Reinforcing Value of Caffeinated and Noncaffeinated Beverages After Acute Exposure in Children and Adolescents

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Background: When caffeine is added to beverages, it increases beverage liking and the relative reinforcing value (RRV) of these beverages after repeated exposure. The purpose of this study was to test the hypothesis that a single acute exposure to caffeine increases liking and motivation to consume sugar-sweetened beverages (SSBs) relative to placebo.

Methods: Participants were children ages 8–9 years ($n=36$) and adolescents ages 15–17 years ($n=41$) with an approximately equal number of boys and girls. A double-blind, placebo-controlled crossover study was conducted where participants sampled a SSB containing caffeine (1 and 2 mg/kg) on one visit and placebo (quinine 0.01 and 0.02 mg/kg) on a second visit day and then, on a third visit, played a computer game to earn points for the beverages and rated liking and taste sensations. They returned to the laboratory after a 1-week washout and had the alternate dose combination.

Results: Acute exposure to the higher dose of caffeine increased the RRV of the SSB relative to placebo, but only when that dose was presented in the first week and only in female participants. The liking of the caffeine-containing SSB at the higher dose was lower than the placebo at all time points.

Conclusions: These data suggest that a single exposure to a caffeinated SSB can impact its RRV and liking, but only under certain conditions and only in females. This supports previous work suggesting that caffeine can increase desire to consume SSB.

Keywords: caffeine, children, adolescents, reinforcing value, hedonics, bitterness

Introduction

CAFFEINE IS THE MOST commonly used psychoactive substance throughout the world.¹ Although generally recognized as safe in adults, the impact of caffeine use among children is relatively understudied. Given that some caffeine containing beverages are marketed directly to children² and that caffeine use is on the rise among children,³ it is important to understand the potential effects of caffeine use within this population and to determine mechanisms by which caffeine influences behavior.

One mechanism by which caffeine influences beverage consumption is by increasing the relative reinforcing value (RRV) of beverages containing caffeine. The RRV of a food or beverage is determined by how hard an individual is willing to work for access to it,⁴ and previous

studies have demonstrated that greater RRV is associated with greater consumption.^{4–6} Data from adults,⁷ the rising consumption patterns of caffeine in children,^{3,8,9} and a recent study from our laboratory¹⁰ lend support to the hypothesis that caffeine added to sugar sweetened beverages (SSB) enhances their RRV. One question that remains is how much exposure is required to alter the RRV of a caffeine-containing beverage. Our previous study used daily exposure for 1 week,¹⁰ but it is possible that caffeine acts more rapidly than that.

Another mechanism by which caffeine could influence SSB consumption is by increasing hedonic properties of caffeine-containing beverages. A previous study in adolescents demonstrated that exposure to a novel-flavored beverage containing caffeine led to a dose-dependent increase in self-reported liking of that beverage over a 5-day period.¹¹ This was replicated and extended in a

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second study showing that repeated pairing of a caffeine-containing SSB with a novel-flavored yogurt increased liking of that yogurt over a 5-day period.¹²

Increases in liking and RRV of caffeine-containing SSB may occur independently or synergistically. Studies in our laboratory and others have shown that repeated exposure to the same food every day can increase its RRV despite decreasing self-reported liking.¹³ Studies in both human and animal models suggest that hedonic evaluations are related to activation of the opioid system, whereas RRV and motivation are related to activity of the dopaminergic system.^{14–16} Caffeine acts on both of these neural systems to produce positive subjective effects, such as enhanced feelings of well-being, self-confidence, and increased talkativeness in adults.¹⁷ A previous study in adolescents showed that a single acute exposure to caffeine increased reports of “feeling high,” “liking the way they are feeling,” and “wanting more,”¹⁸ This suggests that caffeine can act acutely to influence perception and, potentially, change behavior.

The purpose of this study was to determine if a single exposure to a caffeine-containing SSB influences liking and RRV of that beverage relative to an SSB containing placebo. In addition, we assessed the taste properties of the SSB used in this study to compare taste perception with behavioral and hedonic outcomes. This study provides the foundation for understanding the mechanisms of caffeine-induced SSB reinforcement in children and adolescents.

Methods

Participants and recruitment

Boys and girls aged 8–9 and 15–17 years ($n = 77$) were recruited through flyers, emails, newspaper, and Facebook™ ads. Inclusion criteria were as follows: previous

ingestion of caffeine without an adverse reaction, not taking medications known to interact with caffeine (such as attention deficit hyperactivity disorder medications), nor hormone-based contraceptives, being a nonsmoker, and being Tanner Stage 1–2 or 4–5. Participants were asked to abstain from caffeine for 24 hours and to not consume any food or drink besides water for 2 hours before each scheduled visit. This was verified at each appointment with a 24-hour dietary recall, and if the participant was not compliant, they were rescheduled.

Experimental procedures

Participants attended six laboratory sessions at the Nutrition and Health Research Laboratory at the University at Buffalo. The visits were scheduled in groups of three with a 1-week washout period in between (Table 1). Following a within-subjects, double-blind, placebo-controlled experimental design, each participant was randomized to receive acute doses of 1 and 2 mg/kg caffeine, as well as placebo beverages prepared with quinine (0.01 or 0.02 mg/kg) over the course of the study. The doses of caffeine were chosen based on findings from previous studies showing physiological and subjective response effects at both of these doses.^{18,19} The dose of quinine was selected based on equivalent bitterness ratings to the 1 mg/kg dose of caffeine in previous pilot studies conducted in our laboratory (unpublished observations). The order of beverage exposure was counter-balanced. During the first and second appointments, participants consumed a 300 mL beverage with caffeine on one visit and placebo on another visit. On a third visit, the participants completed the RRV task (see section entitled reinforcing value task) for portions of each beverage. After a 7-day washout period, the paradigm was repeated with a different set of caffeine and placebo doses.

TABLE 1. EXPERIMENTAL DESIGN

Sex	Pubertal stage	Visit 1	Visit 2	Visit 3	Washout	Visit 4	Visit 5	Visit 6
Males	Pre	A	B	A vs. B	7 days	C	D	C vs. D
		B	A			D	C	
	Post	A	B	C vs. D		C	D	A vs. B
		B	A			D	C	
	Pre	C	D			A	B	
		D	C			B	A	
	Post	C	D			A	B	
		D	C			B	A	
Females	Pre	A	B	A vs. B		C	D	C vs. D
		B	A			D	C	
	Post	A	B	C vs. D		C	D	A vs. B
		B	A			D	C	
	Pre	C	D			A	B	
		D	C			B	A	
	Post	C	D			A	B	
		D	C			B	A	

A, low dose placebo; B, low dose caffeine; C, high dose placebo; D, high dose caffeine.

The caffeine and placebo solutions were prepared by an individual uninvolved in the study to maintain the double-blind design. The caffeine solution was prepared using anhydrous caffeine and flattened Sprite™ (10 and 20 mg/mL). The placebo solution was prepared using flattened Sprite and quinine (0.11 and 0.22 mg/mL). Both solutions were frozen and then thawed before being added to the flavored beverage with dosage based on participant body weight (0.1 mL/kg) during each visit.

Upon arrival to the laboratory for the first visit, participants and their parents read and signed consent and assent forms. To reduce subject expectations about the effects of caffeine, participants were told that the beverage they would be given during the study could have had one or more of the following substances added: sugar, artificial sweetener, caffeine, or artificial coloring. Both the parents and children completed Tanner stage and Pubertal Development Scale assessments to classify pubertal phase. After these assessments were completed, the parents answered a demographic questionnaire, while the participant provided a 1.0 and 2.5 mL saliva sample, which were then frozen for possible future caffeine and hormone analyses. Height and weight measurements were then taken using a QuickMedical™ digital stadiometer and SECA™ scale, respectively. Participants then completed a 24-hour dietary recall interview and a hunger and thirst scale (100 mm visual analog scale; [VAS]). Next, participants completed a taste test to select their assigned beverage flavor. They sampled six 50 mL portions of novel flavored sodas (Cream, Mango, Grapefruit, Black Cherry, Grape, Pineapple) to which 1.5 mL of quinine (0.11 mg/mL) solution had been added to increase bitterness of the beverages. Participants rated each beverage flavor using 100 mm VAS for the following taste properties: sweetness, bitterness, sour, acidity, novelty, and liking. The drink flavor that they rated >70 mm for novelty and highest for liking was provided to them for the remainder of the study.

Following the taste test, participants consumed 300 mL of their selected drink containing either placebo (0.01 and 0.02 mg/kg) or caffeine (1 or 2 mg/kg) and then watched an age appropriate television show for 30 minutes. During this time, the participants completed a Caffeine Usage Questionnaire to assess average caffeine intake. At the end of the visit, participants completed hunger and thirst ratings once again. All procedures were approved by the University at Buffalo Institutional Review Board.

Reinforcing value task

Participants were instructed on the use of the computer task where they responded to earn points for drinks on two separate computers. On one computer, the participants earned points toward portions of the placebo containing beverage, and on the other, participants earned points toward portions of the caffeine-containing beverage. The

computers were labeled with the letters corresponding to the beverages that the participants had sampled earlier in the week (A and B 1 week and C and D the other week). The RRV task was similar to a slot machine where every time the mouse button was clicked, the shapes rotated and changed color. When all of the shapes matched, the participant received a point. For every five points they received a 50 mL portion of the beverage for which they were playing. The schedule of reinforcement was a progressive variable ratio which required more clicks to earn points after each round was completed: VR20, VR40, VR80, VR160, VR320, VR640, VR1280, VR2560, and VR5120. This task was developed at the University at Buffalo and has been used extensively by our laboratory^{13,20–22} and others.^{5,6,23,24} This task has been validated against other commonly used measures of reinforcing value in both adults and children.²⁵

Questionnaires

Tanner stage evaluation. Participants were given gender-specific line drawings of five stages of pubertal development and asked to circle the one that looked most like them. Parents were independently asked to rate their child's current development based on the drawings. The average of the child and parent scores was taken. This self-assessment of pubertal stage has been shown to be an accurate and acceptable substitute when physical examinations are not feasible.^{26,27} We only included children who were Tanner Stage 1–2 (prepubertal) or 4–5 (postpubertal). Children classified as Tanner Stage 3 were excluded from the study.

Pubertal development scale. This questionnaire assesses secondary sex characteristics for boys (growth of body hair, changes in voice, etc.) and girls (breast development, menstruation, etc.) Each characteristic was rated on a scale of 1–4, anchored by “has not yet begun” and “seems completed.” The Pubertal Development Scale was used as a secondary measure of pubertal development. This was also completed by the child's parent independently, and the two scores were averaged.

Caffeine usage questionnaire. This questionnaire assesses sources and frequency of caffeine intake and sources of caffeine intake in children and adolescents. The questionnaire calculates a daily average caffeine intake in milligrams. This questionnaire was adapted from Miller 2008.²⁸ Estimates of daily intake were based on information from the U.S. Department of Nutritional Services for a variety of caffeine sources.

Demographic questionnaire. The demographic questionnaire was completed by the participants' parents and collected information about household income, education level, profession, and race/ethnicity.

Analysis

Two mixed model analyses of covariance (ANCOVA) were conducted to investigate the effect of caffeine dose on the RRV of the beverages. We created plots of responses across different schedules of reinforcement and calculated the area under the curve as our measure of RRV. In the first model, beverage type (exposure to caffeine vs. placebo) was a within-subjects factor and sex, pubertal status, and exposure order (between weeks = high dose vs. low dose combinations first; within week = placebo vs. caffeine first) were entered as between-subject factors. Covariates in the model included average daily caffeine usage, baseline liking ratings of caffeine and placebo, and the participant's weight. Body weight was included in the model because, although we felt it necessary to provide caffeine and quinine based on body weight to account for differences in subjective effects of the drug, the additional caffeine/quinine given to people who weighed more had the potential to increase bitterness and reduce palatability, which could have influenced liking and RRV. Different liking scores were included to account for differences in baseline liking. The second ANCOVA model was the same as the first, but compared the lower doses of caffeine and placebo. *Post hoc* comparisons of caffeine versus placebo were conducted within each sex and order using individual ANCOVA within each sex.

Examinations of the hedonic ratings of each drink type were conducted using two mixed-model ANCOVAs; one for the high doses of placebo and caffeine and one for the low doses. For each hedonic rating, beverage type (exposure to caffeine vs. placebo) was a within-subjects factor, and sex, pubertal status, and exposure order were entered as between-subject factors with average daily caffeine usage and participant weight included as covariates. All analyses were conducted using SPSS version 17.0.

Results

Participant characteristics

The sample included 77 children and adolescents, 38 female and 39 male. Among the female participants, 19 were prepubertal and 19 were postpubertal. Among the male participants, 17 were prepubertal and 22 were postpubertal. The sample was highly educated, with 75% of the parents completing college or graduate degrees. The sample was a little more than half Caucasian, with the other half predominantly African American and multiracial (Table 2).

Acute caffeine alters the reinforcing value of soda

For the highest caffeine dose, there was a main effect (ME) of beverage type on reinforcing value [$F(1, 64) = 5.36$; $p = 0.024$], with the placebo beverage more rein-

forcing than the caffeinated beverage. There was also a significant interaction between beverage type and between-week order [$F(1, 64) = 5.78$; $p = 0.019$], with high caffeine being more reinforcing than placebo when presented the first week, but the opposite pattern when presented the second week. This effect was driven by changes in the RRV of the high-dose placebo beverage. There was also a three-way drink $\times$ sex $\times$ order interaction [$F(1, 64) = 4.43$; $p = 0.039$]. *Post hoc* comparisons revealed that males found caffeine and placebo equally reinforcing regardless of between-week order [$F(1, 64) = 0.62$; $p = 0.44$; Fig. 1B]. However, in females, the caffeinated beverage was more reinforcing than placebo when the highest doses were presented the first week, but the placebo was more reinforcing than the caffeine when the highest dose was presented the second week [$F(1, 64) = 9.68$; $p = 0.004$; Fig. 1A]. There were no differences in RRV between the different beverage types for the lower dose of caffeine and placebo and there was no impact of within-week order.

Acute caffeine reduces liking of soda relative to placebo

For the highest caffeine dose, there was an interaction of beverage type and weight on liking [$F(1, 65) = 4.9$; $p = 0.03$], with all participants liking placebo more than caffeine, but lower weight participants liking both beverages more than higher weight participants. There was a three-way interaction of drink type $\times$ pubertal phase $\times$ order [$F(1, 65) = 6.25$; $p = 0.015$]. When the higher caffeine and placebo doses were presented during the first week, both the pre- and postpubertal participants liked the placebo beverage more than the caffeinated beverage, with a larger difference in beverage liking among the prepubertal participants. Likewise, when the higher caffeine and placebo doses were presented during the second week, both pubertal groups liked the placebo beverage more than the caffeinated, but both beverages were more highly liked by prepubertal youth compared to the postpubertal group. There were no significant effects of drink type on liking at the lower doses of caffeine and placebo and no significant impact of within-week order. In addition, unlike with RRV, there was no significant influence of sex on liking of beverages (Fig. 2).

Caffeine primarily increases bitterness, but does not affect other taste sensations relative to placebo

Bitterness. There was no ME of beverage type at the highest doses of placebo and caffeine in terms of bitterness rating (Table 3). There was an interaction of beverage type and participant weight on bitterness ratings [$F(1, 65) = 9.10$, $p = 0.004$]. Both higher and lower weight participants rated the caffeine drink as more bitter than the placebo drink; however, the lower weight participants rated the higher dose of quinine as more bitter than did the higher weight participants, despite the higher

TABLE 2. CHARACTERISTICS OF THE STUDY POPULATION

	<i>Prepubertal</i>		<i>Postpubertal</i>	
	<i>Male (n = 17)</i> <i>Mean ± SEM</i>	<i>Female (n = 19)</i> <i>Mean ± SEM</i>	<i>Male (n = 22)</i> <i>Mean ± SEM</i>	<i>Female (n = 19)</i> <i>Mean ± SEM</i>
BMI percentile	60.5 ± 6.8	64.5 ± 6.9	59.3 ± 6.5	66.2 ± 5.9
Caffeine dose given				
1 mg/kg	34.0 ± 3.4	31.7 ± 1.5	69.0 ± 4.7 ^a	67.0 ± 5.2 ^a
2 mg/kg	68.0 ± 6.8	63.4 ± 3.0	138.0 ± 9.4 ^a	134.0 ± 10.4 ^a
Average caffeine use (mg/day)	27.6 ± 9.2	20.9 ± 4.6	81.8 ± 21.3 ^a	82.3 ± 19.0 ^a
Caffeine sources (servings/week)				
Soda	1.21 ± 0.47	0.44 ± 0.08	1.34 ± 0.40	1.05 ± 0.38
Tea	0.82 ± 0.41	0.60 ± 0.17	1.47 ± 0.37 ^a	1.95 ± 0.46 ^a
Coffee	0.04 ± 0.04	0.013 ± 0.01	0.39 ± 0.23 ^a	1.42 ± 0.53 ^a
Energy drinks	0.02 ± 0.02	0.11 ± 0.06	0.36 ± 0.23	0.01 ± 0.01
Chocolate	1.69 ± 0.37	1.57 ± 0.43	1.76 ± 0.44	2.17 ± 0.43
Medications	0.00 ± 0.00	0.00 ± 0.00	0.23 ± 0.13 ^a	0.10 ± 0.04 ^a
	n (%)		n (%)	
Education level of primary caregiver				
Completed high school	0 (0)	2 (11)	1 (5)	5 (26)
Some college	2 (12)	1 (5)	6 (27)	2 (11)
Completed college	8 (47)	12 (63)	11 (50)	7 (37)
Completed graduate degree	7 (41)	4 (21)	4 (18)	5 (26)
Family income				
<10,000	0 (0)	1 (6)	0 (0)	2 (13)
\$10,000–49,999	5 (29)	8 (47)	14 (36)	4 (25)
\$50,000–69,999	0 (0)	3 (18)	2 (5)	3 (19)
\$70,000–89,999	8 (47)	2 (12)	6 (15)	2 (13)
\$90,000–109,999	3 (18)	2 (12)	10 (26)	3 (19)
\$110,000–139,999	1 (6)	0 (0)	4 (10)	0 (0)
>\$140,000	0 (0)	1 (6)	3 (8)	0 (0)
Race				
White	12 (55)	9 (47)	16 (73)	9 (50)
Black/African American	2 (12)	4 (21)	5 (23)	8 (44)
Other	0 (0)	3 (16)	0 (0)	0 (0)
Multiracial	3 (18)	3 (16)	1 (4)	1 (6)

^aSignificantly different from prepubertal participants ($p < 0.05$).
SEM, standard error of the mean.

weight participants having more quinine added to their beverage. There were no significant MEs or interaction in terms of bitterness for either dose of caffeine or the lower doses of quinine and no impact of order.

Sweetness. There were no MEs in terms of sweetness at the higher doses of caffeine and placebo. There was an interaction of beverage type and participant weight [$F(1, 65) = 6.71$, $p = 0.012$]. The lower weight participants showed little difference in rating of sweetness between caffeine and placebo. However, the higher weight participants rated the placebo as sweeter than the caffeine. There were no MEs or interactions in terms of sweetness at the lower doses of caffeine and placebo and no impact of order at either dose.

Acidic. There were no MEs of beverage type in terms of acidity ratings at the high dose of caffeine and pla-

cebo. At the lower doses of caffeine and placebo there was a ME of beverage type [$F(1, 65) = 5.34$; $p = 0.024$] with the placebo rated as less acidic than the caffeinated drink. There was also an interaction of beverage type and pubertal phase in terms of acidity in the lower doses [$F(1, 65) = 4.22$; $p = 0.044$]. Postpubertal participants rated the caffeinated drink as more acidic than did the prepubertal participants. The pattern of acidity rating was reversed for the placebo drink, but the difference was much smaller.

Sourness and novelty. There were no MEs or interactions for ratings of novelty or sourness at either dose of caffeine or placebo. There was a ME of within-week order on novelty ratings at the high dose, with novelty rated higher when the high dose placebo was presented first compared with when the high dose caffeine was presented first [$t(75) = 2.05$; $p = 0.044$].

FIG. 1. Mean $\pm$ SEM area under the curve for RRV of SSB containing placebo (black bars) or caffeine (gray bars) after a single exposure to each one. Females are shown in (A) and males are shown in (B). Data from the low dose combination are shown on the left and the high dose combination are shown on the right. Finally, within each set of doses, data from participants who were given the high doses during the first week are shown on the left and the data from those who were given the low doses during the first week are shown on the right. There was a significant drink $\times$ sex $\times$ order effect on RRV of SSB [$F(1, 64) = 4.43$; $p = 0.039$]. *Post hoc* comparisons were conducted in males and females separately. There were no significant effects of order or beverage type in males [$F(1, 64) = 0.62$; $p = 0.44$], but in females, the high dose of caffeine was more reinforcing than placebo when the high dose was presented during the first week and the placebo was more reinforcing than caffeine when the low dose was presented the first week [$F(1, 64) = 9.7$; $p = 0.004$]. *significantly different from placebo ($p < 0.05$); RRV, relative reinforcing value; SEM, standard error of the mean; SSB, sugar sweetened beverage.

FIG. 2. Mean $\pm$ SEM area liking ratings for SSB containing placebo (black bars) or caffeine (gray bars) after a single exposure to each one. Females are shown in (A) and males are shown in (B). Data from the low dose combination are shown on the left and the high dose combination are shown on the right. Finally, within each set of doses, data from participants who were given the high doses during the first week are shown on the left and the data from those who were given the low doses during the first week are shown on the right. There was a main effect of beverage type on liking in the high dose combination [$F(1, 65) = 4.9$; $p = 0.03$], with the high dose of caffeine rated as less liked than the high dose of placebo, regardless of order. There were no differences with the low dose comparisons ($p > 0.05$). *Significantly different from placebo ($p < 0.05$).

Discussion

Caffeine use is widespread among children and adolescents, and the primary source in this population is SSB.²⁹ It is important to understand factors that contribute to

TABLE 3. AVERAGE TASTE RATINGS

	<i>Low dose</i>				<i>High dose</i>			
	<i>Placebo</i>	<i>SEM</i>	<i>Caffeine</i>	<i>SEM</i>	<i>Placebo</i>	<i>SEM</i>	<i>Caffeine</i>	<i>SEM</i>
Bitter	23.5	2.6	28.7 ^a	3.0	26.4	3.0	35.7 ^a	3.4
Sweet	57.4	2.8	53.7	2.8	52.6	3.2	58.0 ^a	2.8
Sour	28.4	3.1	26.4	3.0	29.0	3.3	30.5	3.5
Acidity	36.8	3.0	38.5	3.2	39.6	3.2	39.3	3.4
Novelty	40.5	3.8	37.9	3.5	41.6	3.9	49.5	3.7

Ratings on a 100 mm visual analog scale with “0”, not at all, and “100”, extremely.

^aSignificantly different from placebo.

excess SSB intake and caffeine may be one. The purpose of this study was to test the hypothesis that a single exposure to caffeinated SSB increases the RRV of SSB in a dose-dependent manner. We found a ME of beverage type on RRV, with SSB+caffeine found to be less reinforcing than SSB+placebo at the highest doses. However, there was also a significant interaction with order of beverage presentation on RRV. Specifically, when high doses of caffeine and placebo were presented in the first week, the caffeinated SSB was more reinforcing than placebo SSB, but when the low doses were presented during the first week, the placebo SSB had greater RRV than caffeine SSB. This may be due to expectancy in that when the higher dose beverages were presented first, there is no expectation based on previous experience about their taste properties, but when the higher doses were presented in the second week, they would be more bitter than expected based on the initial exposure the week before. We also found that higher body weight, and thus more caffeine and quinine added, was associated with lower ratings of quinine bitterness, but also lower ratings of liking for the high dose of both caffeine and quinine. These data suggest that caffeine can have a mild influence on RRV of SSB, but that taste properties and expectancy have a stronger influence on acute RRV of SSB.

Based on our previous findings with longer term caffeinated SSB exposure, we predicted that acute caffeine exposure would result in an increase in RRV of caffeinated SSBs to noncaffeinated SSBs.¹⁰ Instead we found the opposite at the highest doses and no differences at the lower dose. There are several potential explanations for this. First, it may be that several days of repeated SSB consumption is required to shift the RRV of SSBs paired with caffeine. This repeated pairing has been shown to reduce perceived bitterness and increase hedonic ratings, but it takes several days.¹¹ Second, it could be that a single exposure was not enough to allow participants to associate the beverage with the postingestive consequences, especially given that the placebo and the caffeine were the same base beverage. If the placebo and caffeine were presented in different flavored beverages, there would have been additional cues that participants could have used to create associations between the beverages and the postingestive consequences. In

this study, the only cues were the letter labels. These data suggest that repeated pairing of caffeine and SSB is necessary to shift the reinforcing properties of SSBs. When combined with our previous studies, we expect that it takes between two and five exposures to shift hedonics and RRV.

Our previous studies suggest that boys find caffeinated SSBs more reinforcing after a week of daily exposure, but females find caffeinated SSBs less reinforcing after this same time period.¹⁰ In the current study, we found no differences in RRV of placebo and caffeinated SSBs in males, regardless of dose or order of administration, but that females found the high dose of caffeine more reinforcing than placebo when the high dose was presented first, but less when the low dose of caffeine was presented first. These results suggest that acute RRV of caffeinated SSB is higher in females than in males, but that the sex difference shifts over time after repeated administration. One potential mechanism for this is that postingestive consequences arising from caffeinated SSB consumption increase the RRV in boys and decrease the RRV in females. However, it is important to be cautious about over interpreting these interactions, as the sample size is relatively small. More work needs to be done to assess these potential sex differences.

There were also differences in taste properties of caffeinated and noncaffeinated SSBs. Specifically, for the high dose of caffeine, bitterness ratings were higher and liking ratings were lower than for placebo. The ratings for placebo and caffeine were similar for the lower dose. In a previous study where we examined changes in taste ratings and hedonics after repeated exposure, we found that liking of a caffeinated SSB increased after five exposures and ratings of bitterness went down after five exposures to a caffeinated SSB. This suggests that more than a single exposure is necessary to lead to changes in taste perception and hedonics. The taste and liking ratings may have directly impacted the RRV, as flavors that are bitter and not liked highly would not be ones for which participants are likely to work. In fact, it is worth noting that, for the high dose combination, males and females both rated the caffeine as less liked than the placebo, but females had a higher RRV of caffeine than placebo and males showed no difference in RRV

of placebo versus caffeine. This is consistent with our previous studies showing that hedonic ratings and RRV are often dissociated.^{13,30,31}

This study had several strengths. First, we used a double-blind, placebo-controlled crossover design. This improved our power and our generalizability. We also used an objective behavioral task coupled with subjective ratings to measure RRV and hedonics. This technique allows for a more quantitative approach to understanding motivation. Third, we used children and adolescents, allowing us to examine developmental changes in motivation to consume beverages, which is particularly relevant for SSB as their use escalates during this time. This study was not without weaknesses. First, the sample size ($n=77$) was relatively small considering the investigated interactions between pubertal stage and sex. Future studies should perhaps focus on one age group and recruit a larger sample of participants. Second, the beverages became more bitter as the children got bigger, since we provided caffeine and placebo based on body weight and the sugar content of the beverage remained constant. We have controlled for this in our statistical analysis, but it would have been better to completely mask the bitterness in the beverages. Future studies will investigate better beverage formulas for masking caffeine and quinine bitterness. Finally, the sociodemographic distribution of our population was primarily middle class, white, and well educated. This makes generalization to the population as a whole difficult.

Summary/Conclusions

This study showed that a single exposure to a caffeinated beverage is unlikely to result in significant changes in RRV of beverages. This may be due to drink hedonics and perception, such as low levels of liking and high levels of bitterness. This is akin to an adolescent consuming black coffee for the first time. It is unlikely that a single exposure will turn someone into a black coffee drinker, but after repeated exposure, the perceived bitterness decreases and the coffee becomes predictive of positive postingestive consequences. These findings may explain why caffeine is typically introduced to children in very sweet beverages with the sweetness of caffeinated beverages of choice decreasing through adolescence and adulthood. As caffeine use continues to rise and our understanding of the health implications of excess caffeine consumption improves, it is important to understand developmental factors that influence caffeinated beverage choice. This study adds to the growing body of literature on this subject.

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Author Disclosure Statement

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