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Caffeine-induced physiological arousal accentuates global processing biases

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ABSTRACT

The effects of caffeine-induced arousal on global versus local object focus were investigated in non-habitual consumers using a double-blind, within-subjects, repeated-measures design. Following an overnight fast, low caffeine consumers (N = 36; M = 42.5 mg/day caffeine) completed 5 counterbalanced test sessions (normal consumption, 0 mg, 100 mg, 200 mg, and 400 mg) separated by at least 3 days. During each session, volunteers either consumed their normal amount of caffeine or were administered 1 of 4 treatment pills. One hour later they completed two tasks assessing visual attention, in counterbalanced order. Measures of mood, salivary caffeine and cortisol were taken at multiple time points. Dose-dependent elevation of caffeine in the saliva demonstrated the experimental manipulation was effective. Furthermore, analyses of the mood and arousal measures detected consistent changes on arousal subscales and caffeine administration elevated saliva cortisol. Analyses of the visual attention tasks revealed that caffeine-induced physiological arousal produced global processing biases, after as little as 100 mg caffeine. These data suggest caffeine consumption may influence how individuals attend to and process information in their environment and could influence daily tasks such as face recognition, learning new environments and navigation, especially for those who normally consume little caffeine.

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1. Introduction

The ability to identify familiar objects in one's environment or the faces of friends and enemies depends on the ability to selectively attend to and recognize both global and local stimulus features (Kimchi, 1992). Work in the area of visual perception provides convincing evidence that focusing on global information is the dominant human strategy; that is, processing of the 'whole' is thought to precede processing of the 'parts' (Fiske and Taylor, 1991; Navon, 1977; but also see Lamb and Robertson, 1990). While there is strong evidence for this global processing bias, recent work suggests this bias can be altered by individual differences, situational constraints, age, developmental disorders, cultural norms, mood, and emotional arousal (Gasper and Clore, 2002; Kuhnen and Oyserman, 2002; Scherf et al., 2008; Yovel et al., 2005). For instance, positive moods increase focus on global features and negative moods have the opposite effect (Gasper and Clore, 2002). The effects of arousal, however, are less clear.

A large body of work suggests arousing stimuli can lead to a local focus, whereas other work suggests an aroused emotional state can lead to a global focus. Much of the work assessing attentional focus and memory biases for arousing versus neutral stimuli finds that arousal-inducing elements of a scene produce narrowing of attention and reduced memory for details (Easterbrook, 1959; Loftus, 1979; Loftus and Burns, 1982; Siegel and Loftus, 1978). In contrast, work that places participants into high or low emotional arousal states and investigates memory for neutral stimuli suggests an induced emotional arousal state leads to global processing biases (Corson and Verrier, 2007; Fiedler and Stroehm, 1986). Furthermore, recent evidence suggests excitement and other approach-oriented emotional states encourage a global focus (Brunyé et al., 2009; Gasper and Clore, 2002). Thus, there is a clear difference emerging in the literature differentiating the processing characteristics induced by arousal-inducing stimuli and the effects of heightened emotional state on processing of neutral stimuli.

The effects of physiological arousal on visual perception, specifically local versus global focus remain relatively unknown. Limited work to date suggests physiological arousal may lead to increased global focus. For example, patients with post-traumatic stress disorder (PTSD), who are characterized by heightened basal arousal levels, show advantages in global processing and disadvantages in local processing when compared to controls (Vasterling et al., 2004). In addition, when athletes perform submaximal physical exercise, they show global attentional biases and increased fluidity in switching from local to global tasks (Pesce et al., 2007).

To further elucidate the effects of physiological arousal on visual attention, the present work systematically manipulated physiological

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arousal in a dose–response fashion using caffeine (1,3,7-trimethylxanthine) and measured its effect on global versus local attention during two visual tasks. Caffeine was chosen due to its well known effects on the central nervous system (for a review, see Lieberman, 2003; Nehlig et al., 1992; Smith et al., 1994) and the prevalence of consumption in the United States (Barone and Roberts, 1996).

Caffeine occurs naturally in many foods and beverages, such as coffee, tea and chocolate, and has recently become popular as a supplement in commercially available energy drinks and food bars. In fact, caffeine is the most commonly consumed stimulant in the world. Some major coffee houses provide single 20-oz servings of beverages that contain more than 400 mg of caffeine and popular energy drinks can contain up to 505 mg caffeine in a single serving 12 oz can (McCusker et al., 2003; Reissig et al., 2009). Population surveys of consumption in the United States indicate that over 80% of adults habitually consume caffeine (average 280 mg/day; Barone and Roberts, 1996). This may be due, in part, to the fact caffeine reliably up-regulates central nervous system activity, generally resulting in increased physiological and subjective experiences of arousal, enhanced mood and improvement in vigilance and speeded responses, without substantial negative side-effects (IOM (Institute of Medicine), 2001).

There is a wealth of literature supporting the well known effects of caffeine on the central nervous system which include increased alertness, wakefulness, motivation, and motor activity, as well as increased neuronal activity (for a review, see Lieberman, 2003; Nehlig et al., 1992; Smith, 2002). Caffeine is often cited for its positive effects on attention and basic psychomotor tasks, such as simple reaction time (Wesensten et al., 2005), choice reaction time (Kenemans and Lorist, 1995; Lieberman et al., 2002b), and visual vigilance (Fine et al., 1994; Frewer and Lader, 1991; Lieberman et al., 2002b; Mitchell and Redman, 1992). Other studies have shown that caffeine can also affect higher-order visual attention and executive control (Brunyé et al., 2010; Hasenfratz and Bättig, 1992; Kenemans et al., 1999; Lorist et al., 1994; Lorist and Snel, 1997 but also see Kenemans and Verbaten, 1998; Tieges et al., 2009).

Based on previous work showing relatively large effects of emotional arousal on the processing of word lists and geometric shapes (Corson and Verrier, 2007; Storbeck and Clore, 2005; Gasper and Clore, 2002), as well as work with patients with PTSD (Vasterling et al., 2004), and athletes under conditions of submaximal physical exercise (Pesce et al., 2007), we hypothesize that physiological arousal induced by caffeine consumption will produce increased global processing biases on tasks requiring visual attention.

2. Material and methods

2.1. Design

A double-blind, repeated-measures design with four levels of caffeine (0 mg, 100 mg, 200 mg, and 400 mg) was used. The highest dose of caffeine was chosen due to its similarity to the dose of caffeine found in the 20 oz serving of coffee at a major franchise coffee house (420 mg). Treatment order was counterbalanced across participants using a Latin square design. In addition, to ensure effects of caffeine observed were not due to withdrawal, all participants were low or non-habitual consumers and completed a "normal consumption" test day in which they consumed their usual amount of caffeine prior to testing.

2.2. Participants

Thirty-six male and female volunteers between the ages of 18 and 35 years were recruited from the Tufts University student population. Their physical characteristics were age 19.1 ± 1.3 years, height 67.5 ± 3.5 in., and weight 150.3 ± 25.1 lbs (minimum 110 lb and maximum 208 lbs). All participants were low caffeine consumers (self-report of 42.5 ± 28.7 mg/day), non-smokers, in good health, did not use prescription medication other than oral contraceptives, and did not use nicotine in any form. Written informed consent was obtained, and all procedures were jointly approved by the Tufts University Institutional Review Board and the Human Use Review Committee of the U.S. Army Research Institute for Environmental Medicine.

2.3. Cognitive tests and questionnaires

2.3.1. The Hierarchical Shape Task

The Hierarchical Shape Task involved selecting one of two options that best match a single standard figure (Kimchi and Palmer, 1982). Participants viewed a target array located on the upper portion of a computer screen and two comparison arrays located below the target. One of the comparisons matched the global configuration of the target and the other matched the target's local configuration. The task was to indicate which of the two comparison arrays was more similar to the target by pressing a corresponding key. For example, a target figure could consist of either a square or a triangle (global form) made up of smaller squares or triangles (local form). Thus it was possible to perceive a single figure from either a global or a local perspective. The dependent measure was the proportion of local versus global matches selected. Participants completed 24 self-paced trials, with the global comparison and the local comparison presented an equal number of times on the left and the right side.

2.3.2. The Hierarchical Letter Task

The classic Hierarchical Letter Task (Navon, 1977) involved responding to either the globally- or locally-defined letter when presented with a large letter (e.g., A) comprised of multiple smaller letters (e.g., H). Participants were given alternating global or local goals, and were thus required to inhibit interference of the letter presented in the competing level of focus. Participants were instructed to respond either to the smaller (local) letter or the larger (global) letter by pressing designated keys on the keyboard. The dependent measure was the response time decrement that was produced as a function of performing local versus global letter determinations when letter arrays were congruent (e.g., K within K, A within A), incongruent (e.g., K within A, A within K) or neutral (e.g., K within O, O within K) across the local and global levels. Participants had up to 3000 ms to respond to a target. Each participant completed 48 trials per session.

2.3.3. Profile of Mood States Questionnaire

The questionnaire is an inventory of self-reported mood states (McNair et al., 1971). Each volunteer was asked to rate a series of 65 mood-related adjectives on a five point scale, with the instructions to respond to "How are you feeling right now?" The adjectives factor into six mood subscales (tension, depression, anger, vigor, fatigue, and confusion; McNair et al., 1981). The POMS is sensitive to a wide variety of environmental factors; sleep loss, nutritional manipulations and sub-clinical doses of various drugs (Banderet and Lieberman, 1989; Fine et al., 1994; Lieberman et al., 1996, 2002a). The POMS required about 5 min to complete.

2.3.4. Brief Mood Introspection Scale (BMIS; Mayer and Gaschke, 1988)

Participants were asked to rate their current mood and arousal state in accordance with 16 adjectives (8 positive and 8 negative) on a series of Likert scales anchored at 1 (definitely do not feel) to 4 (definitely feel).

2.4. Measurements and calculations

Saliva was collected for analyses of caffeine and cortisol (the most accepted biomarker of arousal; Kirschbaum and Hellhammer, 1989).

Participants were instructed to rinse their mouth at least twice with water and then spit through a straw into a saliva collection tube. They were instructed to avoid touching the mouth of the tube with their hands. Samples were immediately aliquoted and stored at −70 °C until they were assayed for cortisol and caffeine using standard ELISA procedures.

Saliva cortisol was assessed using the Salimetric® High Sensitivity Salivary Cortisol Enzyme Immunoassay Kit (Salimetrics, LLC, State College, PA) which has a published sensitivity of <0.003 μg/dL. The published intra-assay mean for low replicates is 0.097 μg/dL with a standard deviation of 0.004 μg/dL and a coefficient of variation 3.65%. The published intra-assay mean for high replicates is 0.999 μg/dL with a standard deviation of 0.033 and a coefficient of variation 3.35%. The published inter-assay mean for low replicates is 0.101 μg/dL with a standard deviation of 0.006 μg/dL and a coefficient of variation 6.41%. The published inter-assay mean for high replicates is 1.020 μg/dL with a standard deviation of 0.038 μg/dL and a coefficient of variation 3.75%.

Saliva caffeine was assessed on a Synchron CX® Systems analyzer (Beckman Coulter, Inc, Brea, CA) using a Syva® Emit® Caffeine Enzyme Immunoassay Kit (Siemens Healthcare Diagnostics Inc., Newar, DE) which has a manufacturer-reported sensitivity of <0.05 μmol/L. The manufacturer-reported intra-assay mean for low replicates is 6.9 μg/mL with a coefficient of variation of 4.9% and the mean for high replicates is 7.0 μg/mL with a coefficient of variation of 3.2%. The manufacturer-reported inter-assay mean for low replicates is 11.0 μg/mL with a coefficient of variation of 4.2% and manufacturer-reported inter-assay mean for high replicates is 11.0 μg/mL with a coefficient of variation 3.6%.

2.5. Caffeine or placebo administration

In order to control for taste, caffeine or placebo was administered in capsule form. Each treatment dose was administered in an identical color, size, weight and shape capsule. Capsules contained 0 mg, 100 mg, 200 mg, or 400 mg of caffeine. Placebo capsules were filled with physiologically-inert microcrystalline cellulose powder, which was also used as filler material in the two lower-dose caffeine capsules. The caffeine was 99.8% pure anhydrous USP-grade powder. Capsules were provided by a Registered Pharmacist at Compounded Solutions, Monroe, CT.

2.6. Procedure

Participants completed all four treatment conditions and the normal consumption day on separate days. Volunteers and investigators were blind to the experimental treatment. There was a minimum three day washout period between test sessions. Participants were instructed not to eat or drink anything (with the exception of water) after 9:00 PM the night before a test session and not to use any over-the-counter medications or herbal supplements 24 h prior to testing. Participants were asked to get a normal night sleep prior to testing days, but sleep was not controlled or reported. During the normal consumption day, participants were allowed to consume their normal amount of caffeine prior to arrival for testing.

When participants arrived in the morning (between 8:00 and 9:00 AM) a baseline saliva sample was collected and the questionnaires were administered. Participants then consumed a capsule that either contained a specified dose of caffeine or placebo along with a cup of water. Sixty minutes after consuming the capsule, participants provided a second saliva sample, completed a second set of questionnaires, and began the cognitive tests. Sixty minutes after the second saliva sample, volunteers then provided a final saliva sample, and completed the questionnaires. The testing sequence was identical for each of the treatment conditions.

2.7. Statistical analyses

Analyses of the mood and arousal questionnaires and saliva measures was conducted using an Analyses of Variance (ANOVA) with Treatment (0 mg, 100 mg, 200 mg, and 400 mg) and Time (baseline, 60 min post consumption and 120 min post consumption) as within-participant variables. Analyses of the cognitive tasks consisted of repeated measures ANOVA with Treatment (0 mg, 100 mg, 200 mg, and 400 mg) as a within-participants variable. An effect was deemed statistically significant if the likelihood of its occurrence by chance was $p \leq 0.05$. When an ANOVA yielded a significant main effect, post-hoc tests using the Bonferroni correction were conducted with significance level again set at $p<0.05$. All statistical analyses were performed using SPSS 12.0. Results are given for only those analyses yielding significant effects.

3. Results

3.1. Salivary caffeine

Analyses of salivary caffeine revealed main effects for Treatment $F(3,105)=67.88$, $p<0.01$ and Time $F(2,70)=101.23$, $p<0.01$. Salivary caffeine (ug/mL) was significantly different for each treatment (0 mg $\bar{x}=0.23$, SEM = 0.08; 100 mg $\bar{x}=0.94$, SEM = 0.11; 200 mg $\bar{x}=1.69$, SEM = 0.17; 400 mg $\bar{x}=2.94$, SEM = 0.25). Salivary caffeine (ug/mL) was also significantly different for each time point (baseline $\bar{x}=0.14$, SEM = 0.03; 60 min. $\bar{x}=2.39$, SEM = 0.20; 120 min. $\bar{x}=1.82$, SEM = 0.16). Analyses also revealed a Treatment by Time interaction $F(6, 210)=41.76$, $p<0.01$, such that salivary caffeine remained constant across time points in the placebo condition, whereas in the caffeine conditions, salivary caffeine increased 60 min post capsule consumption and starts to decline 120 min post capsule consumption (see Fig. 1).

3.2. Salivary cortisol

Analyses of salivary cortisol (ug/dL) revealed a main effect for Time $F(2,70)=40.80$, $p<0.01$, such that cortisol was significantly different for each time point (baseline $\bar{x}=0.39$, SEM = 0.04; 60 min $\bar{x}=.26$, SEM = 0.03; 120 min $\bar{x}=.18$, SEM = 0.02). Analyses also revealed a Treatment by Time interaction $F(6,210)=3.06$, $p<0.01$, such that cortisol (ug/dL) declined less throughout the morning in the 400 mg caffeine condition (see Fig. 2). Cortisol levels typically decline over the day (Kirschbaum and Hellhammer, 1989).

3.3. Mood and arousal questionnaires

Four subscales were derived from the BMIS corresponding to energetic, tired, happy, and sad. Analyses revealed a Treatment by Time interaction for energetic $F(3,105)=5.57$, $p<0.01$, such that

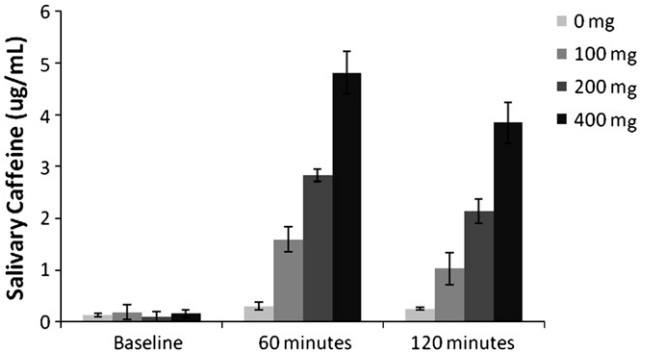

Fig. 1. Salivary caffeine (ug/mL) at each time point.

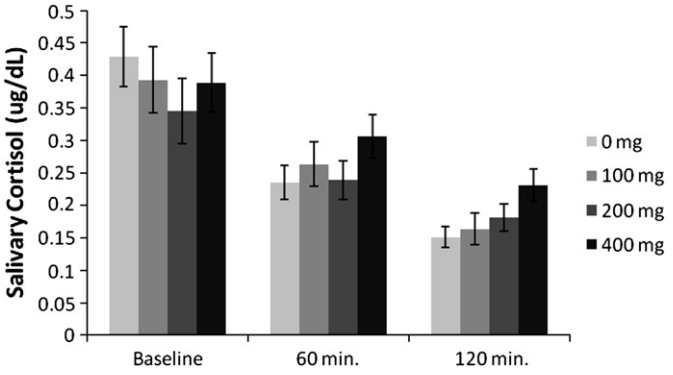

Fig. 2. Salivary cortisol (ug/dL) at each time point by caffeine condition.

volunteers felt more energetic 60 min after consuming 100 mg and 400 mg caffeine compared to placebo.

The POMS was analyzed using the six mood subscales corresponding to tension, depression, anger, vigor, fatigue, and confusion. Analyses of the tension/anxiety subscale revealed main effects for Treatment $F(3, 105) = 5.791$, $p < 0.01$ and Time $F(2, 70) = 5.355$, $p < 0.01$. Tension/anxiety was higher following 400 mg compared to 0 mg or 100 mg (0 mg $\bar{x} = 2.57$, SEM = 0.68; 100 mg $\bar{x} = 2.51$, SEM = 0.65; 200 mg $\bar{x} = 3.86$, SEM = 0.89; 400 mg $\bar{x} = 4.75$, SEM = 0.91); it was also higher at 120 min post treatment compared to baseline or 60 min post treatment (baseline $\bar{x} = 2.861$, SEM = 0.67; 60 min $\bar{x} = 3.132$, SEM = 0.708; 120 min $\bar{x} = 4.271$, SEM = 0.822).

Analyses of the vigor subscale revealed a main effect for Treatment $F(3, 105) = 4.582$, $p < 0.01$, such that vigor was higher after 100 mg and 400 mg compared to 0 mg (0 mg $\bar{x} = 6.68$, SEM = 0.85; 100 mg $\bar{x} = 8.86$, SEM = 1.07; 200 mg $\bar{x} = 8.05$, SEM = 0.85; 400 mg $\bar{x} = 8.81$, SEM = 0.94). Analyses also revealed a Treatment by Time interaction $F(6, 210) = 2.388$, $p < 0.05$, such that vigor declined throughout the morning in the 0 mg condition and not the caffeine conditions (see Fig. 3). Conversely, analyses of the fatigue subscale revealed a Treatment by Time interaction $F(6, 210) = 4.280$, $p < 0.01$, such that fatigue declined throughout the morning in the 200 mg and 400 mg caffeine conditions but not in the 0 mg condition.

3.4. Cognitive tasks

Analyses from the hierarchical shape task reveal a main effect of treatment $F(3,105) = 6.98$, $p < 0.01$, thereby demonstrating a significant global processing bias with all doses of caffeine starting at 100 mg, as compared to placebo (See Fig. 4).

Analyses of the hierarchical letter task revealed a main effect of stimulus type (congruent, incongruent or neutral), such that response times were fastest when a congruent stimulus was presented ($F(2, 70) = 4.08$, $p < 0.05$), however, stimulus type did not interact with treatment or focus. A main effect of focus instruction (global versus local) $F(1, 35) = 106.95$, $p < 0.01$, showing a significant global processing bias (RT Global $\bar{x} = 332.64$, SEM = 11.30; RT Local $\bar{x} = 456.33$, SEM = 13.75) was also observed. In addition, a treatment by focus interaction was present ($F(3,105) = 3.877$, $p < 0.05$), such that response times with a global goal decreased with caffeine but response times for a local goal remained unchanged (see Fig. 5).

To confirm that these results are not attributable to caffeine withdrawal effects, *t*-tests were conducted to compare performance on the normal consumption day and the 0 mg day for both the hierarchical shape task and the hierarchical letter task. No significant differences were found.

3.5. Predicting global focus from arousal alterations

To assess whether caffeine-induced arousal is a reliable predictor of global perceptual focus, we conducted a series of four simple linear regressions. In each regression, we used POMS subscale difference scores that subtracted 0 mg from 400 mg subscale scores at 60 min $[(400\ mg_{60\ min}) - (0\ mg_{60\ min})]$; these scores were used to predict difference scores indicating increased global focus at 400 mg versus 0 mg caffeine $[(400\ mg_{global}) - (0\ mg_{global})]$. Two regressions were conducted using data from the fatigue subscale, one for the hierarchical letter and one for the hierarchical shape task; the same was done for data from the vigor subscale.

Data from the fatigue subscale revealed that individuals with more pronounced caffeine-induced fatigue decreases tended to show the largest increases in global focus; this inverse trend was most pronounced with the hierarchical letter task, $\beta_{std} = -.20$, $R^2 = .04$, relative to the hierarchical shape task, $\beta_{std} = -.09$, $R^2 = .01$; neither analysis reached statistical significance. Similarly, data from the vigor subscale revealed that individuals with more pronounced caffeine-induced vigor increases tended to show the largest increases in global focus; this trend was evident with the hierarchical letter task, $\beta_{std} = .09$, $R^2 = .01$, and the hierarchical shape task, $\beta_{std} = .08$, $R^2 = .02$. We note that these results should be interpreted with caution given the relatively large sample sizes required to adequately detect predictive value in the current experimental design (i.e., Hsieh et al., 1998).

4. Discussion

The present study examined the effects of a range of caffeine doses (0–400 mg) on attentional biases in the perceptual analyses of objects using hierarchical letter (i.e., Navon, 1977) and pattern (i.e., Kimchi and Palmer, 1982) stimuli. Converging evidence from the physiological

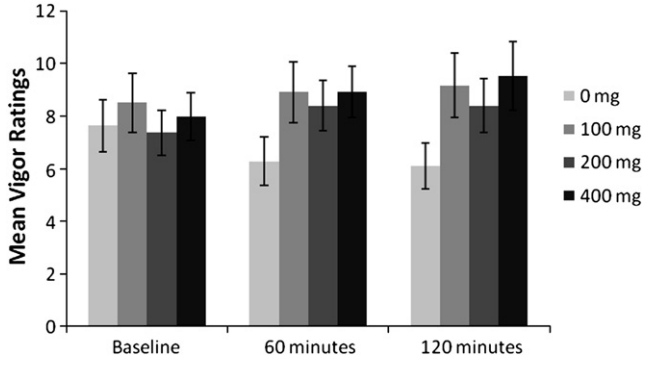

Fig. 3. Mean ratings and SEM for Vigor subscale on POMS by time for each caffeine treatment.

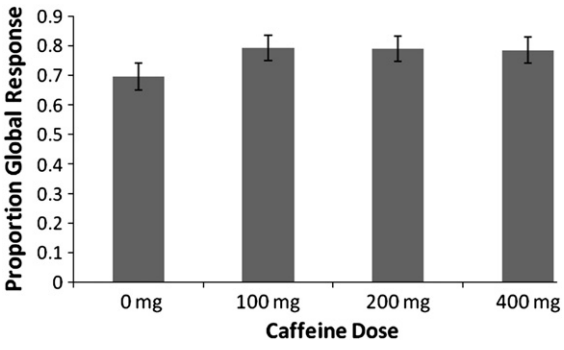

Fig. 4. Response times (ms) and SEM for Global and Local stimuli for each caffeine condition during the hierarchical shape task.

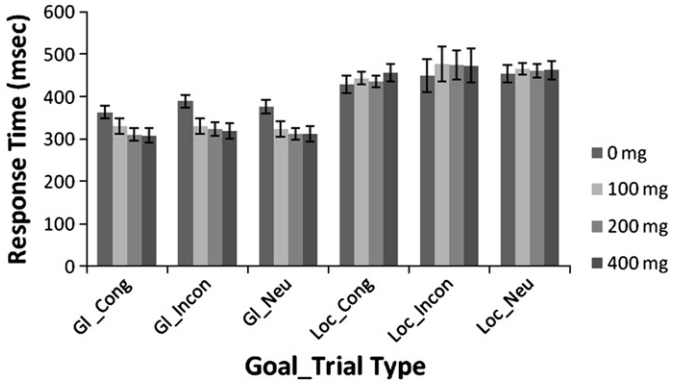

Fig. 5. Response times (ms) and SEM for Global and Local stimuli by trial type for each caffeine condition during the hierarchical letter task.

marker of arousal, i.e. cortisol, self-report questionnaires, and visual processing tasks demonstrated that caffeine intake elicits reliable increases in arousal and, in turn, increased global processing biases. Specifically, participants experienced higher arousal levels and greater global processing biases after consuming as little as 100 mg of caffeine.

Analyses of the mood and arousal measures confirmed caffeine significantly influenced subjective and physiological arousal as demonstrated by consistent changes on arousal subscales of both the POMS and BMIS and elevated salivary cortisol. The dose-dependent elevation of caffeine observed in the saliva demonstrates the experimental manipulation was effective. First, the effectiveness of the arousal manipulation was validated by results from both the BMIS and the POMS. As expected, when volunteers consumed caffeine, regardless of dose, they reported more energy and less fatigue throughout the morning. They also reported significantly more tension/anxiety at the highest dose of caffeine compared to placebo or the 100 mg dose. These results are consistent with previous work reporting that caffeine increased the perception of alertness and wakefulness (Amendola et al., 1998; Leatherwood and Pollet, 1982; Rusted, 1999) and sometimes anxiety at higher doses (Lieberman, 1992; Loke et al., 1985; Sicard et al., 1996). In addition, analyses of salivary measures provided further support. As expected, salivary caffeine was significantly higher 60 min post consumption in the caffeine conditions which is consistent with previous work showing peak plasma concentrations of caffeine occur in as few as 15 min and on average approximately 45 min after ingestion (Arnaud, 1987; Smith, 2002). Further, in the caffeine treatment conditions salivary cortisol levels were significantly higher following caffeine, with the highest dose of caffeine producing the greatest increase in cortisol. Elevated salivary cortisol confirms that physiological arousal was induced by caffeine administration. Increased release of the hormone cortisol is the most widely accepted biological marker of activation of the hypothalamus–pituitary–adrenal axis (HPA) in humans (Laudat et al., 1988; Kirschbaum and Hellhammer, 1989). Furthermore, greater cortisol release at the highest dose is consistent with previous work suggesting consumption of caffeine typically results in increased cortisol release (al'Absi and Lovallo, 2004), especially in non-habitual consumers given moderate or high doses of caffeine (Lovallo et al., 2005).

Analyses of the visual attention tasks support the hypothesis that caffeine-induced physiological arousal produces larger global processing biases. This occurred after participants consumed as little as 100 mg of caffeine. A well-validated hierarchical shape task was used (Kimchi and Palmer, 1982) which involved selecting one of two options that best matched a single standard figure. Each standard figure (e.g., a square) was comprised of congruent smaller geometric figures (e.g., triangles). The two choice options matched either the global (e.g., a square made of triangles) or local (e.g., a triangle made of squares) geometry of the standard figure. Results from the present study support earlier work showing that the majority of time, participants choose the global rather than local matching option, suggesting perception of visual stimuli is dominated by configural form (i.e., Kimchi and Bloch, 1998). When participants consumed placebo they responded with a response pattern indicating a global matching bias (i.e. higher proportion of global responses). In addition, the present work shows that when participants consumed as little as 100 mg caffeine this global bias became more pronounced. While the hierarchical shape task cannot directly assess visual perception processes, it allows for insights into how information processing and decision making may be affected by physiological arousal.

In addition to the hierarchial shape task, the study incorporated a more direct test of early visual perception, a classic hierarchical letter task (Navon, 1977). This task involved responding to either the globally- or locally-defined letter when presented with a large letter (e.g., A) comprised of multiple smaller letters (e.g., H). Participants were given alternating global or local goals, and were thus required to inhibit interference of the letter presented in a competing level of focus. As with the hierarchical shape task, the letter task showed participants developed an increased global bias with caffeine, beginning with a dose as little as 100 mg. Specifically, the data demonstrated the expected main effects of stimulus type (congruent, incongruent and neutral) and goals (global versus local). Participants responded more quickly to congruent stimuli and had higher overall response times with local relative to global goals. These results are in agreement with previous work showing participants identify global letters faster in the face of local interference, and identify local letters slower in the face of global interference; thereby suggesting a larger 'spotlight' of visual attention facilitates global letter identification (with less interference presented by local letters), and conversely a smaller spotlight facilitates local letter identification (Kinchla et al., 1983; Lamb and Robertson, 1988, 1990). In addition, our results show that goals interacted with caffeine consumption, such that when participants consumed caffeine, regardless of dose, response times decreased with a global goal, but remained unchanged with a local goal. Thus caffeine consumption increased the inherent selective processing bias towards global goals.

Taken together, data from both the manipulation checks and the visual perception tasks support the hypotheses caffeine-induced physiological arousal, regardless of dose administered, produces selective processing biases towards global features exceeding that observed during normal physiological functioning. These finding support and extend previous work suggesting emotional arousal leads to global processing biases (Brunyé et al., 2009; Corson and Verrier, 2007). It should be noted that effects in the present study occurred after as little as 100 mg and higher doses did not significantly alter that effect. The lack of a dose response effect in this study may be due to the fact that reaching asymptotic performance occurs at lower doses in participants with lower consumption profiles. Participants in the present study were not habitual caffeine consumers. It is likely that those who do not normally consume caffeine exhibit effects even after relatively low doses and higher doses do not change the process beyond that effect. In fact asymptotic effects of caffeine are not unusual (i.e., Lieberman et al., 1987; Robelin and Rogers, 1998). Finally, by testing only non-habitual consumers and comparing data between a normal consumption day and the placebo day we were able to determine that the observed effects were due to caffeine consumption, rather than withdrawal.

The mechanism by which caffeine may influence global versus local processing is unknown. One potential mechanism may involve up-regulation of the right hemisphere through increases in norepinphrine and serotonin following caffeine consumption. Evidence for this potential mechanism comes from work showing that; (1) the right hemisphere is biased towards global processing, (2) arousal up-regulates the right hemisphere through increased release of norepinephrine and

serotonin, and (3) caffeine acts on serotonergic and noradrenergic neurons, with limited work suggesting it may affect the left and right hemispheres differentially.

There is evidence that specialized functions may exist in the left and the right hemispheres for the level of detail to which attention is allocated. This evidence comes from behavioral, patient, and functional neuroimaging studies suggesting the cerebral hemispheres play asymmetric roles in attending to global versus local aspects of an object's shape, such that the right hemisphere is biased toward global processing and the left for local processing (Fink et al., 1997; Kimchi and Merhav, 1991; Martinez et al., 1997; Robertson and Delis, 1986; Robertson et al., 1988; Sergent, 1982; Weissman and Banich, 1999; Yamaguchi et al., 2000). For example, when healthy adults perform a visual search task using stimuli of large letters made of small identical letters presented in the right, left, or central visual field, there is left-field superiority when a decision has to be made on a large (global) letter alone, and a right-field advantage when a small (local) letter has to be processed (Sergent, 1982).

Also, as noted above, it has been suggested that the arousal system may be particularly influential in the right hemisphere (Tucker and Williamson, 1984; Paus et al., 1997). For example, examinations of the time course of brain activity changes during a 60-minute vigilance task indicate cerebral blood flow decreased only in the right hemisphere as a function of time on task, a change hypothesized to be related to a decrease in arousal state (Paus et al., 1997). Experimental data showing asymmetries in brain norepinephrine (NE) and serotonin activity also support the idea that there may be a greater right hemisphere influence of the arousal system (Arato et al., 1991; Denenberg, 1981; Pearlson and Robinson, 1981; Robinson, 1979). For example, post-mortem studies of the thalamus have shown higher right- than left-hemisphere NE levels in both rats and humans (Oke et al., 1978, 1980) and postmortem neurochemical investigations show higher serotonin metabolite (5-HIAA) content in the right compared to the left hemisphere (Arato et al., 1991).

Data supporting the notion that caffeine, itself, differentially affects the right and left hemispheres is limited (Barry et al., 2005; Lorist and Snel, 1997), so future work is needed to address this issue and determine if any effects observed are influenced by normal consumption habits.

In summary, these results provide converging evidence that caffeine reliably produces changes in physiological arousal, and that arousal whether emotional (as indicated in previous work; Corson and Verrier, 2007, Payne et al., 2002) or physiological, produces consistent and pronounced increases in global biases in human perception of neutral stimuli. This is potentially due to up-regulation of activity in the right hemisphere following caffeine consumption resulting from increased levels of serotonin and/or norepinephrine there. These results add to a growing body of literature demonstrating that the perceptual salience of local versus global features is not predetermined and fixed. Rather, many psychological or physiological variables may alter the local versus global focus. Approximately 80% of the U.S. population regularly consumes coffee and caffeine. The doses administered in this study can be found in servings of many commercially available products in the United States (McCusker et al., 2003; Reissig et al., 2009). Therefore, the results of this study may have significant implications for the manner in which caffeine consumers attend to and process information in their environment. Daily tasks such as face recognition, studying, test-taking, learning new environments, and spatial navigation may be altered by caffeine consumption, especially for those who normally consume little caffeine.

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