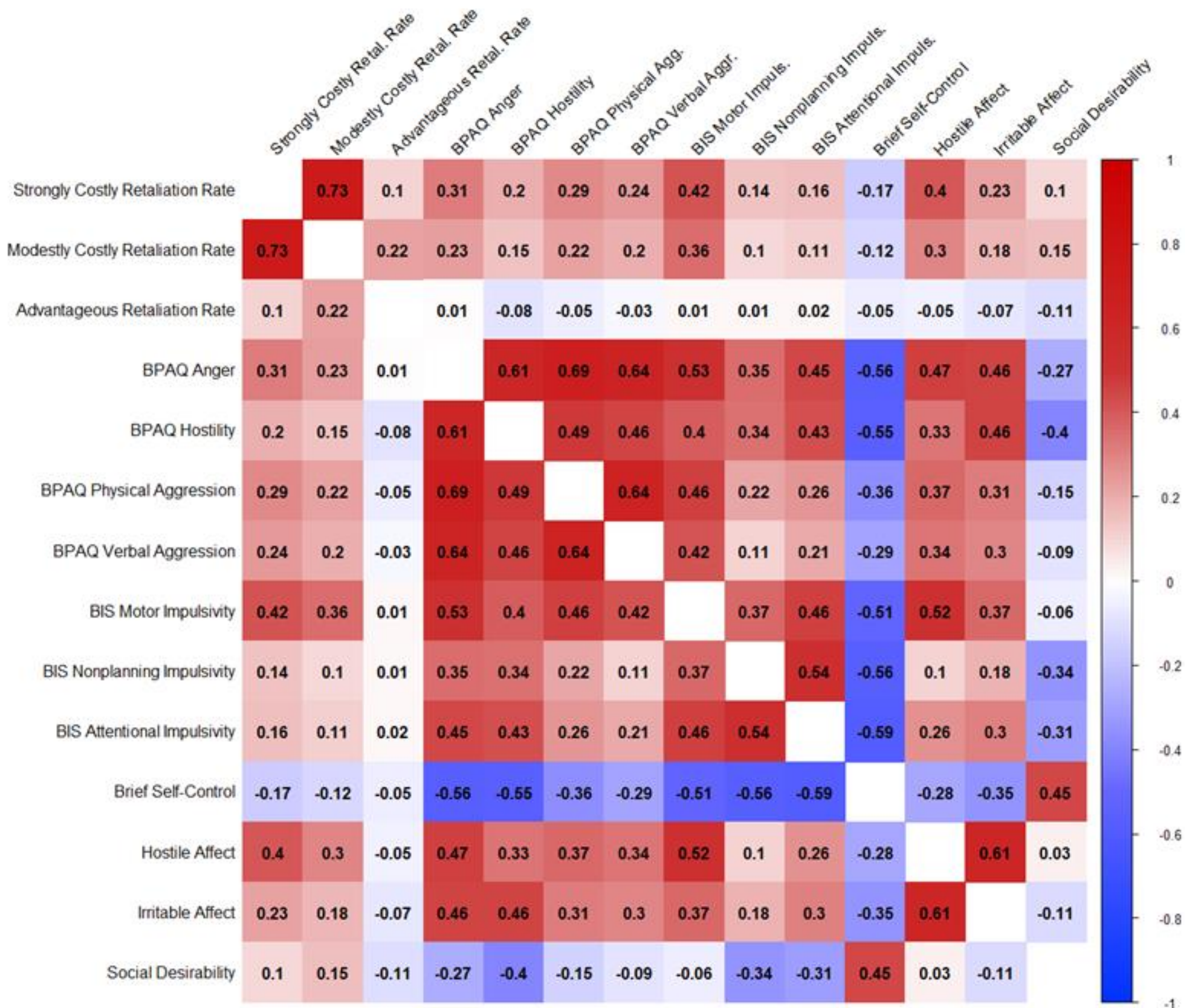
Our first hypothesis was that participants who reported higher trait level aggression and impulsivity, and lower trait self-control would show higher levels of costly retaliation on this paradigm. As specified in our pre-registration, we tested this by examining correlations between rates of modestly costly and strongly costly retaliation and self-reported aggression (BPAQ), impulsivity (BIS-11), and self-control (BSC). Though no relationship was expected between advantageous retaliation and any of the self-report measures, these correlation coefficients are also displayed in the correlation matrix. Based on Bonferroni correction for the 32 statistical tests we pre-registered (strongly costly retaliation rate and 11 self-reports, modestly costly retaliation and 11 self-reports, social desirability with other 10 self-reports), p-values < 0.00156 (critical $r = 0.168$) were considered significant. **[Figure 4]**

For trait aggression, positive correlations were found between all subscales of the BPAQ (Anger, Hostility, Physical Aggression, and Verbal Aggression) and both forms of costly retaliation (i.e., modestly costly and strongly costly). Anger was significantly correlated with modestly costly ($r = 0.23$, $p < 0.001$) and strongly costly retaliation ($r = 0.31$, $p < 0.001$), as was physical aggression ($r = 0.22$, $p < 0.001$ and $r = 0.29$, $p < 0.001$, respectively), and verbal aggression ($r = 0.20$, $p < 0.001$, and $r = 0.24$, $p < 0.001$, respectively). Hostility was significantly correlated with strongly costly aggression ($r = 0.20$, $p < 0.001$) but not with modestly costly aggression ($r = 0.15$, $ps = 0.006$) [**See Figure 4**]. A correlation coefficient of 0.1 is considered a small effect and > 0.3 a medium effect.

Therefore, the correlations between trait aggression and strongly costly aggression (*r* between 0.2 and 0.31) reflect small-to-medium effects and the correlations with modestly costly aggression (between 0.15 and 0.23) suggest small effects.

For trait impulsivity, significant positive correlations were found between motor impulsivity (BIS-Motor) and both forms of costly retaliation (modestly costly: $r = 0.36$, $p < 0.001$; strongly costly: $r = 0.42$, $p < 0.001$), both medium-sized effects. When correcting for multiple comparisons, the other BIS subscales (Attentional and Non-planning) were not significantly correlated with strongly costly retaliation (Attentional $r = 0.16$, $ps = 0.003$; Non-planning $r = 0.14$, $ps = 0.008$) or modestly costly retaliation ($ps = 0.03$ and 0.07, respectively). For self-control, lower scores on the BSC were not significantly negatively correlated with strongly costly retaliation ($r = -0.17$, $ps = 0.0018$) or modestly costly retaliation ($r = -0.12$, $ps = 0.02$). It's worth noting that for the correlations between costly retaliation and non-planning impulsivity, attentional impulsivity, and self-control, most were significant before Bonferroni correction (i.e. $p < 0.05$ uncorrected) and were small effects (*r* between 0.12 and 0.17).

Figure 4. Correlation matrix for self-report measures and costly retaliation in all participants



Relationship Between Costly Retaliation & Angry Affective State

Our second hypothesis was that negative affective state, particularly feelings of anger, would be associated with costly retaliation. To test this, and as specified in our pre-registration, we conducted correlations between retaliation rate and two items from the PANAS that best reflected an angry affective state: hostile and irritable.

When examined across all participants, a significant, positive association was found between hostile affective state and both modestly costly ($r = 0.30$, $p < 0.001$) and strongly costly retaliation ($r = 0.40$, $p < 0.001$). For irritability, significant positive correlations were also found with modestly ($r = 0.18$, $p = 0.001$) and strongly costly retaliation ($r = 0.23$, $p < 0.001$). Effect sizes for hostile affect were in the medium range and the effect sizes for irritability were in the small range. Taken together, these results suggest that both an angry emotional state and trait-level aggression and motor impulsivity contribute to the likelihood of engaging in costly, reactive aggression.

Effects of Social Desirability

Our final confirmatory hypothesis was that this task would provide a measure of impulsive aggression that would not be affected by socially desirable responding. We predicted that social desirability would negatively correlate with measures of aggression and impulsivity, positively correlate with self-control, and would be unrelated to the retaliation rate on the RC-RAGE.

Overall, social desirability was negatively correlated with self-reported aggression, positively correlated with self-control, and negatively correlated with impulsivity. Significant correlations were found between social desirability and BPAQ-Anger ($r = -0.27$, $p < 0.001$), BPAQ-Hostility ($r = -0.4$, $p < 0.001$), BIS-Non-planning ($r = -0.34$, $p < 0.001$), BIS-Attentional ($r = -0.31$, $p < 0.001$), and Brief Self Control ($r = 0.45$, $p < 0.001$). There were not significant correlations between social desirability and BPAQ-Physical ($r = -0.15$, $p = 0.006$), BPAQ-Verbal ($r = -0.09$, $p = 0.1$), or BIS-Motor Impulsivity ($r = -0.06$, $p = 0.29$), though these were all in the expected direction. Critically, social desirability was not significantly correlated with modestly costly retaliation rate (r = 0.15, p = 0.006) or strongly costly retaliation (r = 0.1, p = 0.068) and these correlations were positive (i.e. higher social desirability, higher rates of retaliation), suggesting that individuals do not refrain from impulsive aggression on the RC-RAGE due to a desire to maintain socially acceptable behavior

Comparing the Relationships between Impulsivity/Self-Control and Costly Aggression

The confirmatory correlation analyses suggested that there may be a stronger link between costly aggression and the tendency to act impulsively than other forms of impulsivity and self control. To directly test whether this is the case, one sided z-tests specifically testing whether correlations with costly retaliation and BIS-Motor were larger than correlations with other measures of self-control were used. The detailed results of these correlations are presented in **Table 2**. Motor impulsivity showed a significantly larger correlation with strongly costly retaliation rate than did attentional impulsivity, non-planning impulsivity, and self-control (all p < 0.001). The same was true for modestly costly retaliation rate, where larger correlations were found with motor impulsivity than other measures of impulsivity or self-control (all p < 0.001). These results suggest that retaliation on the RC-RAGE where the demands on self-control are high is most tightly linked to individual differences in the tendency to act impulsively.

Table 2. Z-tests comparing impulsivity/self-control measures and costly retaliation rate.

	***z*-test vs. BIS-Motor ~ Strongly Costly RR**	***z*-test vs. BIS-Motor ~ Modestly Costly RR**
BIS- Attentional	$z = 5.06$, $p < 0.001$	$z = 4.78$, $p < 0.001$
BIS- Nonplanning	$z = 5.06$, $p < 0.001$	$z = 4.61$, $p < 0.001$
Brief Self-Control	$z = 5.11$, $p < 0.001$	$z = 4.81$, $p < 0.001$

Predicting Costliness of Retaliation by Self-report Measure

In addition to the confirmatory correlations, exploratory logistic mixed effect regressions were conducted to examine interactions between the self-report measures and retaliation rate as a function of how costly retaliation was. This was conducted for two primary reasons. First, this approach allows for a specific examination of how the costliness of retaliation (rather than retaliation in general) relates to trait aggression, impulsivity, self-control, and angry affect. Second, as the values of retaliation rate are limited to being between 0 and 1 and do not follow a normal distribution (see **Fig. 3**), conducting a logistic regression is more appropriate than the linear regression used in correlations, which are presumed to follow a gaussian distribution. These models were run separately (as opposed to all in one regression) due to high inter-measure correlations which caused multicollinearity if included in the same model. For each self-report measure, the model was specified as:

glmer(Retaliation_Rate ~ Costliness * Self-report_Measure + (1 | sub), family = binomial, nAGQ = 10), where costliness was a categorical factor corresponding to the robber appearing at position 1-or-2 (advantageous), position 3-or-4 (modestly costly), or position

6-or-7 (strongly costly). Detailed results for dispositional aggression can be found in **Table 3** and **Figure 5**.

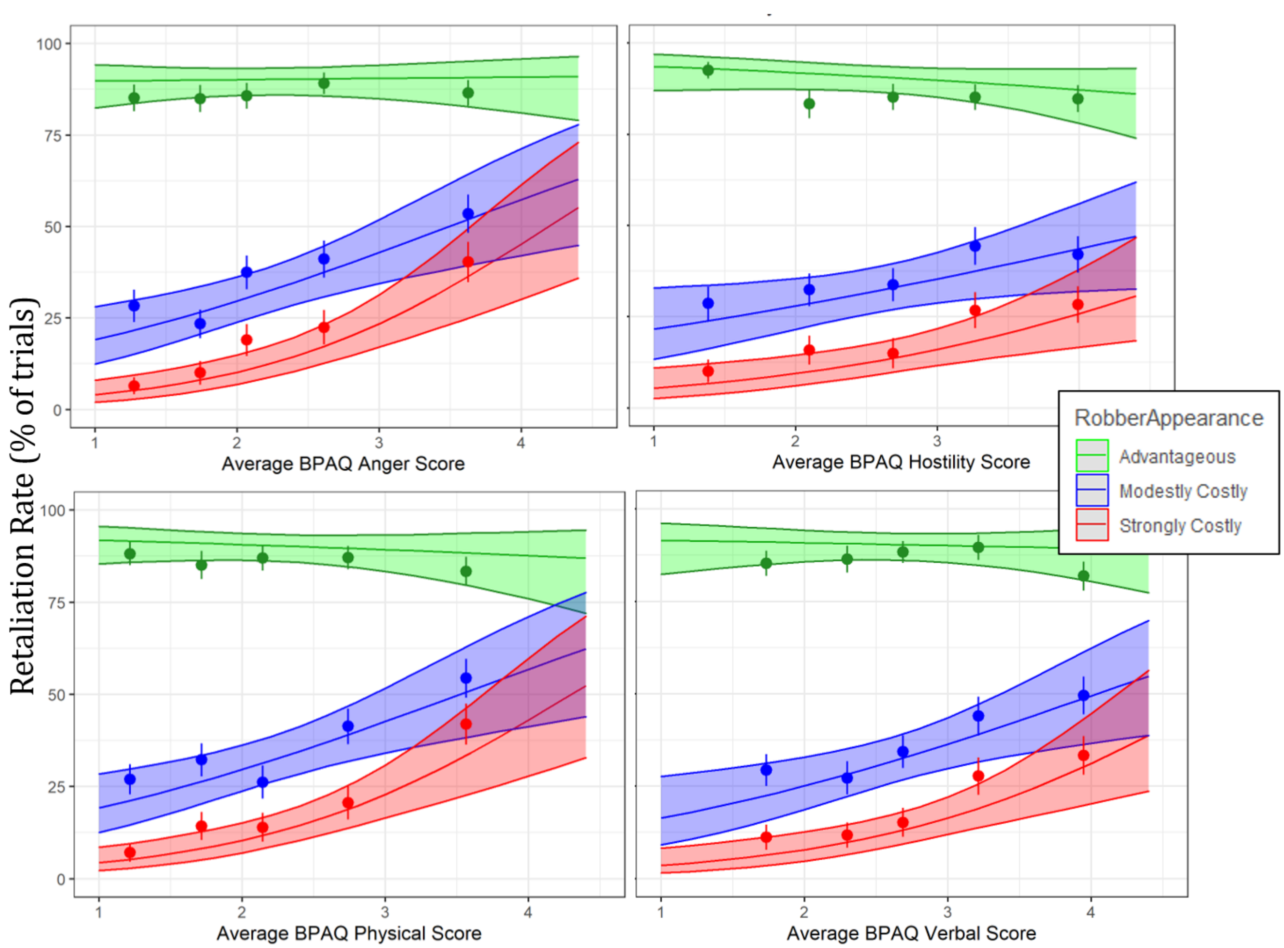
Self-reported aggression as measured by all 4 BPAQ subscales (physical, verbal, anger, and hostility) significantly interacted with how costly retaliation was in predicting retaliation rate. More specifically, dispositional aggression showed a greater relationship with retaliation rate when it was modestly costly or strongly costly relative to when it was advantageous. This interaction effect was largest for physical aggression and anger (See **Table 3** and **Figure 5**). The tendency to act impulsively (as measured by the BIS-Motor subscale) also yielded significant interactions with costliness of retaliation in predicting retaliation rate, wherein participants higher on motor impulsivity also retaliated more when it was modestly costly and strongly costly relative to advantageous (**Table 3, Figure 5**). Neither of the other BIS scales (attentional, non-planning) showed a significant interaction, nor did trait self-control as measured by the Brief Self-Control Scale (**Figure 5**). Both hostile and irritable state affect also showed significant interactions with costliness of retaliation rate. In both cases, higher levels of state hostility and irritability were more related to modestly costly or strongly costly retaliation than advantageous retaliation (**Figure 5, Table 3**).

Figure 5. Predicted Probabilities + Averaged Data for Retaliation Rate as a function of Costliness (Retaliation Type) and Dispositional Measures

Line graphs represent predicted responses of fixed effects from logistic regression models presented in Table 3. Shaded areas indicate standard errors. Point-range plots reflect actual data and were calculated by splitting participants into 5 groups based on self-report measures. For BPAQ, BIS, and BSC, groups were calculated using quintiles. For affect measures, the raw values (1-5) were used. Dots represent the mean retaliation by robber appearance within groups and bars represent standard errors.

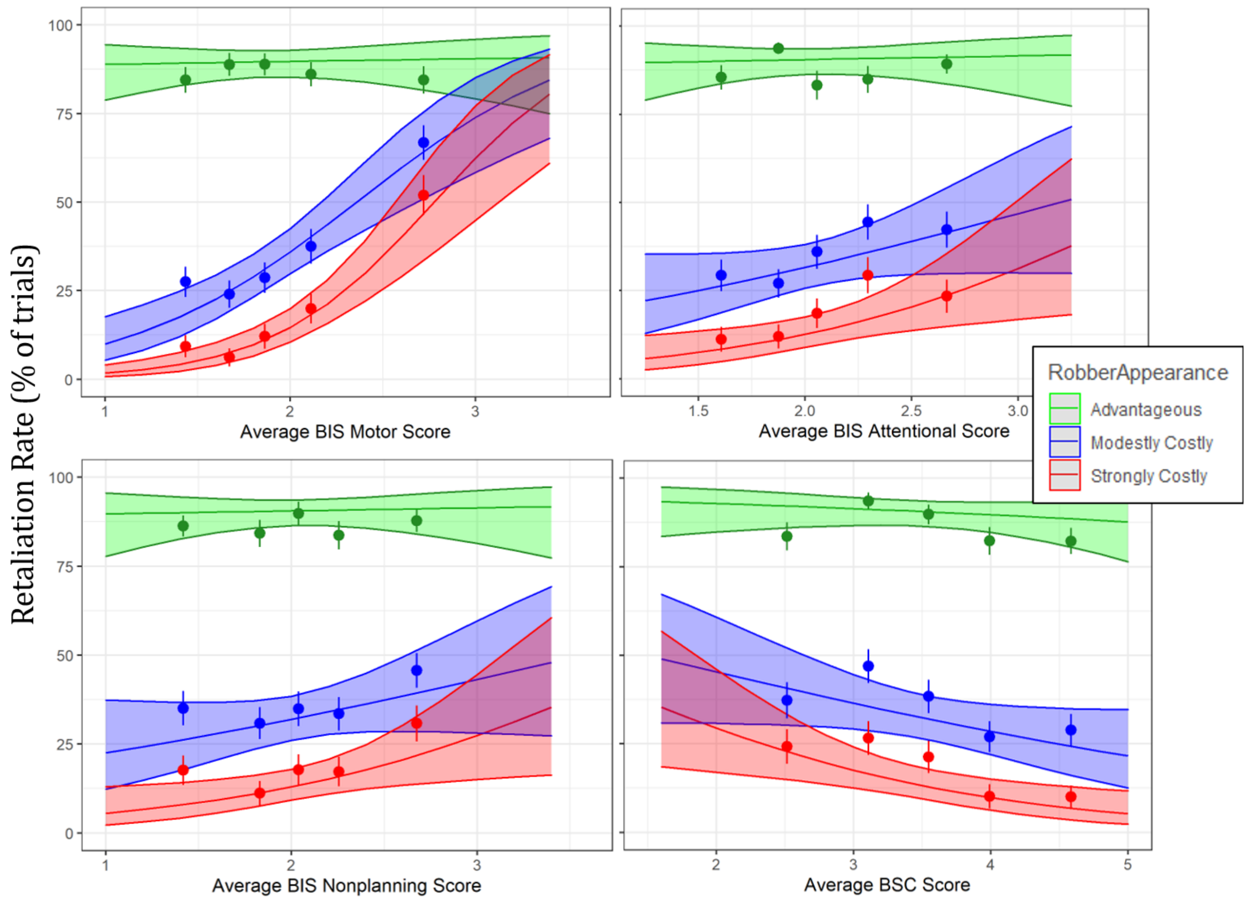
Panel A. Trait Aggression (BPAQ)

All 4 scales generated significant interactions for both modestly costly (BPAQ Anger: $p = 0.028$; BPAQ Hostility: $p = 0.01$; BPAQ Physical: $p = 0.003$; BPAQ Verbal: $p = 0.03$) and strongly costly retaliation (BPAQ Anger: $p < 0.001$; BPAQ Hostility: $p < 0.001$, BPAQ Physical: $p < 0.001$; BPAQ Verbal: $p = 0.002$) relative to advantageous retaliation. For average BPAQ measures, the range of responses is 1-5, with higher values indicating greater aggression.



Panel B. Dispositional Impulsivity (BIS) and Self-Control (BSC)

Only BIS Motor Impulsivity generated significant interactions for both modestly ($p < 0.001$) and strongly costly retaliation ($p < 0.001$) relative to advantageous retaliation. BIS Non-planning, BIS-Attentional, and Brief Self-Control did not show significant interactions. For averaged BIS scores, the range of responses is 1-4 with higher values indicating greater impulsivity. For average BSC score, the range is 1-5 with higher values indicating higher self-control.



Panel C. Angry Affect

Both Hostile Affect and Irritable affect showed significant interactions with modestly costly retaliation ($p < 0.001$, and $p = 0.005$, respectively) and strongly costly retaliation (both $p < 0.001$). For both measures, the range of responses was 1-5, with higher values indicating higher levels of angry affect.

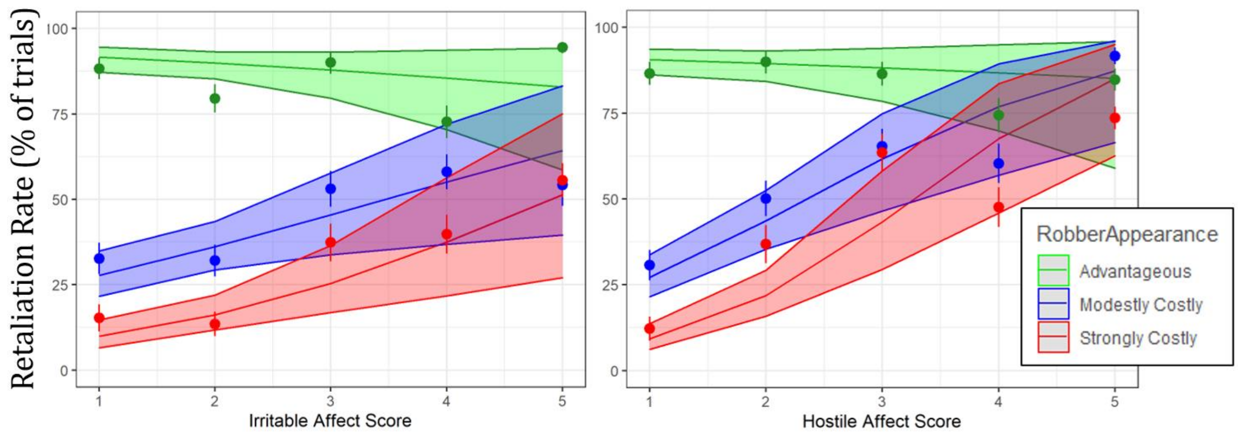


Table 3. Logistic Mixed Effects Regression Tables with Significant Interactions

Logistic Regression Models Predicting Retaliation Rate by Costliness Condition (Advantageous, Modestly Costly, Strongly Costly) and Self-report measures: BPAQ Anger, BPAQ Hostility, BPAQ Physical Aggression, BPAQ Verbal Aggression, BIS Motor Impulsivity, Hostile Affect, and Irritable Affect. Models without significant interactions not shown but output is accessible on OSF project page). Full models are reported but interactions (tests of primary interest) are highlighted in purple.

For costliness conditions, advantageous retaliation was used as the reference. Fixed effects results are reported as estimates (B) with standard errors, z-values, p-values. Mixed effects values are calculated through multi-level bootstrapping to generate boot mean estimates (B) and 95% confidence intervals.

BPAQ Anger	**Fixed Effects Est.** ***B* (Std. Error)**	**Mixed Effects Est.** ***B* [95% CI LL, UL]**	***z***	***p***
Intercept	2.13 (0.49)	3.22 [1.66, 4.85]	4.31	< 0.001
Modestly Costly Retaliation	-4.15 (0.62)	-6.74 [-8.6, -4.65]	-6.75	<0.001
Strongly Costly Retaliation	-6.28 (0.73)	-9.91 [-12.18, -7.74]	-8.62	< 0.001
BPAQ Anger	0.04 (0.2)	0.05 [-0.61, 0.73]	0.21	0.84
Modestly Costly * Anger	0.54 (0.24)	0.80 [0.00, 1.57]	2.19	0.028
Strongly Costly * Anger	0.95 (0.27)	1.56 [0.75, 2.42]	3.54	<0.001

Random Effects	**Variance**	**Std. Dev**
Subject (n = 354)	1.20	1.1
AIC	769.2	
Log Likelihood	-377.6	
Observations	1062	

BPAQ Hostility	Fixed Effects Est.	Mixed Effects Est.		
	B (Std. Error)	*B* [95% CI LL, UL]	*z*	*p*
Intercept	2.93 (0.58)	4.59 [2.90, 6.27]	5.06	< 0.001
Modestly Costly Retaliation	-4.57 (0.70)	-7.59 [-9.82, -5.44]	-6.57	<0.001
Strongly Costly Retaliation	-6.40 (0.80)	-9.61 [-12.5, -7.44]	-8.02	< 0.001
BPAQ Hostility	-0.25 (0.20)	-0.47 [-1.05, 0.15]	-1.27	0.20
Modestly Costly * Hostility	0.60 (0.24)	0.99 [0.25, 1.74]	2.54	0.011
Strongly Costly * Hostility	0.86 (0.26)	1.38 [0.55, 2.26]	3.31	<0.001
Random Effects	**Variance**	**Std. Dev**		
Subject (n = 354)	1.35	1.2		
AIC	787.6			
Log Likelihood	-386.8			
Observations	1062			

BPAQ Physical Aggression	Fixed Effects Est.	Mixed Effects Est.		
	B (Std. Error)	*B* [95% CI LL, UL]	*z*	*p*
Intercept	2.58 (0.51)	3.73 [2.21, 5.50]	5.01	< 0.001
Modestly Costly Retaliation	-4.58 (0.64)	-7.67 [-9.67, -5.66]	-7.21	<0.001
Strongly Costly Retaliation	-6.60 (0.75)	-10.2 [-12.6, -7.7]	-8.86	< 0.001
BPAQ Physical Aggression	-0.15 (0.21)	-0.19 [-0.90, 0.46]	-0.74	0.46
Modestly Costly * Physical	0.72 (0.25)	1.22 [0.44, 2.00]	2.91	0.003
Strongly Costly * Physical	1.09 (0.27)	1.69 [0.80, 2.6]	4.00	<0.001
Random Effects	**Variance**	**Std. Dev**		
Subject (n = 354)	1.24	1.2		
AIC	771.4			
Log Likelihood	-378.7			
Observations	1062			

BPAQ Verbal Aggression	Fixed Effects Est.	Mixed Effects Est.		
	B (Std. Error)	*B* [95% CI LL, UL]	*z*	*p*
Intercept	2.47 (0.64)	3.70 [1.76, 5.70]	3.88	< 0.001
Modestly Costly Retaliation	-4.64 (0.78)	-7.81 [-10.2, -5.27]	-5.96	<0.001
Strongly Costly Retaliation	-6.61 (0.89)	-10.2 [-13.0, -7.41]	-7.42	< 0.001
BPAQ Verbal	-0.09 (0.23)	-0.14 [-0.85, 0.57]	-0.38	0.20
Modestly Costly * Verbal	0.62 (0.27)	1.06 [0.18, 1.90]	2.33	0.02
Strongly Costly * Verbal	0.92 (0.29)	1.44 [0.48, 2.38]	3.16	0.002
Random Effects	**Variance**	**Std. Dev**		
Subject (n = 354)	1.35	1.2		
AIC	781.5			
Log Likelihood	-383.8			
Observations	1062			

BIS Motor Impulsivity		Fixed Effects Est.	Mixed Effects Est.		
		B (Std. Error)	*B* [95% CI LL, UL]	*z*	*p*
Intercept		1.99 (0.74)	2.79 [0.34, 4.93]	2.69	0.007
Modestly Costly Retaliation		-5.81 (0.95)	-9.43 [-12.2, -6.48]	-6.14	<0.001
Strongly Costly Retaliation		-8.31 (1.07)	-12.6 [-16.0, -9.28]	-7.77	< 0.001
Motor Impulsivity		0.09 (0.38)	0.23 [-0.84, 1.47]	0.23	0.81
Modestly Costly * Motor		1.53 (0.47)	2.40 [0.97, 3.78]	3.30	<0.001
Strongly Costly * Motor		2.19 (0.50)	3.28 [1.67, 4.83]	4.40	<0.001
Random Effects	**Variance**	**Std. Dev**			
Subject (n = 354)	0.98	0.99			
AIC	736.8				
Log Likelihood	-361.4				
Observations	1062				

Hostile Affect		Fixed Effects Est.	Mixed Effects Est.		
		B (Std. Error)	*B* [95% CI LL, UL]	*z*	*p*
Intercept		2.40 (0.33)	3.38 [2.26, 4.4]4	7.16	<0.001
Modestly Costly Retaliation		-4.11 (0.43)	-6.56 [-8.01, -5.22]	-9.52	<0.001
Strongly Costly Retaliation		-5.68 (0.50)	-8.60 [-10.3, -7.08]	-11.37	< 0.001
Hostile Affect		-0.13 (0.19)	-0.04 [-0.63, 0.67]	-0.69	0.49
Modestly Costly * Hostile		0.86 (0.24)	1.19 [0.38, 1.95]	3.64	<0.001
Strongly Costly * Hostile		1.13 (0.24)	1.66 [0.81, 2.50]	4.72	<0.001
Random Effects	**Variance**	**Std. Dev**			
Subject (n = 354)	1.12	1.09			
AIC	751.5				
Log Likelihood	-368.7				
Observations	1062				

Irritable Affect		Fixed Effects Est.	Mixed Effects Est.		
		B (Std. Error)	*B* [95% CI LL, UL]	*z*	*p*
Intercept		2.59 (0.36)	3.67 [2.57, 4.80]	7.17	<0.001
Modestly Costly Retaliation		-3.93 (0.44)	-6.29 [-7.75, -4.90]	-8.86	<0.001
Strongly Costly Retaliation		-5.37 (0.51)	-7.93 [-9.49, -6.41]	-10.57	< 0.001
Irritable Affect		-0.20 (0.18)	-0.19 [-0.78, 0.46]	-1.15	0.25
Modestly Costly * Irritable		0.59 (0.24)	0.81 [0.10, 1.52]	2.80	0.005
Strongly Costly * Irritable		0.76 (0.22)	1.00 [0.20, 1.75]	3.51	<0.001
Random Effects	**Variance**	**Std. Dev**			
Subject (n = 354)	1.37	1.17			
AIC	784.2				
Log Likelihood	-385.1				
Observations	1062				

Effects of Social Desirability

Another key goal of this study was to identify whether this aggression task would provide a reliable measure of costly aggression not influenced by socially desirable responding. Therefore, we examined whether the interactions between costliness of retaliation and trait aggression, motor impulsivity, and angry affect remained when controlling for social desirability. To test this, each model which showed a significant interaction was run again with social desirability as an additional term in the regression. Results of these regressions showed that when accounting for individual differences in social desirability, all interactions maintained their statistical significance. (Output of these models can be accessed at the OSF project page: https://osf.io/796rs/)

Discussion

The link between self-control, impulsivity, and aggression has been hypothesized for decades, influencing key theories of criminal behavior and psychiatric disorders (Best et al., 2002; Gottfredson & Hirschi, 1990; Siever, 2008). However, a more nuanced understanding of how impulsivity and impaired self-control might lead to aggression upon provocation requires a metric of reactive aggression that: 1) can be used in an experimental setting, 2) allows for immediate, impulsive responding, 3) has a tangible cost associated with retaliation, thereby creating a conflict between desired and financially optimal responding, and 4) is not influenced by socially desirable responding. The RC-RAGE was designed to fill this methodological gap, and the results of our pre-registered, confirmatory analyses showed that costly retaliation was linked to trait-level aggression, the tendency to act impulsively, and angry state affect, but was not negatively related to social desirability. Subsequent regressions demonstrated that in each of these cases, the relationships were stronger as the financial disadvantage to retaliating increased. In addition to the experimental utility provided by this task, the results of this work provide support for the idea that the tendency to act impulsively and without thinking can lead to reactive aggression upon provocation despite clearly stated incentives to inhibit an aggressive response.

As hypothesized, costly retaliation on the RC-RAGE was positively related to dispositional aggression. The results of these relationships were either equivalent to or larger in magnitude to the correlations typically found using the point subtraction aggression paradigm in non-clinical populations (Geniole et al., 2017; McCloskey et al., 2009), which demonstrates that the external validity of this task is on par with other laboratory aggression measures.

This work showed a robust link between the tendency to act impulsively (i.e., motor impulsivity) and costly aggression. However, trait self-control and other forms of impulsivity (attentional impulsivity and non-planning) were not significantly related (in the multivariable logistic regressions), suggesting that costly, reactive aggression is strongly influenced by the tendency to act impulsively, but less related to the tendency to plan ahead or delay gratification. While the ability to delay gratification, resist temptation, or persevere on tasks are important elements of self-control more broadly, the results of *z*-tests comparing these correlations suggest that reactive aggression upon provocation is more specifically linked to the tendency to act on impulse. This finding is consistent with the neurobiological frameworks of reactive aggression, which suggests that aggression will occur when there is a mismatch between the urge to retaliate driven by subcortical, limbic regions and inhibition of this desired action by prefrontal cortical regions (Davidson et al., 2000; Siever, 2008).

Consistent with research demonstrating the link between angry emotional states and aggression (Beames et al., 2020; Denson et al., 2009), we found that costly retaliation was also related to both hostile and irritable affect. For each item, the more angry the affective state, the more likely a participant was to retaliate when it was financially costly but not when it was financially advantageous. While this result does suggest that affective state may also influence costly reactive aggression, it is also possible that those participants reporting high state anger are also more irritable or hostile on a dispositional/trait level. Previous work has demonstrated a strong link between trait anger and reactive aggression (Wilkowski & Robinson, 2010), and as trait anger and hostility (as measured by the BPAQ) were correlated with state hostility and irritability in our sample, the extent to which this effect is primarily driven by current emotional state cannot be readily determined. In subsequent studies, it would be interesting to experimentally induce feelings of anger to better elucidate the role that state affect plays in costly reactive aggression.

Furthermore, we found interactions between dispositional aggression, the tendency to act impulsively, state anger and the costliness of retaliation. This feature is important, as it suggests that it’s not simply the retaliation response itself that is associated with trait aggression, impulsivity, or anger on our task, but rather, the relationship is with financially costly retaliation that ought to be inhibited. That is, in the situation where a person is provoked, those high on trait aggression, motor impulsivity, and state anger are more likely to disregard the explicit financial incentives to ignore the provocation, choosing instead to retaliate despite a cost, which is suboptimal from a financial perspective.

It's worth noting that, while aggression is generally perceived as socially undesirable behavior, there are still scenarios in which choosing to behave aggressively may be incentivized, as in the case of instrumental aggression (where inflicting harm may be more of a means to an end) or in the case of a competition (i.e., behaving aggressively in a sport or competition; Taylor, 1967). It is generally agreed upon that there may be multiple motives to act aggressively in any given situation and many researchers now argue against a simple dichotomization of instrumental vs. hostile aggressive motives (Allen & Anderson, 2017; Bushman & Anderson, 2001). However, to understand the role of self-control and impulsivity in reactive aggression, the current task was designed to specifically create situations where participants were instructed to ignore provocation and use self-control processes to carry on with the task at hand. This work demonstrates that the RC-RAGE task is effective in identifying trait and state predictors of impulsive aggression upon provocation where the goals of the task (earn money) and the desirable response (retaliation) are at odds.

Our study contains a few notable limitations. Unlike most other laboratory-based aggression tasks where participants are ostensibly told they are harming another real individual, participants are not led to believe that the opponent ("robber") is indeed another human that they are harming. As a consequence, it can be argued that costly retaliation on the RC-RAGE is not real aggression, and indeed we propose that the task provides a proxy for reactive aggression rather than measuring aggression itself. We opted to sacrifice the cover story for two key reasons.

First, standard laboratory-based aggression tasks typically rely on cover stories and clever experimental set-ups (i.e., the person experiencing harm is in "another room"), which is less feasible in an online or non-traditional lab context. This approach also mitigates the question of whether participants either "buy" the deception and whether participants are simply responding in accordance with what the experimenter wants (McCarthy & Elson, 2018). We aimed to create a task that could be used in a greater variety of settings, such as an online environment or alternative testing site, which would allow the experiment to be conducted in much larger and more diverse samples than previous aggression studies. This would also afford flexibility for potential environmental manipulations to look at some of the physical environmental effects on reactive aggression (i.e., in a place with natural scenery vs. urban scenery; Kuo & Sullivan, 2001).

Second, a common issue with aggression tasks more broadly is that the severity of aggression is generally required to be very mild if it is to be believed by the participant while remaining an ethical experiment (Lobbestael, 2015; McCarthy & Elson, 2018). For example, in the Point Subtraction Aggression Paradigm, aggression arises from subtracting points from a (fictional) opponent (Cherek et al., 1996). In order to better understand how self-control and impulsivity may relate to violent, physical aggression, our goal was to create a proxy for this physically aggressive response, which cannot be directed at an ostensibly real person in a psychology experiment without some experimenter permissibility. Therefore, while this design choice does limit the extent to which this task may index real aggression, we would argue that as it strongly correlates with self-reported trait aggression, the RC-RAGE does have reasonable ecological validity as a task-based aggression measure. However, future work could test whether this paradigm could be altered to give the impression of another person playing as the robber.

Additionally, although this study identified both state and trait predictors of costly, reactive aggression, it did not examine the effects of longer-term situational or environmental factors. This is important as physical and social environmental influences have been identified as key determinants of self-control and decision-making processes (Sheehy-Skeffington, 2020). This emerging body of research demonstrates that it is not only the short-term situational context that influences self-control, impulsivity, and aggression, but chronic exposure to environmental stressors, structural prejudice against groups, financial and environmental instability, and the effects of low socio-economic status can have major impacts on aggressive behavior (Figueredo et al., 2020; Lawson et al., 2018; Sheehy-Skeffington, 2020). Therefore, a key next step in this research would be to examine how longer-term environmental effects may relate to impulsivity and costly, reactive aggression on the RC-RAGE task.

In summary, the current work introduces a novel experimental paradigm to test the trait and state-level predictors of costly impulsive, reactive aggression. By including an immediate retaliation option and making aggression costly, the RC-RAGE places high demands on self-control and allows for impulsive responses. The results demonstrated that the tendency towards acting impulsively was more predictive of costly retaliation than other types of self-control, and suggest that while self-control (broadly defined) can predict a variety of aggressive or antisocial behaviors (Gottfredson & Hirschi, 1990), costly reactive aggression is best predicted by impulsivity. This effect is also consistent with the neurobiological theories of aggression (Coccaro et al., 2011; Nelson & Trainor, 2007; Siever, 2008), and an exciting future direction for this work would be to use this paradigm to disentangle the contributions of reactivity to provocation (driven by limbic regions) and impaired impulse inhibition (subserved by prefrontal cortical regions) in an experimental setting. Going forward, this work also provides a more general opportunity for future research on further elucidating the state-level, trait-level, and environmental predictors of costly reactive aggression upon provocation.

Materials and Methods

Experimental design

To examine whether retaliation on this novel task: 1) corresponds to individual differences in dispositional aggression, impulsivity, and self-control, and 2) provides a measure costly reactive aggression unaffected by social desirability, we had participants complete a number of questionnaires either before or after completing the RC-RAGE. The order was counterbalanced so that one half of participants would complete the questionnaires first and the other half would complete the RC-RAGE first. To see whether costly retaliation on our task was also sensitive to current emotional state, particularly feelings of hostility, all participants completed a state affect assessment directly before performing the RC-RAGE.

Participants

All participants were recruited via CloudResearch (https://www.cloudresearch.com/; Litman et al., 2017) to complete the full study procedures via Amazon Mechanical Turk. Study procedures were approved by the University of Chicago Institutional Review Board (IRB no. 14-1065). Participants were excluded if they failed more than 2 attention check questions in the questionnaires or if they completed fewer than 6 trials where they were provoked (as provocation could occur at one of 6 potential times). Additionally, due to a somewhat high rate of HITs returned due to the browser window size requirements, fewer participants completed the task than the target *N*s specified on CloudResearch.

For the confirmatory study reported in this work, the targeted N was 378 participants and 364 participants completed all study procedures. This target N was specified in our pre-registration and was chosen to match the sample size from the initial version of this task where all retaliation was equally costly so that comparisons between versions could be made. Of the 364 participants collected, 10 were excluded from data analysis: 4 were excluded due to failed attention check questions, 5 were excluded due to insufficient number of trials, and 1 participant was excluded for both of these reasons, resulting in a final N of 354. Per our pre-registration, we set up the HIT to have equivalent proportions of male and female participants and to restrict the age range of participants to those between 18 and 55. Of the 354 analyzed participants, 174 identified as male, 174 identified as female, 4 identified as non-binary or other, and 2 preferred not to disclose their gender. All participants were between 19 and 61 years of age[1] (M = 36.0, SD = 8.6). The order of task procedures were roughly equal, with 178 participants completing the RC-RAGE first and 176 participants completing the questionnaires first.

The Retaliate or Carry-on: Reactive AGgression Experiment (RC-RAGE)

[1] Requested age range was specified at the level of setting up the HIT, but actual age was determined by self-reported year of birth, suggesting some participants may not be truthful about their age in their Mturk profile.

In the RC-RAGE, participants were asked to maximize their earnings in 12 minutes by clicking on green dots (referred to as apples) moving around the 800 x 600 pixel game board at the center of the screen. When they clicked on an apple, it disappeared and appeared after 500 ms at a random location, which is sampled from a uniform distribution across the game board and at least 200 pixels away (if the location within the 200 pixels was sampled, sampling was repeated). Once participants clicked on 10 apples in a row (i.e., a harvest), they were able to cash out and 10 cents was added to their total earnings.

Occasionally, an opponent (referred to as the "robber") would appear on the screen, steal 5 cents of their money, and remain there for some period of time. Participants could retaliate against the robber and get 3 cents back by shooting him twice to destroy him, but when they did so, they would lose their progress towards their harvest. For example, if a participant clicked on 7 apples in a row, their current progress towards the harvest would be 7/10, and if the robber appeared at this point and the participant retaliated, they would get 3 cents back but their progress towards the harvest would return to 0/10 (i.e., when they retaliate they lose progress on the current harvest, but get some money back from their banked total earnings). The robber always disappeared before participants could complete their progress towards the 10 apples, and after he disappeared, they would lose their chance to get 3 cents back. Thus, the robber forced participants to continuously choose between whether to retaliate and lose progress or to ignore him and carry on.

The time at which the robber appeared was manipulated so that, depending on how much progress the participant had made towards the harvest of 10 apples, the cost associated with retaliation was varied. For example, the progress lost by retaliation was greater when the robber appeared after the participant had already clicked on 7 apples (progress count: 7/10) than if the participant retaliated after the participant had only clicked on 1 apple (progress count: 1/10). To quantify the extent to which retaliation was more or less costly, we calculated the monetary value of each mouse click during the task and compared the value of mouse clicks across conditions. To calculate the value of each mouse click, we defined a trial as consisting of two harvests (i.e., two instances of 10 apple clicks in a row) and designed the robber to always appear during the first harvest. If the robber did not appear in that trial, participants completed two harvests and earned 20 cents by clicking 20 apples without interruption, resulting in 1 cent per click. [**Figure 2**]

If the robber appeared when participants have only clicked one apple (i.e., progress count: 1/10) and they chose to ignore and carry on, they would earn 15 cents (two harvests - 5 cents taken by the robber) by clicking 20 apples in a row, resulting in 0.75 cents per click. If they chose to retaliate and reset their progress, they would earn 18 cents (by getting back 3 cents) by making 23 clicks (one lost click + two clicks to destroy the robber + 20 apples), resulting in 0.783 cents per click. Thus, when the robber appears at the 1/10 progress, the value of each click is slightly higher with retaliation than self-restraint (ignoring the robber and carrying on).

If the robber appeared when participants have clicked two apples (i.e., progress count: 2/10) and they choose to ignore and carry on, the value of click remained the same 0.75 cent per click (15 cents divided by 20 clicks). If they chose to retaliate and reset their progress, they would earn 18 cents by making 24 clicks (two lost clicks + two clicks to the robber + 20 apples), resulting in 0.75 cents per click. Thus, when the robber appears at the 2/10 progress, the value of click is the same between retaliation and self-restraint.

If the robber appeared when participants have clicked three apples (i.e., progress count: 3/10) and they chose to retaliate and reset their progress, they would earn 18 cents by making 25 clicks (three lost clicks + two clicks to destroy the robber + 20 apples), resulting in 0.72 cents per click. If the robber appeared when the progress count was 7/10, they would earn 18 cents by making 29 clicks (seven lost clicks + two clicks to the robber + 20 apples), resulting in 0.62 cents per click. Thus, when the robber appears at the 3+/10 progress, the value of click is lower with retaliation (0.72 cents per click or less) than self-restraint (0.75 cents per click).

Based on this calculation, participants were instructed that it is financially best to ignore the robber if they have already clicked on more than 2 apples (i.e., progress count is more than 2/10). However, if they have only clicked on 1 or 2 apples, it's financially advantageous to destroy the robber right away. In this task, the robber may appear at 6 different times: when progress is 1/10, 2/10, 3/10, 4/10, 6/10 or 7/10. Six possibilities were included (rather than all potential progress points, 0 to 9) to increase the likelihood that participants would experience each condition multiple times throughout the experiment. To ensure participants experience all conditions, these six conditions were grouped into a batch of nine trials by adding three trials in which the robber does not appear, and the order of these nine trials was randomized so that the robber appeared on two-thirds of trials. As a trial consisted of two harvests, the robber appeared on one-third of harvests [**Figure 2**]. Three batches of the shuffled nine trials (thus 27 trials total) were prepared for each participant to complete within 12 minutes. On average, participants completed 20 trials (M = 19.8, SD = 3.5) with 431 clicks (M = 431.4, SD = 69.2), earning a bonus of 348 cents (M = 348.1, SD = 59.7).

Participants were taken through step by step instructions and given 2 minutes to practice before beginning the real experiment. Money earned during these 2 minutes did not count towards their total earnings. For the main experiment, participants performed the RC-RAGE for 12 minutes, and their total earnings were credited as a cash bonus at the end of the session. During both practice and main rounds, attention checks appeared where a letter of the alphabet is auditorily presented, and participants were asked to press the alphabet key they just heard right away, as the timer continues during these attention checks. This was to ensure that participants did have their sound on and were continuously performing the task.

A working version of this task (including all the instructions, audio checks, and practice), which can be run on any modern web browser, can be accessed here: https://kywch.github.io/RC-RAGE_jsPsych/rc-rage-demo.html. The task was programmed using jsPsych (de Leeuw, 2015), a javascript-based library designed for running behavioral experiments via web browser.

Questionnaires

The self-report constructs of primary interest in this work were aggression, impulsivity, self-control, and social desirability. To measure trait-level aggression, the Buss-Perry Aggression Questionnaire was used (Buss & Perry, 1992), which includes 29 statements where participants are asked to rate how characteristic each statement is of them on a scale of 1-5 (1 = extremely uncharacteristic of me, 5 = extremely characteristic of me). The BPAQ measures total aggression as well as 4 subscales of aggression: Physical Aggression (example statement: "If somebody hits me, I hit back"), Verbal Aggression (example statement: “I can’t help getting into arguments when people disagree with me”), Anger (example statement: “Sometimes I fly off the handle for no good reason”), and Hostility (example statement: “At times I feel like I have gotten a raw deal out of life”).

To measure impulsivity, the Barratt Impulsivity Scale (BIS-11) was used (Patton et al., 1995). On the BIS-11, participants read 30 statements about the ways people act and think and respond on a 1-4 scale (1 = rarely/never and 4 = almost always/always) whether it applies to them. The BIS-11 generates a score for 3 second-order factors of impulsivity: Motor (example statement: “I do things without thinking”), Attentional (example statement: “I am restless at the theater or lectures”), and Non-planning (example statement: reverse coded “I plan tasks carefully”).

Self-control was measured using the Brief Self-Control Scale (Tangney et al., 2004), which generates a total self-control score. For each of the 13 items, participants are asked to rate whether the statement (such as “I am good at resisting temptation” or “I have a hard time breaking bad habits”) applies to them on a scale of 1-5 (1 = not at all, 5 = very much).

Socially desirable responding was measured using the Marlowe-Crowne Social Desirability Scale (MCSDS; Crowne & Marlowe, 1960). The MCSDS is a 33-item scale where participants respond with whether the statement is true or false of them. Higher total scores on this questionnaire suggests the respondent is presenting themself in an unrealistically positive manner. Sample items on the MCSDS include “I never hesitate to go out of my way to help someone in trouble” and “I’m always willing to admit it when I make a mistake.”

State affect was calculated using the short form of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988). Though overall positive and negative affect were calculated for exploratory analyses, confirmatory analyses were conducted looking specifically at ratings for the “Hostility” and “Irritability” items.

Correlations between the self-report measures are shown in **Figure 4**.

Procedure

All participants provided informed consent and were required to pass a CAPTCHA validation before continuing. Participants whose browser windows were not sufficiently large (minimum = 1024 x 660 pixels) or did not pass the sound check (testing that experiment audio could be heard clearly) were prevented from completing further experimental procedures. Order of task and questionnaires was randomized using built-in Qualtrics functions. Regardless of order, all participants completed the PANAS directly before beginning the RC-RAGE. Between instructions, practice, and actual experiment, the RC-RAGE component took approximately 15-18 minutes. In addition to the questionnaires collected for confirmatory analysis, participants also completed the Novaco Anger Scale (Novaco, 1994), the Selfishness Questionnaire (Raine & Uh, 2019), and the Big Five Inventory (John et al., 1999). After completing all questionnaires and the RC-RAGE, participants completed a brief demographics questionnaire, followed by a few questions regarding participants’ experiences with the RC-RAGE.

Statistical Analysis

Statistical analysis was conducted using R version 3.5.1 (R Foundation for Statistical Computing, www.rproject.org). Correlations between retaliation rates and other variables of interest were calculated using the function ‘rcorr’ in the ‘Hmisc’ package (Harrel et al., 2020). *P*-values for confirmatory tests were Bonferroni corrected to control the family-wise error rate (alpha = 0.05/31 confirmatory correlations = 0.0015). Comparison of correlation coefficients was conducted using the function 'cocor.dep.groups.overlap' in the 'cocor' package (Diedenhofen & Musch, 2015). This specific function tests for significant differences in correlation coefficients in one group with an overlapping variable and a one-tailed alpha of 0.05 was used to test for significance.

For logistic mixed effects regressions, the function 'glmer' in the 'lme4' package (Bates et al., 2015) was used. For each self-report measure, the model was specified as: glmer(Retaliation_Rate ~ Costliness * Self-report_Measure + (1 | sub), family = binomial, nAGQ = 10), where costliness was a categorical factor corresponding to the robber appearing at position 1-or-2 (advantageous), position 3-or-4 (modestly costly), or position 6-or-7 (strongly costly). In this model, estimates are based on an adaptive Gaussian Hermite approximation of the likelihood using 10 integration points. To get the mixed effects results, a multilevel bootstrapping procedure was employed to obtain bootstrapped mean estimates and 95% confidence intervals. For each analysis, 1000 bootstrapped samples were used. Predicted probability plots were created using the 'ggpredict' function of the 'ggeffects' package (Lüdecke, 2018).

Data and Code Availability Statement

- Data from confirmatory study (present work) and pilot study are available at the project OSF page: https://osf.io/796rs/ Rmarkdown analysis code and output can also be found on the OSF page for this project.
- Pre-registration for this study is available at: https://osf.io/czn43/
- A working version of the task is accessible at https://kywch.github.io/RC-RAGE_jsPsych/rc-rage-demo.html

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