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14. ABSTRACT

This study examined the ability of a commercial energy drink to enhance acceleration tolerance, strength under G-load, and cognitive performance immediately prior to and following acceleration exposure. Eight experienced centrifuge subjects completed three separate experimental acceleration exposures following ingestion of 11.5 ml/kg body weight of a) a commercial energy drink, providing 5.0 mg caffeine/kg body weight, b) a commercial energy drink without caffeine or c) placebo. The acceleration exposures consisted of a relaxed gradual onset run to peripheral light loss, a rapid onset run to 6.0 G for 15 s, and a simulated air combat maneuver (SACM) run of repeated alternations between 4.5 G for 15 seconds and 7G for 15 seconds until volitional exhaustion. Cognitive tests were performed prior to and after the acceleration profiles. Relaxed G-tolerance was significantly higher under the caffeine session, whereas SACM duration did not differ among the drink conditions. Hip adductor muscle strength was lower during the placebo session than during the other two sessions. Cognitive reaction time was faster post-acceleration than pre-acceleration, and faster under the caffeine condition than the placebo condition. We conclude that consumption of a caffeine-based energy drink enhances relaxed G-tolerance and may increase strength, but does not impact acceleration duration. We further conclude that cognitive reaction time is improved by the caffeinated drink, as well as by the physical exertion during the acceleration exposure.

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Acceleration Tolerance After Ingestion of a Commercial Energy Drink

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WALKER TB, BALLDIN U, FISCHER J, STORM W, WARREN GL. *Acceleration tolerance after ingestion of a commercial energy drink.* **Aviat Space Environ Med 2010; 81:1–7.**

Background: Caffeine ingestion has been demonstrated to increase physical performance in some situations. This study examined the ability of a commercial energy drink containing caffeine to enhance acceleration tolerance and strength under G load. ***Methods:*** Eight experienced centrifuge subjects completed three separate experimental acceleration exposures following ingestion of 11.5 ml · kg^{-1} bodyweight of 1) a commercial energy drink, providing 5.0 mg caffeine/kg bodyweight; 2) a commercial energy drink without caffeine; or 3) a placebo. The acceleration exposures consisted of a relaxed gradual onset run to peripheral light loss, a rapid onset run to 6 G for 15 s, and a simulated air combat maneuver (SACM) run of repeated alternations between 4.5 G for 15 s and 7 G for 15 s until volitional exhaustion. ***Results:*** Relaxed G tolerance was 13% higher under the caffeinated energy drink session, whereas SACM duration did not differ among the drink conditions. Hip adductor muscle strength was 37% lower during the placebo session than during the other two sessions. ***Conclusion:*** Consumption of a caffeine-based energy drink may enhance relaxed G tolerance and may increase strength, but does not impact acceleration tolerance duration.
Keywords: caffeine, G tolerance, centrifuge.

ADVANCED FIGHTER aircraft are capable of operating in high-G environments and are often limited by the physiological capabilities of the aircrew. Aircrew members must perform an anti-G straining maneuver (AGSM) just prior to and during a high-G aircraft maneuver to prevent G-induced loss of consciousness (GLOC). The inability to maintain and repeatedly perform an AGSM can result in the loss of life and aircraft. Millions of dollars have been spent on the development of life support equipment to help prevent GLOC, yet performance of a proper AGSM remains the most effective protection against GLOC. Ergogenic aids containing caffeine, such as energy drinks, are readily available and may prove to enhance performance of the AGSM during high G via reduction of muscle fatigue associated with repeated isometric contractions. Recent studies have demonstrated that relatively low doses of caffeine are effective in improving exercise performance (6,22) and may specifically enhance muscular strength (13,25) and muscular endurance (14,18,25). Particular to the type of contraction used in the AGSM, Plaskett and Cafarelli (23) and Meyers and Cafarelli (20) have demonstrated that caffeine significantly increases time to fatigue during isometric contractions, making it a potentially valuable aid in the high-G combat environment. While one study (10) of rhesus monkeys failed to show any effect of caffeine on cardiovascular function or relaxed G tolerance (without performing AGSM), the efficacy of caffeine in humans to aid an active AGSM has not been investigated. This study was conducted to evaluate the ability of a caffeine-based energy drink to serve as an inexpensive yet effective aid by enhancing the performance of AGSM in a high-G environment.

METHODS

Subjects

There were 10 volunteer subjects, including 2 women, mean age 30.2 ± 7.4 yr, who were recruited from the Brooks City-Base human centrifuge subject panel. Centrifuge panel members are prescreened for appropriate health and fitness and demonstrate the capability to consistently tolerate exposures up to +9 G_z when wearing standard G-protection ensembles. The research protocol for this study was reviewed and approved by the Air Force Research Laboratory Institutional Review Board prior to subject recruitment and the subjects gave written informed consent before participating. Female subjects provided a negative pregnancy test within 72 h prior to each of their centrifuge exposures.

Experimental Design

This study employed a repeated measures design and double blind procedures. Each subject participated in three dosing conditions. The design goal was to balance the order of the dosing conditions to avoid confounding due to any potential carry-over or learning effects. While perfect balance is not possible with 10 subjects and 3 treatments, we created a partially balanced model in which each of the 6 permutations of the 3 conditions was used once and 4 were repeated. These 10 combinations were randomly entered into a list and as a subject entered the study they were assigned to the next combination in the

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list. The conditions consisted of ingesting 1) a commercially available caffeinated energy drink (Full Throttle®, produced by the Coca-Cola Company, containing 9.0 mg caffeine per 1 oz fluid); 2) a modified version of the energy drink comprised of the same ingredients but for the removal of caffeine and guarana; or 3) a placebo version of the drink with all of the 'energy' ingredients removed (i.e., no high-fructose corn syrup, B-vitamins, ginseng, guarana, L-carnitine, or taurine). In this paper the three dose conditions will be respectively referred to as caffeinated energy drink, non-caffeinated energy drink, and placebo. All drinks were prepared by the Coca-Cola Company and administered to the subjects in sealed bottles which had coded labels so as to obscure each drink's composition.

Procedure

Dosing and testing schedules: The three experimental sessions were conducted at approximately the same time of day for each subject, with approximately 72 h lapsing between sessions to allow for recovery. Subjects were asked to avoid strenuous physical exercise on the day before and the same day as the trials. Immediately prior to each trial the subjects received a brief medical exam and were asked about their general condition and health, including potential caffeine intake. Subjects abstained from caffeine consumption for 14 h, and from food and tobacco consumption for 6 h, before each session. Dosing was based on each subject's weight and, for each experimental session, administered in two drinking portions. In each experimental condition, the first drink consisted of 10.95 ml of drink per kg bodyweight; the second 5.48 ml of drink per kg bodyweight. For the caffeine trial this volume resulted in a caffeine dose of 5.0 mg caffeine per kg of bodyweight. This dosage was based on previous work by one of the co-investigators. In a study investigating the effects of a caffeinated sports drink (6), it was found that a nearly identical dosage (5.3 mg $\cdot$ kg^{-1}) improved both endurance exercise performance and knee extensor strength. Furthermore, the beneficial effect of caffeine on muscle strength has been found to be independent of the dosage used, at least over the range of 1 to 9 mg $\cdot$ kg^{-1} (25). The first drink was issued to the subject 1-3 d prior to the day of each experimental session for self-administration by the subject prior to reporting to the centrifuge facility. Subjects were instructed to keep the drink refrigerated until ingesting it 2.5 h prior to the scheduled centrifuge run. Subjects ingested the second drink immediately on arriving at the centrifuge facility 30-45 min prior to the centrifuge run. Each drink was consumed within 2 min. After ingesting the second drink, the subject was given a brief medical examination and instrumented with electrocardiograph (ECG) monitoring leads as required for centrifuge exposure. The subject then completed brief subjective mood and alertness surveys. On completion of the surveys, he/she was emplaced in the centrifuge gondola for acceleration testing, which required 15-30 min depending on the subject's G-tolerance. On completion of acceleration testing an 8-ml sample of venous blood was drawn from the subject for subsequent assay of serum caffeine. Serum caffeine concentration was determined using a homogeneous enzyme immunoassay technique using commercially available reagents (Emit Caffeine Assay; Dade-Behring Syva, Cupertino, CA). Subjects then completed the mood and alertness surveys for a second time, were debriefed, and departed the facility.

Acceleration profiles and G tolerance measures: All centrifuge exposures were conducted in the 711th Human Performance Wing's human centrifuge capable of G onset rates of 6 $G_z \cdot s^{-1}$. The 6.1-m rotating arm produces centrifugal force and the free swinging action of the gondola orients the human subject such that the resultant G vector is aligned with the subject's z-axis, producing $+G_z$ (so that blood is forced from head to feet) as is most common in tactical aviation. For this study an F-16 seat (30° back tilt) was installed in the centrifuge gondola and subjects did not wear an anti-G suit. Subjects were sequentially exposed to the same three acceleration profiles during each experimental drink session. Baseline (resting) heart rate (from the ECG recordings using the Gould Bioelectric amplifier 13-6615-58, Valley View, OH, and a Astro-Med MT9Sk2 recorder, West Warwich, RI) and blood pressure data were collected at each session prior to conducting the acceleration profiles.

Gradual onset profile: This profile measured what is commonly known as relaxed G-tolerance. Each subject was exposed to this profile once for each of the three conditions. Subjects were exposed to a profile consisting of 0.1 G $\cdot$ s^{-1} onset rate to a maximum of +9 G_z while maintaining a relaxed state (i.e., no AGSM) to the point of 100% loss of peripheral vision or 50% loss of central vision. Subjects were highly trained in the centrifuge before participating in the protocol and were well practiced at remaining as relaxed as possible during these exposures. The outcome measures were maximum G level attained, systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) measured at a common G level during the centrifuge run. A "common G level" is defined as the lowest maximum G level attained by a subject across the three experimental sessions and was determined for each subject individually. It was necessary to compare blood pressures and heart rate at a common G level to avoid bias when comparing the three drink conditions. For example, if a subject went to +6 G_z under one drink and +9 G_z under another drink, his/her blood pressures and/or heart rates might differ simply due to the additional stress of the higher G, not because of a difference caused by the drinks.

Rapid onset profile: This profile employed an onset rate of 6 G $\cdot$ s^{-1} to +6 G_z where the subject remained for 15 s, during which the subject did perform AGSM. Each subject was exposed to this profile once for each of the three conditions. Outcome measures were the duration of time at 6 G, HR, SBP, and DBP (measured at a common point in time, as per the argument presented in the above paragraph), and estimated subjective maximum effort required to perform AGSM (where maximum effort is

the effort level required to perform an adequate straining maneuver during high-G, measured on a modified Borg scale of 0-11, where 0 = no effort, and 11 = extreme maximal physical effort).

Simulated aerial combat maneuver: Each subject was exposed to a simulated aerial combat maneuver (SACM) profile once for each of the three conditions. This profile consisted of up to 15 repeated alternations between +4.5 G_z for 15 s and +7 G_z for 15 s, during which the subject performed AGSM as needed until the subject self-terminated due to fatigue, light loss, or completion of 15 alternations. Immediately prior to the start of the profile the subjects performed a maximum voluntary isometric contraction (MVIC) of their hip adductor muscles, during which strength was measured. During the first 5 s of each +7 G_z exposure the subjects repeated the MVIC as part of their AGSM. Outcome measures were duration (i.e., time at G), HR, SBP, DBP, MVIC strength (all measured at a common point in time, i.e., at the lowest duration observed for all three conditions in each subject), and subjective effort. MVIC strength was measured by a padded force transducer [Load Cell MLP-150 (lb) Transducer Techniques, Temecula, CA] located between the subject's knees. Arterial blood pressure was recorded during all the G exposures by a noninvasive photoplethysmographic technique (Portapres®, TNO, Delft, The Netherlands) with a pressure cuff around the midphalanx of the third finger on the left hand. The forearm and hand were supported by a sling and the hand positioned at heart level and enclosed in a preheated glove to avoid vasoconstriction of the finger blood vessels by a cool environment.

Subjective measures: One instrument from the Automated Neuropsychological Assessment Metrics (ANAM; 24) battery and one paper-and-pencil survey, the Profile of Mood States (POMS; 19) were selected to assess alertness and affective state immediately before and after each subject's centrifuge exposure. Each survey session required about 3 min for the subjects to complete, always in the following sequence.

Alertness: The ANAM battery offers an automated version of the Stanford Sleepiness Scale that maintains the original seven-point scale, rating subjective sleepiness from "1—very alert, wide awake, and energetic" to "7—very sleepy and cannot stay awake much longer."

Affect: Subjective evaluations of mood were acquired using the POMS. This survey consists of 65 adjectives describing feeling and mood to which the subject responds according to a five-point scale ranging from "Not at all" to "Extremely." Subjects were instructed to indicate mood status for "how you feel right now" with regards to each item. A standardized "state" measure is generated for each of six mood categories: anger, confusion, depression, fatigue, tension, and vigor.

Statistical Analyses

For each of the centrifuge acceleration variables, a repeated measures analysis of variance (ANOVA) was performed to test for differences among the three drink conditions. When a significant drink effect was found, Fisher's LSD procedure was used to identify specific differences among the three drinks. For each subjective mood variable, a repeated measures ANOVA with two factors was performed to test for drink main effects, pre- versus post-acceleration main effects (hereafter referred to as 'acceleration' main effect), and drink-by-acceleration interaction. For the Stanford Sleepiness Scale (alertness), nonparametric procedures (Friedman's and Wilcoxon signed rank tests) were used to test for acceleration and drink effects. The statistical package SPSS 11.5 was used for all statistical analyses. Alpha = 0.05 was used as the level for statistical significance for all tests.

RESULTS

Of the 10 subjects completing this study, only 8 were included in the analyses. One subject experienced G-induced loss of consciousness on the majority of the rapid onset and SACM rides. We concluded that, while this subject was an experienced rider who usually performed satisfactorily when wearing a G suit, the G levels used in this study were slightly too high for this individual's unprotected innate G tolerance. Another subject, upon post-study analysis of the serum data, was found to have significant serum caffeine levels (> 5 μM) during all three of the experimental conditions, suggesting that the subject did not abstain from caffeine as directed by the protocol. Unfortunately, the loss of these two subjects resulted in our experimental design no longer being balanced. In fact, of the eight subjects analyzed, six of them experienced the placebo run before they experienced the caffeine run. The potential impact of this imbalance is addressed in the Discussion section below. Finally, due to technical problems, blood pressure data was not always available for all centrifuge runs of each subject. Thus, for each blood pressure outcome measure, only subjects with data for all three conditions were included in the analysis.

Serum Caffeine Levels

For the eight subjects used in this study, serum caffeine levels averaged 33.37 ± 8.45 μM under the caffeinated energy drink, 2.49 ± 1.09 μM under the non-caffeinated energy drink, and 2.70 ± 1.38 μM under the placebo drink, thus confirming adherence to the protocol with respect to the use of caffeinated products and study drink intake.

Acceleration Tolerance

The centrifuge acceleration measures are summarized in **Table I**. There were four outcomes of primary interest in this study: relaxed gradual onset G tolerance; rapid onset G exposure duration (with AGSM); SACM G-exposure duration; and MVIC strength (measured at a common point in time during the SACM). For two of these (rapid onset G-exposure duration and SACM duration), no significant differences were found among drink conditions. For relaxed gradual onset G tolerance, there was a significant drink main effect [MSE = 0.183,

F(2,14) = 9.69, P = 0.002]. Follow-up t-tests revealed that G tolerance was significantly higher under the caffeinated energy drink condition than under the non-caffeinated energy drink and placebo conditions by 0.9 $+G_z$ (P = 0.004) and 0.7 $+G_z$ (P = 0.017), respectively.

There was no statistical difference among the three drink conditions with respect to the MVIC control data measured before the centrifuge runs. MVIC strength measured at a common time point during the SACM exposures was lower than MVIC control for all three conditions, with the largest drop occurring during the placebo condition. The drink main effect was significant for MVIC strength measured at a common time point during the SACM [MSE = 225.2, F(2,14) = 3.96, P = 0.043] and post hoc tests revealed that the means were significantly higher under the two energy drink conditions than under the placebo condition by 29% and 32%, respectively (P = 0.043 in each case).

No significant drink effects were found for any of the physiologic measures (SBP, DBP, HR). Subjects' perceived effort required to complete the various profiles also did not differ among drink conditions. Finally, because of the nature of the cardiac arrhythmia data and the small sample size, no statistical tests were performed on these measures. However, the distribution of the data (see Table I) suggests a trend toward more subjects being affected and more overall occurrences of arrhythmias under the caffeinated energy drink condition than under the other two conditions.

Mood States and Alertness

No significant drink by acceleration interactions or drink main effects were detected for any of the six POMS mood states. Acceleration main effects were found for confusion, fatigue, and vigor. The average standardized score for confusion significantly increased from 34.5 before acceleration to 37.8 after acceleration [MSE = 16.21. F(1,7) = 8.43, P = 0.023], fatigue significantly increased from 36.7 to 43.3 [MSE = 68.667, F(1,7) = 7.77, P = 0.027], and vigor significantly decreased from 49.4 to 44.6 [MSE = 25.85, F(1,7) = 10.48, P = 0.014]. The scale range for confusion is 30-80, fatigue 34-77, and vigor 30-76. Thus, the pre- to post-acceleration changes in score for these three mood factors, while statistically significant, were very small and, in absolute terms, indicative of the subjects' being in a positive and alert affective state both before and after exposure to acceleration. For the Stanford Sleep Scale subjective alertness scores, no significant drink, acceleration, or interaction results were found. The overall average score was 1.8 before acceleration exposure and 2.4 following exposure, both scores indicating a high level of alertness (scale range = 1 to 7).

DISCUSSION

The primary finding of this investigation was that ingestion of a caffeinated energy drink, delivering 5.0 mg of caffeine per kg bodyweight, did not significantly influence acceleration endurance for subjects while performing the AGSM during rapid onset or SACM exposures. However, ingestion of a caffeinated energy drink did result in a significant improvement in relaxed gradual onset G-tolerance, and appeared to increase hip adductor strength levels measured during the performance of the AGSM.

An effective AGSM can improve G tolerance by over 3 $+G_z$ (11), but can be very fatiguing. Acceleration tolerance is usually related to the ability to maintain a sufficient heart level and cerebral arterial blood pressure. Before a gray-out, blackout, and/or G-LOC, retinal and cerebral arterial blood pressure usually fall drastically. During relaxed (no AGSM) G-exposure the cardiovascular response, through arterial and cardiac baroreceptors, increases heart rate and blood pressure within 6-9 s in an attempt to counteract the G-induced decrease in blood pressure. Heart level blood pressure is partially restored in 10-15 s through this baroreceptor effect (3). The endurance to withstand repeated G loads is also related to the ability to maintain an effective respiratory and muscular AGSM. During G exposures with an AGSM, blood pressure is immediately elevated 1) through muscle contraction of the legs and abdomen, causing peripheral vasoconstriction; and 2) through the respiratory straining maneuver, which increases intrathoracic pressure and heart contractility.

Caffeine is known to stimulate the cardiovascular and central nervous systems through the activation of the sympathetic nervous system (7), but also to cause relaxation of smooth muscles. It influences cardiovascular stress reactivity and potentiates the body's stress response (15). In response to caffeine ingestion, blood pressure rate of increase appears to be highest during the first 30 min, with a smaller rise during the next 30 min, followed by a weak response after an hour (21).

Caffeine has also been well demonstrated to enhance exercise performance, although its ergogenic benefits seem highly dependent upon the duration, intensity, and mode of exercise. In the athletic arenas most closely resembling performance of the AGSM under G exposure, the literature is incomplete, but suggests caffeine ingestion may be beneficial. For example, Beck et al. (2) observed that ingestion of a caffeinated energy drink enhanced performance of a one-repetition maximum (RM) bench press, but did not improve performance of a 10-RM bench press or a 10-RM leg extension exercise, nor did it improve performance of repeated 30-s Wingate tests. However, Andersen et al. (1) observed that short distance (2000-m) rowing performance was improved after ingesting 6 mg $\cdot$ kg^{-1} bodyweight of caffeine, the improvement being most apparent within the first 500 m. Meyers and Caferelli (20) determined that ingesting 6 mg $\cdot$ kg^{-1} bodyweight of caffeine increased time to exhaustion during submaximal knee extension. In a recent meta-analysis, Warren et al. (25) concluded that caffeine is ergogenic for both strength and high-intensity muscular endurance exercise. However, they suggested that the strength benefits of caffeine ingestion may be greatest in the knee extensors, which are not primary actors in the AGSM.

TABLE I. ACCELERATION DATA MEANS (SD).

G-Profile	Variable	N	Drink Condition		
			Caffeine	Non-Caff.	Placebo
Resting	SBP (mmHg)	6	146 (8)	129 (23)	138 (17)
	DBP (mmHg)	6	74 (11)	63 (15)	72 (13)
	HR (bpm)	8	63 (12)	67 (21)	64 (15)
Relaxed Gradual Onset Run	G-level Attained	8	6.9 (1.6)*	6.0 (1.2)	6.2 (1.5)
	SBP (mmHg)	5	214 (36)	209 (40)	177 (59)
	DBP (mmHg)	5	124 (17)	114 (13)	110 (30)
	HR (bpm)	8	96 (11)	99 (14)	91 (19)
Rapid Onset Run (with AGSM)	Duration (s at 6 G)	8	15 (0)	14 (2)	15 (0)
	SBP (mmHg)	4	237 (23)	203 (43)	256 (18)
	DBP (mmHg)	4	138 (20)	124 (36)	152 (25)
	HR (bpm)	8	139 (18)	134 (21)	132 (20)
	Perceived Effort	7	6.4 (1.4)	6.4 (2.1)	6.3 (2.4)
Simulated Air Combat Maneuver (with AGSM)	Duration (s)	8	206 (131)	173 (92)	204 (102)
	SBP (mmHg)	5	252 (55)	264 (31)	243 (67)
	DBP (mmHg)	5	153 (21)	132 (21)	137 (28)
	HR (bpm)	8	151 (20)	148 (23)	146 (23)
	Max MVIC control	8	88 (23)	87 (17)	94 (24)
	MVIC at Common G	8	76 (23)	78 (28)	59 (26)**
	Perceived Effort	8	9.0 (1.7)	9.1 (1.6)	7.9 (2.1)
Arrhythmias (PVCs & bigeminis)	# of subjects with arrhythmia	8	6	3	4
	# of occurrences of arrhythmia.	8	49†	5	17

† Includes 12 bigeminis, all from 1 subject. No bigeminis were seen for the no-caffeine and placebo conditions.
* Significantly higher than the no caffeine and placebo means ($P \leq 0.05$, Fisher's LSD post hoc tests).
** Significantly lower than the caffeine and no caffeine means ($P \leq 0.05$, Fisher's LSD post hoc tests).

Caffeine-induced increases in blood pressure and heart rate, along with potential increases in muscular strength and endurance, would theoretically be beneficial for increasing G tolerance. Maximal MVIC control (pre-SACM) means did not differ among the drink conditions. MVIC during the SACM run dropped (compared to the MVIC control) by 10 to 14% under the two energy drink conditions and by 37% under the placebo condition. In general, the MVIC strength reduction during the SACM likely reflects the inability of the subjects to devote complete attention to performing MVIC due to the need to concentrate on achieving a good AGSM. The fact that the drop was less under the two energy drink conditions than under placebo suggests that caffeine (and/or the other "energy" ingredients in the no-caffeine energy drink) did have a positive effect on muscular endurance. In fact, our analysis showed that MVIC strength during the SACM was significantly higher in both of those conditions compared to placebo. Despite this finding, we did not see any statistical differences or even a trend toward differences in SACM endurance among the drink conditions. SACM endurance was the variable of primary interest for this study as that measure is strongly applicable to the air combat environment. Apparently the impact of caffeine on muscular endurance was insufficient to positively affect SACM endurance in our scenario of high-intensity muscular work.

Notably, G tolerance was significantly higher by +0.9 and +0.7 G_z during the gradual onset runs under the caffeinated energy drink condition compared to the non-caffeinated energy drink and placebo, respectively. Since the lower body muscles are relaxed during this condition and the breathing muscles are engaged for no more than normal breathing (no AGSM), the improved G tolerance is not explained by an improved stimulating effect on the voluntary muscles. However, the stimulating effect of caffeine on the cardiovascular system discussed above (7) could have contributed to the improved G tolerance during the relaxed gradual onset run. This enhanced cardiovascular response while riding relaxed was apparently mild and was not revealed by an increase in the registered blood pressure. During SACM the cardiovascular response was likely overwhelmed/masked by the voluntary increase in muscle tension and intrathoracic pressure exerted while performing the AGSM. For probably the same reason, this effect was not seen during the rapid onset runs to + 6 G_z with AGSM. However, this apparent lack of effect during the + 6 G_z rapid onset run could also be due to the fact that all but one subject reached the maximum run time of 15 s during all three conditions. In other words, the G-level may have been too low and the duration too short during the rapid onset runs to reveal potential benefits from caffeine.

Our results did not show any statistically significant differences in systolic or diastolic blood pressure among the drink conditions during either the resting or G-exposure conditions. There was a slight trend to increased systolic blood pressure during the caffeinated energy drink condition while resting before the centrifuge runs, but it was not statistically significant. Possibly, the increase in blood pressure usually associated with caffeine was not sufficient to have any further effect over the already strong baroreceptor response during increased G or when straining maneuvers were used to increase blood pressure for improved G tolerance. It is also possible

that the lack of significant results was partially a product of the reduced sample size. (Due to technical problems, we were able to measure blood pressure in only six subjects during the resting condition and in four subjects during the increased G exposures).

Surprisingly, heart rate was not significantly higher under the caffeinated energy drink condition than under the other drinks either at rest or at the various G exposures. An increased heart rate under caffeine is expected through its activation of the sympathetic nervous system both during rest and during physical activity, but this effect was perhaps overwhelmed by increased sympathetic activity due to a G-anticipatory effect before the centrifuge runs or the even stronger sympathetic activity during the hard physical work when straining maneuvers were used at increased G.

Caffeine is known to induce and increase the frequency of cardiac arrhythmias (4,9). Since arrhythmias are often seen during exposures to high G loads in the centrifuge (26), one could expect that caffeine should increase these arrhythmias at high G loads. However, we observed relatively few arrhythmias in this study (only a total of 71 occurrences during the entire 72 G exposures). The number of subjects experiencing arrhythmias and the total occurrences of arrhythmias tended to be higher under the caffeinated energy drink condition than under the non-caffeinated energy drink and placebo conditions, suggesting that caffeine may have some impact on the number of arrhythmias normally experienced during high G acceleration. Importantly, however, none of the 72 centrifuge exposures had to be stopped due to serious arrhythmias.

In addition to its physiological effects, caffeine ingestion has been observed to influence mood (16,17). In studies evaluating the administration of caffeine, especially in sleep-deprived subjects, enhanced or recovered performance is typically accompanied by a decrease in fatigue scores and an increase in vigor scores (8,16,17) compared to the effects of a placebo. Because variations in mood have been demonstrated to affect both physiological response to exercise (5) and perceived exertion during exercise (12), we suspected the caffeinated energy drink SACM trials may have been perceived as less taxing. However, we found no differences in any of the POMS factors among the caffeinated energy drink, non-caffeinated energy drink, and placebo conditions in our well-rested subjects prior to or after acceleration exposure. Nor did we observe significant differences in SACM RPE between drink conditions. The lack of significant differences in the current study between conditions for POMS fatigue and vigor may be due, at least in part, to the subjects having been well rested and in a positive, can-do state of mind for all conditions.

There are several limitations to this study, as follows. 1) A limitation common to most human centrifuge studies is the inability, due to safety concerns, to expose subjects to G levels greater then 9.0 $+G_z$. That limitation is why many protocols, including the current study, use SACM duration, rather than maximal G tolerance, as a prime parameter. Fortunately, although maximum G tolerance would be very decisive from a pure physiological perspective, SACM duration is very relevant to actual operations of high performance aircraft. 2) Another limitation is our inability to accurately measure blood pressure at high G levels. Current equipment appears unreliable above approximately 6 $+G_z$. 3) We used a randomized semibalanced design to administer the drink conditions. Unfortunately, given our relatively small starting sample, the elimination of two subjects caused the design to become unbalanced. As indicated earlier, of the eight subjects, six of them received the placebo drink in an earlier session than they received the caffeinated drink. That is, the drink condition and order of presentation were confounded. If a learning trend were present, this would influence the test for drink differences. Given the experience level of our centrifuge panelists, we are comfortable that this was not a problem for the majority of the centrifuge variables studied. However, since performing a good MVIC while simultaneously performing an AGSM may have improved with repeated trials, we cannot say with complete confidence that the increased strength seen in the caffeinated drink condition is entirely due to the drink. 4) Finally, we were limited by our inability to insure that our subjects' motivation levels were identical between trials. The SACM profile is very taxing and, although we provided the same level of encouragement for each run, internal motivation levels may have fluctuated.

Based on the results of this investigation, we conclude that ingestion of a caffeinated energy drink mildly increases relaxed G tolerance, but does not increase the effectiveness of one's AGSM under G. Aircrew should not expect to experience enhanced AGSM performance following caffeine consumption. Therefore, given the considerable strength and muscular endurance necessary to effectively perform an AGSM, fighter and trainer aircrew remain best served by maintaining a rigorous physical training program and by refining their AGSM technique.

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