Running Head: GLUCOSE DECREASES AGGRESSION

Glucose Consumption Decreases Impulsive Aggression in Response to Provocation in Aggressive Individuals

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Abstract

Impaired executive control is implicated in aggression. Research suggests that the acute administration of glucose can improve executive control. In two experiments undergraduates completed a measure of trait aggression and consumed a glucose or placebo beverage before being given the chance to administer a blast of white noise to a fictitious participant. In Experiment 1, all participants were provoked and mentally depleted or not. Glucose was most effective in reducing aggression for those high in trait aggression even when depleted. In Experiment 2, participants were provoked or not. When provoked, glucose reduced aggression among those high in trait aggression. However, when not provoked, glucose increased aggression among those high in trait aggression. These data suggest that the acute administration of glucose can be beneficial in reducing aggression in response to provocation among those high in trait aggression.

Keywords: Aggression, aggressive personality, glucose, executive control

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Provocation is "perhaps the most important single cause of human aggression" (Anderson & Bushman, 2002, p. 37) and aggressive individuals tend to have particular difficulty controlling aggressive impulses following provocation. In neural terms, this implies impaired top down regulation of activity in limbic regions by the prefrontal cortex (Denson, in press; Denson, Pedersen, Ronquillo, & Nandy, 2009; MacDonald, 2008; Raine, 2008), which is the seat of executive control (Banfield, Wyland, Macrae, Munte, & Heatherton, 2004; MacDonald, 2008). Consistent with this understanding, a longitudinal study of physically aggressive boys reported that among various neuropsychological tests, measures of executive functioning had the strongest negative association with aggression (Seguin, Pihl, Harden, Tremblay, & Boulerice, 1995). Furthermore, those who scored poorly on a neuropsychological battery of frontal lobe function administered more intense shocks to a fictitious participant than those who scored highly on the neuropsychological battery (Lau, Pihl, & Peterson, 1995) and prefrontal lesions are associated with increased aggression (Grafman et al., 1996) . These data implicate poor executive functioning in aggressive behavior.

Because the brain relies on glucose for its energy, acute fluctuations in glucose have been implicated in executive functioning (Gailliot & Baumeister, 2007; Gailliot et al., 2007; Gailliot, Peruche, Plant, & Baumeister, 2009). Thus, one method of increasing the energy available to the brain for exercising executive control is by increasing blood glucose levels. In addition to poor executive control, correlational evidence suggests that individual differences in aggressive and criminal behavior are associated with low glucose levels (Gailliot & Baumeister, 2007). As such, acute glucose consumption should reduce aggressive behavior among individuals high in trait aggression because the provision of additional glucose should provide the energy necessary to restrain aggressive impulses when provoked.

Although there has been no experimental test of the effects of glucose on aggressive behavior, the results of two studies provide indirect evidence that glucose can help people restrain aggressive behavior. In one study, six- and seven-year old children consumed a glucose or placebo drink and were asked to play a difficult computer game (Benton, Brett, & Brain, 1987). Children who consumed glucose showed fewer behavioral signs of frustration (e.g., expressions of annoyance) than children who consumed the placebo. In another study, adult participants drank either a glucose or placebo beverage and played a frustrating game that was coupled with an insult from the experimenter (Benton & Owens, 1993a). There were no effects of glucose on self-reported mood; however, among participants who had not eaten breakfast, those given the glucose drink showed fewer signs of frustration (e.g., hitting the equipment, swearing) than participants given the placebo. Additional research has found that glucose consumption can improve self-control in domains unrelated to aggression (Gailliot et al., 2007; 2009).

EXPERIMENT 1

Experiment 1 investigated the effects of glucose in reducing aggression following provocation and mental depletion (Baumeister, Vohs, & Tice, 2007, DeWall et al., 2007; Finkel et al., 2009; Stucke & Baumeister, 2006). Participants were depleted or not and consumed either a glucose or placebo beverage. All participants were then provoked and given the chance to retaliate by blasting the provocateur with loud white noise. Prior research suggests that engaging in self-control consumes blood glucose (Gailliot et al., 2007). We therefore included the depletion manipulation to determine whether glucose would be beneficial in reducing aggressive behavior among those high in trait aggression even after the prior exertion of self-control.

Method

Participants and Design

Eighty undergraduates were randomly assigned to a 2 (depletion, no depletion) x 2 (glucose, placebo) between-participants design. Data from 6 participants were excluded from all analyses: 2 due to expressed suspicion about the provocation procedure and the other 4 due to computer program malfunction, leaving a total sample of 74 (52 women). Self-reported trait aggression was included as a continuous independent variable. Men and women were equally distributed across the experimental conditions, $\chi^2(3)=0.17$, $p=.98$, and no main effects or interactions emerged with the trait aggression measure as the dependent variable (all Fs<1.78, ps>.19), thus ensuring the efficacy of random assignment. No participants reported having a glucose-related disorder. To stabilize glucose levels, all participants acknowledged compliance with a request to fast for three hours prior to the start of the experiment. Participants were told that the experiment would investigate the relationship between glucose and performance on various tasks.

Materials and Procedure

Depletion manipulation. Participants were told that the first task examined cognitive ability. This task, known as the "crossing the *e* task" served as the depletion manipulation, requires participants in the depletion condition to exert self-control by breaking a learned behavior (e.g., DeWall et al., 2007). All participants were presented with a page of text and asked to cross out all 398 instances of the letter *e*. Participants were then presented with a second text. In the *no depletion condition*, they were given the same instructions as the first text. In the *depletion condition*, participants were asked not to cross out the *e* if it was followed by a vowel or if the *e* appeared in a word with a vowel appearing two letters before the *e*. Participants in the depletion condition were therefore required to override a learned response, thereby demanding self-control.

Depletion manipulation check. All participants then rated their current angry affect (α=.86; i.e., *angry, hostile, scornful, grouchy, annoyed, upset, offended, irritable*; 1=not at all, 7=extremely so). Participants also rated the extent to which the second crossing the *e* task was more difficult than the first crossing the *e* task (0=no difference, 7=second task much more difficult).

Double-blind glucose manipulation. Next participants were given a 350ml lemonade drink containing either 40g of sugar (*glucose condition*; Cottee's Lemon Crush) or a sugar substitute and a negligible amount of sugar (2g) that provided a real sugar taste (*placebo condition*; Cottee's no added sugar Lemon Crush). All participants were told they received a sugar drink. The experimenter was blind to glucose condition.

Provocation procedure. Participants were given 10 min to prepare a 2-min speech based on talking points provided by the experimenter (e.g., life goals), which they would later present via a bogus web conference to a participant ostensibly in the laboratory down the hall. In reality, the web conference was prerecorded. To make this deception more realistic, the experimenter began the web conference with a series of simple instructions for a sex-matched actor, timed to ensure that the instructions given by the experimenter and the responses from the bogus participant were coordinated. The experimenter then instructed the participant and the actor not to interrupt each other during the speeches, which helped ensure that the participant did not discover the deception. The actor always spoke first for 2-min, followed by the actual participant's 2-min speech. Participants were then told that they were to evaluate their partner's speech and vice versa via a single online chat message. All participants were then provoked through insulting feedback ostensibly written by the fictitious participant: “Your speech was juvenile and boring. Overall, a very disappointing speech coming from a Uni student. *A waste of my time listening to you*.” Thus, participants were provoked approximately 15 min following glucose consumption. Relative to placebo, glucose consumption can influence cognition and mood within 15 minutes (e.g., Benton & Owens, 1993a, 1993b; Benton et al., 1987).

Aggression paradigm. Participants were then told that they would be engaging in a competitive reaction time task, in which they could deliver blasts of white noise to the same participant who commented on their speech. They completed a 25-trial modernized version of the Taylor (1967) Aggression Paradigm (TAP; Anderson & Dill, 2000; Bushman, 1995). Although the procedure involves 25 trials, the first trial provides the best measure of aggression as participants have not yet received a noise blast from the bogus participant (Konijn, Bijvank, & Bushman, 2007; Bushman & Baumeister, 1998). The remaining 24 trials consisted of 3 blocks of 8 trials each, during which the noise blasts from the bogus participant steadily increased in loudness and duration (i.e., low, medium, and high). After the first trial, subsequent trials are less susceptible to experimental manipulations because participants tend to retaliate by selecting matching levels of loudness and duration.

Participants were told that in order to win the reaction time task they had to be the fastest to click the mouse when the color of a small box on the screen changed from yellow to red. All participants won the first trial. After a win, participants selected numerical values on separate scales from 0 to 10 for both the *intensity* and the *duration* of the white noise blast to be delivered to the fictitious participant. The 0 value served as a non-aggressive option (0db intensity, 0 s duration), whereas the remaining scale points had decibel and time values next to them (intensity ranged from 1=60db to 10=105db; duration ranged from 1=0.5 to 10=2.0 s). Aggression was operationalized as the mean intensity and duration of the scale values (0 to 10) selected by participants on the first trial.

Trait aggression. Participants completed the Aggression Questionnaire (AQ; Buss & Perry, 1992), a widely used measure that assesses individual differences in general aggression. The AQ consists of four subscales: physical aggression (α=.84; M=2.28, SD=0.82), verbal aggression (α=.66; M=2.66, SD=0.71), anger (α=.80; M=2.48, SD=0.77), and hostility (α=.78; M=2.43, SD=0.72). The subscales are analyzed separately or as a combined total score (α=.91; M=2.44, SD=0.61; 1=extremely uncharacteristic of me, 5=extremely characteristic of me; see Bushman, 1995; Anderson & Dill, 2000; Anderson et al., 2008).

Mood and Liking. To assess emotional responses to the provocation manipulation, participants rated the degree to which they experienced each of 4 emotions as a result of the provocation (i.e., *angry*, *annoyed*, *irritated*, *offended*, α=.94). Each emotional descriptor was rated on a 7-point scale (1=not at all, 7=extremely so). Participants also completed 7 items rating the degree to which they liked their partner (α=.84; 1=strongly agree, 7=strongly disagree).

After all measures were completed, the experimenter probed for suspicion, thanked, and debriefed participants.

Results

Manipulation Checks and Gender

Relative to participants in the no depletion condition, depleted participants found the second text more difficult than the first ($M_{depletion}$=3.26, $SD_{depletion}$=1.20; $M_{no\ depletion}$ =0.61, $SD_{no\ depletion}$ =0.84), $F(1,69)$=117.06, p<.001,d=2.57, suggesting a successful depletion manipulation. Following the depletion manipulation, there was no significant difference in self-reported anger between the depletion (*M*=1.79, *SD*=0.82) and no depletion conditions (*M*=1.57, *SD*=0.80), *F*(1,72)=1.44, *p*=.23,*d*=.27. Although gender differences are sometimes observed in aggression research, in Experiment 1, there were no differences between men and women on trait aggression or noise blast level, *ps*>.14. Furthermore, controlling for gender did not alter the significance of our findings. We therefore report the analyses without controlling for gender.

Aggressive Behavior

We conducted hierarchical regression analyses to examine the effects of the experimental manipulations and trait aggression on the mean intensity and duration of the first aggression trial selected by participants. Because our laboratory aggression task was physical in nature (i.e., noise blasts), in separate regression models we examined both the trait physical aggression subscale as well as the broader operationalization of trait aggression as indexed by the total AQ score (Buss & Perry, 1992).

In the first model, which examined trait physical aggression, the categorical variables were contrast coded and trait physical aggression was mean-centered. At the first step, the categorical variables were entered, R^2=.11. The main effect of depletion was significant, β=.26, *t*(71)=2.31, *p*=.02, *d*=.52, indicating that participants in the depletion condition were more aggressive (*M*=4.94, *SD*=2.77) than participants in the no depletion condition (*M*=3.55, *SD*=2.63). There was also a marginal main effect for beverage, β = -.22, *t*(71)=-1.93, *p*=.06, *d*=-.42, suggesting that participants given the glucose beverage were slightly less aggressive (*M*=3.67, *SD*=2.55) than participants given the placebo beverage (*M*=4.82, *SD*=2.91).

At the second step, there was a significant main effect of trait physical aggression, β=.30, *t*(70)=2.71, *p*=.009, R^2=.20, signifying that individuals high in trait physical aggression displayed more aggression in the laboratory than individuals low in trait physical aggression. At the third step, the two-way interaction terms were entered into the model. This resulted in a significant trait physical aggression x beverage interaction, *β*=-.24, *t*(67)=-2.19, *p*=.03, R^2=26. Follow-up tests of simple effects revealed that in the placebo condition, those high in trait physical aggression were more aggressive than those low in trait physical aggression, *β*=.47, *t*(34)=3.06, *p*=.004, R^2 =.22, but not in the glucose condition, *β*=.05, *t*(36)=0.27, *p*=.79, R^2=.00 (Figure 1). There were no other significant two-way interactions, or the 3-way interaction which was entered at the final step.

The second model examining the effects of the total AQ score revealed identical main effects for depletion, *β*=.26, *t*(71)=2.31, *p*=.02, beverage, *β*=-.22, *t*(71)=-1.93, *p*=.06, and total AQ, *β*=.31, *t*(70)=2.79, *p*=.007; however, the total AQ x beverage interaction was not significant, *β*=-.12, *t*(67)=-1.04, *p*=.30.

Thus, following provocation, the glucose beverage was especially beneficial for reducing aggression among those high in trait physical aggression whether depleted or not. The remaining 24 trials showed the typical tit-for-tat responding as indicated by a main effect of block type (low, medium, high), *F*(2,140)=10.78, *p*<.001, R^2=.13, but were not moderated by any of the independent variables.

Mood and Liking

We applied this hierarchical regression model to the angry affect and partner liking data. These analyses revealed a main effect of depletion on partner liking at the first step, *β*=.23, *t*(71)=2.03, *p*=.05, R^2=.06, *d*=.48. Depleted participants reported a more negative impression of the fictitious participant (*M*=4.27, *SD*=1.03) than non-depleted participants (*M*=3.75, *SD*=1.15). There was also a main effect of trait aggression at the second step such that highly aggressive individuals disliked their interaction partner more than less aggressive individuals, *β*=.30, *t*(70)=2.69, *p*=.009, R^2=.14. Thus, glucose did not reduce anger or negative partner impressions, but did reduce aggression.

Discussion

When given the opportunity to retaliate to an insult, aggressive individuals who consumed glucose were less aggressive than those given a placebo beverage. Indeed, glucose consumption among those high on trait aggression reduced aggressive behavior to a level comparable to those low on this dimension (Figure 1). This finding is consistent with correlational and experimental research linking low glucose levels with poor self-control (Gailliot & Baumeister, 2007; Gailliot et al., 2007, 2009). We also replicated prior work demonstrating that ego depletion augments aggression in response to provocation (DeWall et al., 2007; Stucke & Baumeister, 2006).

Our data also suggest that glucose consumption was effective for reducing aggression among those high in trait aggression even following the prior exertion of self-control. In Experiment 2, we investigated whether the benefits of glucose in reducing aggression among those high in trait aggression were limited to situations involving provocation or would extend to more benign circumstances. We therefore manipulated provocation in Experiment 2. We expected that glucose would be effective following provocation because provocation elicits prefrontal cortex activation in regions supporting self-regulation, even among those high in trait aggression (Denson et al., 2009). Glucose should make more energy available for controlling aggressive impulses when provoked. Because increased executive control is unnecessary when not provoked, we expected diminished effects of glucose for participants in the no-provocation condition.

EXPERIMENT 2

Participants were either provoked or not and consumed either a glucose or placebo beverage. The glucose dose was increased from 40g to 50g and the aggression paradigm was reduced to a single trial. We expected that glucose would reduce aggression following provocation and that glucose would be most effective for those high in trait aggression.

Method

Participants and Design

One hundred seventy undergraduates were randomly assigned to a 2 (provocation, no-provocation) x 2 (glucose, placebo) between-participants design. Data from 5 participants were excluded from the final analyses due to expressed suspicion about the reality of the web conference (4 in the provocation/placebo and 1 in the no-provocation/glucose conditions). Data from 4 participants were removed from the no-provocation/placebo condition because Tukey's (1977) boxplot procedure identified them as outliers on the laboratory aggression measure.[1] The final sample consisted of 161 participants (98 female). Trait aggression was included as a continuous independent variable. Men and women were equally distributed across the experimental conditions, $\chi^2(3)=1.09$, $p=.78$, and a 2 (provocation, no-provocation) x 2 (glucose, placebo) between-participants ANOVA revealed no main effects or interactions for the trait aggression measure (all Fs<2.4, ps>.12), ensuring the efficacy of random assignment. Participants reported compliance with a request to fast for three hours. No participants reported glucose-related disorders.

Materials and Procedure

The materials and cover story were similar to the procedure used in Experiment 1. Following consent, participants were given a 375ml lemonade drink containing either 50g of sugar (*glucose condition*) or a sugar substitute with a negligible amount of sugar (2.4g; *placebo* *condition*). Participant and experimenter were blind to the glucose conditions. Participants then completed the AQ and were given 10 min to prepare for a 2-min speech. Participants were required to deliver this speech to another participant via a webcam as in Experiment 1. After the speech, participants received either provoking as in Experiment1 or neutral feedback ("Nice speech, your life goals sound pretty reasonable"). Participants were then asked to engage in a single-trial competitive reaction time game in which they were allowed to select the intensity and duration of a blast of white noise.

Provocation manipulation checks. To assess the efficacy of the provocation manipulation, participants rated the degree to which they experienced each of 7 emotions as a result of the provocation (e.g., angry, annoyed, hostile; α=.94). Each emotional descriptor was rated on a 7-point scale (1=not at all, 7=extremely so). Participants also completed the same 7 partner liking items from Experiment 1 (α=.88).

Results

Manipulation checks

Participants in the provocation condition reported more angry affect (*M*=2.82, *SD*=1.42) than participants in the no-provocation condition (*M*=1.32, *SD*=0.61), $F(1,159)=71.64$, $p<.001$, $d=1.34$.[2] Participants in the provocation condition (*M*=3.69, *SD*=0.99) also disliked their partner more than participants in the no-provocation condition (*M*=2.36, *SD*=0.80), suggesting a successful provocation manipulation, $F(1,159)=86.22$, $p<.001$, $d=1.47$.

Aggressive Behavior

Because men were more aggressive than women (M_{men}=5.06, SD_{men}=2.83; M_{women} =4.07, SD_{women} =2.73), $F(1,159)=4.90$, $p=.03$, $d=.36$, we controlled for gender in our analyses. Hierarchical regression analyses similar to Experiment 1 were conducted. As in Experiment, 1, we analyzed separate models for trait physical aggression and total AQ score. In the first model, the categorical variables were contrast coded and the total AQ score was mean-centered. At the first step, provocation, glucose, and gender were entered simultaneously. This revealed a main effect for provocation, β=.34, t(157)=4.59, p<.001, R^2=.16, d=.74, indicating that participants in the provocation condition were more aggressive (M=5.35, SD=2.93) than participants in the no-provocation condition (M=3.40, SD=2.23). The second step showed a main effect for trait aggression, β=.16, t(156)=2.12, p=.04, R =.18.

At the third step, there was a significant provocation x beverage interaction, β=-.15, t(152)=-2.12, p=.04, R^2 =.20. Follow-up tests revealed aggressive behavior did not differ as a function of beverage when participants were not provoked (F<1), but as expected when participants were provoked and consumed glucose they were significantly less aggressive than when given the placebo, F(1,84)=5.52, p=.02, d=.51 (Figure 2). These effects were qualified by a 3-way trait aggression x provocation x beverage interaction, β = .74, t(151) = 2.24, p=.03, R^2=.23 (Figure 3). Replicating Experiment 1, when provoked and given glucose, those high in trait aggression were not any more aggressive than those low in trait aggression, β=.04, t(44)=0.27, p=.79, R^2=.00. Also as expected, when given placebo and provoked, those high in trait aggression were more aggressive than individuals low in trait aggression, β=.37, t(39)=2.49, p=.02, R^2=.14. Unexpectedly, when not provoked and given glucose, participants high in trait aggression were more aggressive than those low in trait aggression, β=.35, t(38)=2.29, p=.03, R^2=.12.

The second model, which examined the trait physical aggression subscale revealed an identical main effect of provocation, β=.34, t(157)=4.59, p<.001, a marginal effect of trait physical aggression, β=.14, t(156)=.14, p=.07, and the provocation x beverage interaction, β=-.14, t(152)=-1.96, p=.05; however, the three-way interaction was not significant, β=.41,

$t(151)=1.31$, $p=.19$ (see Table 1 for the simple effects and meta-analytic summary of all the AQ subscales in both experiments).

GENERAL DISCUSSION

These two experiments suggest that glucose consumption can be helpful in reducing aggression under some circumstances. For instance, when provocation is likely (e.g., when encountering a difficult supervisor at a work meeting), drinking a sweetened beverage prior to this encounter might increase one's ability to effectively inhibit aggressive impulses, especially for aggressive individuals. Moreover, in both experiments glucose did not reduce anger, suggesting another pathway to aggression reduction (e.g., replenishment of executive control capacity).

Despite the widespread notion that glucose consumption can lead to a "sugar high" resulting in impulsive behavior (cf. Benton, 2007, 2008; Lien, Lien, Heyerdahl, Thoresen, & Bjertness, 2006; Prinz, Roberts, & Hantman, 1980), our data suggest that glucose can increase executive control when provoked. This is consistent with reviews and meta-analytic evidence showing no adverse effects of glucose consumption on hyperactivity and conduct problems (Benton, 2007; 2008; Wolraich, Wilson, & White, 1995). Nonetheless, our data suggest that there may be some truth to the "sugar high hypothesis". When unprovoked, glucose augmented aggression among highly aggressive individuals. This surprising finding deserves further investigation. One possibility is that glucose energized situation-specific dominant responses. When exposed to a competitive situation glucose might have energized aggression among those who tend to respond to such situations aggressively but not for those low in trait aggression. Our data suggest the need for further research and caution prior to providing aggressive individuals with glucose in the absence of provocation.

Future research might investigate the specific neural pathways by which glucose reduces aggression. Drinking a glucose beverage influences activity in the dorsal anterior cingulate cortex and orbitofrontal cortex (Liu, Gao, Liu, & Fox, 2000), both of which have been implicated in anger and aggression (Davidson, Putnam, & Larson, 2000; Denson et al., 2009; Mehta & Beer, in press). The orbitofrontal cortex also plays a pivotal role in reward processing (Rolls, 2004). One alternative explanation for our findings is that the rewarding aspects of consuming a sweet beverage reduced the impact of the provocation and subsequent retaliation motivation. Indeed, our study was limited in that we did not obtain measures of positive affect following drink consumption or liking for the drink. Positive affect can restore self-regulatory capacity (Tice, Baumeister, Shmueli, & Muraven, 2007). Nonetheless, we believe that our findings were not due to positive affect because we did not find any evidence that glucose reduced anger in response to the provocation. Furthermore, even the anticipation of receiving glucose activates the orbitofrontal cortex and dopaminergic midbrain (O'Doherty, Deichmann, Critchley, & Dolan, 2002) suggesting that if the positive affect explanation underlies our findings, participants in the placebo condition should have displayed levels of aggression comparable to participants in the glucose condition.

Future research could also incorporate baseline levels of glucose and assess subsequent change as a result of the drink manipulation. Additional work could examine the effectiveness of glucose on populations known to have difficulties controlling impulsive aggression such as violent offenders. The results obtained for individuals high in trait aggression suggest that this might be a promising avenue to explore. Additional research might also examine whether glucose is effective in reducing different types of aggression. Glucose should not reduce instrumental aggression because this type of aggression is not thought to be the result of a breakdown in self-control. However, glucose could help reduce triggered displaced aggression (Miller, Pedersen, Earleywine, & Pollock, 2003). For instance, consuming a sweetened beverage on the commute home from work following a stressful day could reduce aggression toward family members or fellow drivers if subsequently annoyed.

Our results are also largely consistent with a recent meta-theory of aggression known as I^3 theory (Slotter & Finkel, in press). I^3 theory emphasizes the roles of instigating triggers, impelling forces, and inhibiting forces in determining aggressive behavior. In the present research, provocation would be considered an instigating trigger, high trait aggression would be an impelling force, and glucose consumption and not being depleted would be inhibiting forces. Because glucose and not being depleted are both inhibiting forces in the I^3 framework, the theory would predict main effects of these variables in Experiment 1 (as well as our nonsignificant glucose x depletion interaction). The theory would also predict our significant glucose x provocation interaction in Experiment 2 and the trait aggression x glucose interactions in both experiments. In this sense, our results are largely in line with I^3 theory. However, our findings depart from I^3 theory, in that it would also predict a trait aggression x depletion interaction in Experiment 1, which did not emerge. Because individual differences in aggressive behavior are related to stable deficits in executive control (Hoaken, Shaughnessy, & Pihl, 2003; Santor, Ingram, & Kusumakar, 2003; Seguin et al., 1995), perhaps the depletion manipulation was less impactful for individuals high in trait aggression. If so, our results suggest that low trait aggression and not being depleted might both be best conceptualized as inhibiting forces. Future research might explore when temporary impairment in self-regulatory strength increases aggression among those high in trait aggression.

The timing of glucose administration is important in that our participants received glucose prior to the provocation. Thus, the reduction in aggression following provocation might have been the result of some individuals recruiting stored brain glycogen more effectively than others. Thus, it remains an empirical question whether consuming glucose following a provocation would reduce aggression as well. Often the period following a provocation is occupied by angry rumination (e.g., Caprara, 1986; Sukhodolsky, Golub, & Cromwell, 2001). Angry rumination recruits top down emotion and behavioral regulation regions in the PFC (Denson et al., 2009) and angry rumination may augment aggression by reducing self-control capacity (Denson, 2009). If so, glucose should restore this capacity and thereby also be effective in decreasing aggression *following* provocation.

Future research could also more precisely identify the aspects of trait aggression that contribute to the moderating effects of glucose on aggression. In the present research, although the simple effects of the total AQ score were consistent across both experiments, the trait physical aggression interaction was significant in Experiment 1; whereas the total score interaction was significant in Experiment 2. Because glucose did not influence angry mood or explicit liking in either study, but did influence behavior, it seems that the behavioral components of trait aggressiveness (i.e., trait physical or verbal aggression) are more likely to interact with glucose than the affective (i.e., trait anger) or cognitive components (i.e., trait hostility). Future work could investigate these and other aggression-relevant traits (e.g., angry rumination, impulsivity).

In summary, the current data provide support for the ameliorative effects of glucose on aggressive responses to provocation by people high in trait aggression. By increasing the energy available to the brain via increased blood glucose, the current results suggest that we might be better able to inhibit aggressive responses to interpersonal provocation. This strategy is particularly likely to be effective when provoked and remain effective even after the prior exertion of self-control.

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Footnotes

[1] In accordance with Tukey (1977), outliers were defined as values lying greater than 1.5 times the interquartile range (i.e., the difference between the 25th and 75th percentile) from the upper and lower quartiles. Because even small violations of the assumptions of normality or homogeneity of variance may greatly decrease the sensitivity of parametric and nonparametric tests and produce biased results (Wilcox, 1998; Wilcox & Keselman, 2003; Zimmerman, 1994), we removed the outliers from the analyses. Nonetheless, inclusion of the outliers did not change the key findings. Specifically, the three-way interaction remained significant, β=-.15, t(156)=2.04, p=.04. When provoked and given glucose trait aggression did not predict aggression, β=.004, t(43)=0.28, p=.98, but it did when given the placebo, β=.38, t(38)=2.50, p=.02. When not provoked, trait aggression predicted aggression when given glucose, β=.33, t(36)=2.11, p=.04, but not the placebo, β=.04, t(36)=0.27, p=.79. These same analyses with log-transformed data revealed an identical pattern of significant results.

[2] Although the use of different measures of angry affect across the two experiments was not ideal, this change did not influence our findings. Specifically, repeating the analysis with just the single “angry” item revealed the same pattern of results as the multiple item measures.

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Table 1. Correlations between aggressive personality traits and laboratory aggression following provocation as a function of placebo or glucose.

	Experiment 1		Experiment 2		Meta-analytic estimate	
	Placebo	Glucose	Placebo	Glucose	Placebo	Glucose
Physical Aggression	.47**	.05	.17	.05	.32	.05
Verbal Aggression	.34*	.17	.37*	.01	.36	.09
Anger	.24	.22	.16	-.01	.20	.21
Hostility	.25	-.17	.20	.02	.23	-.08
Total AQ Score	**.41***	**.07**	**.38***	**.03**	**.40**	**.05**

Note: *p<.05, **p<.01. The total AQ score is a mean composite of the 4 preceding AQ subscales. The values for Experiment 2 are partial correlations controlling for gender for participants in the provocation condition. The meta-analytic estimates are corrected for sample size bias (Johnson & Eagly, 2000).

Figure Caption

Figure 1. Effects of trait physical aggression on aggressive behavior as a function of beverage (glucose or placebo) for Experiment 1. The lines are regression slopes for the simple effects.

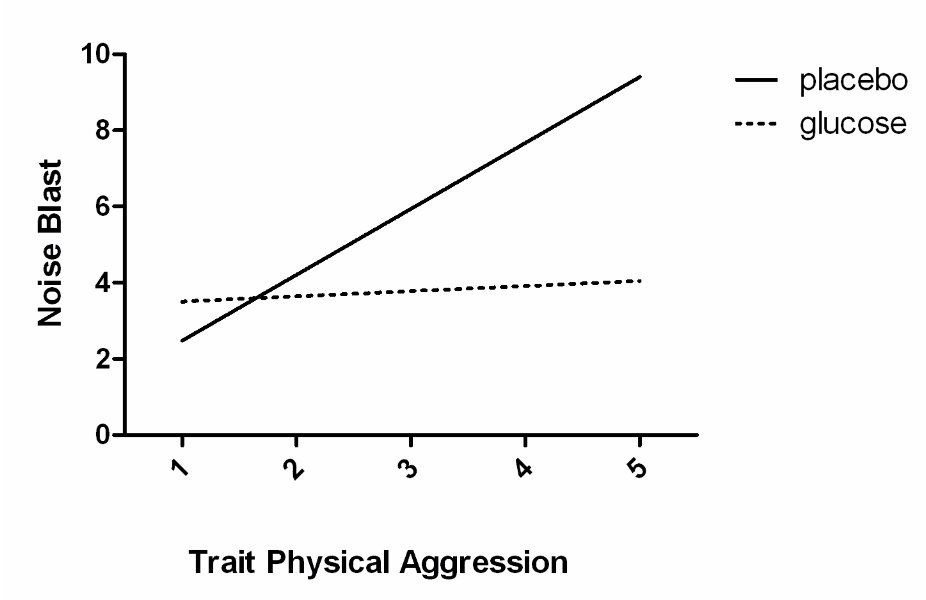

10
8
6
4
2
0
Noise Blast
1
2
3
4
5
Trait Physical Aggression
placebo
glucose

Figure 2. The effects of glucose on aggressive behavior in Experiment 2 as a function of provocation.

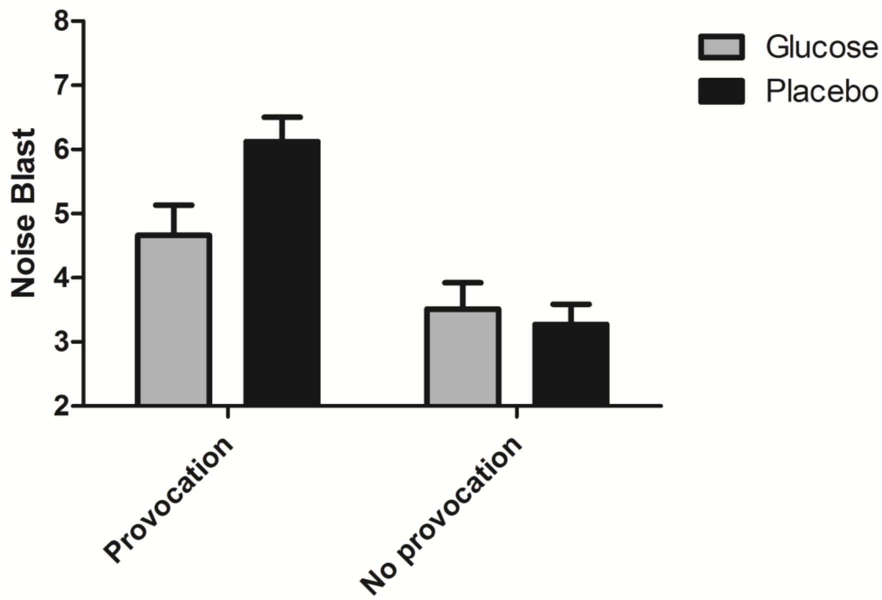
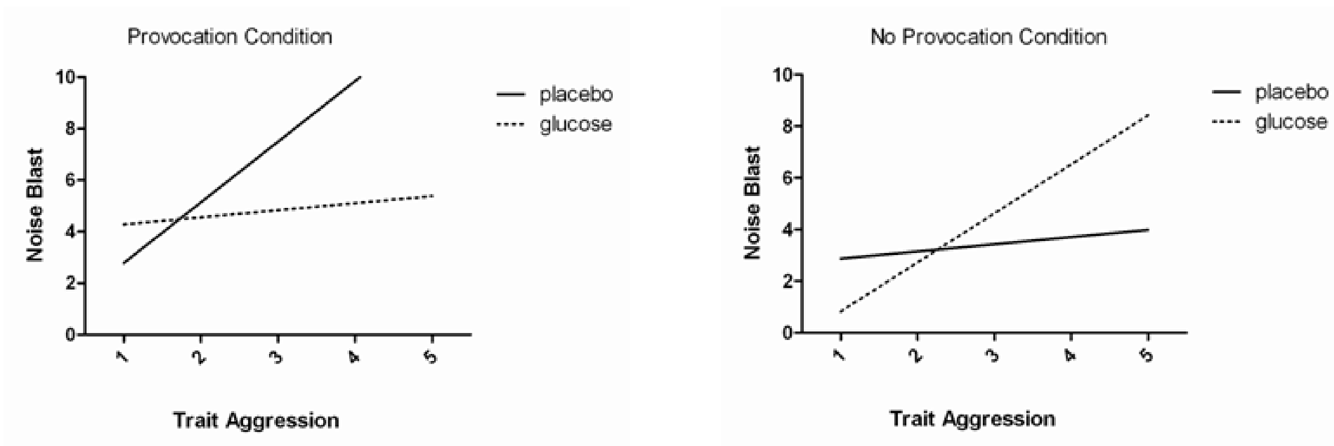

Noise Blast
8
7
6
5
4
3
2
Provocation
No provocation
Glucose
Placebo

Figure 3. Effects of trait aggression on aggressive behavior as a function of beverage (glucose or placebo) and provocation condition for Experiment 2. The lines are regression slopes for the simple effects.


Provocation Condition
Noise Blast
Trait Aggression
placebo
glucose
No Provocation Condition
Noise Blast
Trait Aggression
placebo
glucose