HUMAN PSYCHOPHARMACOLOGY
Hum Psychopharmacol Clin Exp 2003; **18**: 351–359.
Published online 21 May 2003 in Wiley InterScience (www.interscience.wiley.com). **DOI**: 10.1002/hup.501

Effect of caffeine on prospective and retrospective duration judgements

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The effects of caffeine on prospective and retrospective duration judgements were evaluated in a double-blind placebo-controlled experiment. After taking either 200 mg caffeine or a placebo, participants touched a 17-sided polygon for 15 s. Then they verbally estimated the number of angles and the duration. Participants in the prospective group were told in advance they would be making a duration estimate, whereas those in the retrospective group were not told. Caffeine reduced duration estimates in the prospective condition but not in the retrospective condition. The effect of caffeine on very long duration comparisons (the past year compared with a year at one-half and one-quarter of one's age) was also evaluated, but none was found. The findings do not support the hypothesis that caffeine affects duration experience by increasing the internal clock rate as a result of its dopamine D_2 agonist properties. The hypothesis that caffeine produces its effect by enhancing memory was considered and rejected. The most parsimonious explanation is that caffeine increased arousal level, which led to a narrowing of the focus of attention to the most salient task.

KEY WORDS — caffeine; duration judgement; attention

INTRODUCTION

The ability to estimate short durations, on the order of seconds, is important in many everyday situations. If we are engaged in conversation and estimate that the other person has been talking for a relatively long time, we may attempt to interrupt that person. If we are approaching a railroad crossing and estimate that the approaching train has not travelled very far in what seems like a relatively long time, we may attempt to outrace the train. Caffeine, perhaps the most widely used drug in the world and undoubtedly the most widely used stimulant, may influence a person's ability to estimate short durations and to respond to environmental stimuli in adaptive ways.

Cholinergic and noradrenergic effects of caffeine

Caffeine has certain cholinergic effects (reviewed by Fredholm *et al.*, 1999). Its most important consequence is its adenosine antagonism leading to cholinergic stimulation. It attenuates scopolamine induced memory impairment in humans for both short and long term memory (Riedel *et al.*, 1995). It also overcomes age related changes in cognitive function caused by declining changes in information processing (Horgervorst *et al.*, 1998). Habitual caffeine consumption is also related to better long-term memory (Hameleers *et al.*, 2000).

Caffeine also appears to have a noradrenergic site of action. For example, its anxiogenic effect was reversed by propranolol (Baldwin and File, 1989). However, the role of caffeine on duration judgement via its noradrenergic effect seems to be less significant than its cholinergic effects. Rammsayer *et al.* (2001) noted that noradrenergic activity did not seem to play a critical role in temporal information processing in humans (at least in the range of milliseconds).

Caffeine and time estimation (duration judgement)

The physiological and psychological effects of caffeine have been extensively studied (Snel and Lorist, 1998; Spiller, 1998). A few older studies

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Received 17 October 2002
Accepted 17 March 2003

investigated influences of caffeine on various aspects of time (Sterzinger, 1938; Joerger, 1960; Kostenko, 1968), but no researchers have reported an effect on duration judgement until recently. Caffeine in low doses was found to enhance the performance of monkeys in a temporal response differentiation task (Buffalo *et al*., 1993). However, caffeine did not affect the ability of humans to estimate very short durations up to 1 s (Gourevitch and Yanev, 1979). Recently, Botella *et al*. (2001) reported that women who drank 300 mg of caffeine made shorter reproductions of a 10 s duration than did women who drank a placebo, but the same caffeine dose did not affect men's reproductions. This finding is consistent with the notion that caffeine lengthened the females' experienced duration of the reproduction interval (or shortened their remembered duration of the target interval), although the interpretation of these findings is unclear. The finding that caffeine did not affect males' reproductions of the 10 s duration is also unclear. One additional pertinent finding is that Stine *et al.* (2002) noted that low daily consumption of caffeine enhances the accuracy of time estimation in humans.

Dopamine, adenosine and GABA neurotransmission

Any effects of caffeine upon psychological time may possibly be attributable to its agonistic effect on dopamine D_2 receptors (Fuxe *et al*., 1998). Enhanced dopaminergic neurotransmission would, in theory, alter the pacemaker of a hypothetical internal clock (Treisman *et al*., 1992; Meck, 1996). Since amphetamine and methylphenidate are dopamine agonists it can be conjectured that the effects of caffeine on duration judgement should be similar to those drugs. Based on studies involving those drugs (Hicks, 1992), caffeine should produce an increased subjective time rate.

Caffeine may, however, also produce an effect opposite to that of its dopamine D_2 agonist effect (Botella *et al*., 2001). Caffeine is also known to affect adenosine A_{2A} receptors), which affect GABA transmission in an opposite way from that of dopamine D_2 receptors (Beauregard and Ferron, 1991; Shi *et al*., 1993; Concas *et al*., 1995; Zahniser *et al*., 2000). This effect on GABAergic neurotransmission may reduce the rate of the pacemaker of an internal clock. Depending upon the balance between the activities of these two mechanisms by which caffeine affects neurotransmission, caffeine may increase a person's subjective time rate, decrease it, or not affect it. These opposing cerebral effects of caffeine may account for opposite results at different doses, especially when attentional resources are considered (Frewer and Lader, 1991).

Arousal, attentional resources and prospective time estimation

Caffeine both increases general arousal and enhances attention (Smith and Tolla, 1998). According to an attentional-gate model (Zakay and Block, 1996), which includes a pacemaker and emphasizes the role of attention, heightened arousal increases the pacemaker rate of a person's internal clock (i.e. subjective time rate). The effects on time estimates depend on the duration judgement paradigm and on the duration estimation method. The main effects are expected to occur in what is called the *prospective paradigm*, in which a person knows in advance that he or she will need to estimate a duration (Block *et al*., 1998; Zakay and Block, 1996). Prospective timing requires that a person divide attentional resources between nontemporal (stimulus) information processing and temporal information processing. The attentional-gate model makes specific predictions about a prospective situation in which either the pacemaker rate increases or available attentional resources increase (such as under the influence of caffeine): More pulses are accumulated if either the pacemaker produces more pulses per second or if a person has more resources to allocate to temporal information processing (i.e. attending to time), and the attentional gate allows more pulses to pass through to the accumulator. Consider the effects on different duration-judgement tasks. If a person experiences target interval (TI) and then is asked to give a verbal (numerical) estimate of it, the estimate should be larger than in a control condition. The inverse effect typically occurs if the method of production is used, in which a person actively delimits an interval to estimate a verbally stated one, such as 10 s. If the method of reproduction is used, a person experiences a TI and then attempts to actively delimit an interval that is subjectively equal to it. In this case, if information-processing demands are comparable during the TI and during the reproduction, neither increased pacemaker rate nor increased attentional resources should affect the magnitude of the reproduction, because pulse accumulation is increased during both time periods.

Memory, recall and retrospective time estimation

Unless there are also effects of caffeine on memory, the effects of increased pacemaker rate should be minimal in what is called the *retrospective paradigm*, in which a person does not know until after the duration has ended that he or she will be estimating the duration. The potential impact of caffeine on retrospective duration estimates is speculative because no studies have been done with dopamine agonists in the retrospective paradigm. However, caffeine is known to improve memory slightly (Smith *et al.*, 1997; Smith and Tolla, 1998), and because retrospective timing involves memory (Block, 1990) a small effect of caffeine upon retrospective judgement is expected. If a person experiences events under the influence of caffeine, he or she may later estimate or verbally reproduce it as being longer (compared with a placebo condition) because more events or contextual changes were remembered. Predictions based on the effect of caffeine on recall are difficult, however, because dose-related effects are sometimes found. In low doses caffeine may improve recall (Smith *et al.*, 1993), but in high doses caffeine may interfere with access or retrieval of reference information in long-term memory (Thor, 1986).

Purpose of study

The purpose of this study was to test the effects of caffeine on duration estimates involving two widely different ranges. The short test interval chosen was 15 s, a commonly used interval when studying duration judgements (Zakay, 1993), as well as an interval within the range thought to be governed by the internal clock involved in prospective timing. Also investigated was retrospective duration estimation in order to assess effects on memory. Finally, participants were asked to make a very long-term duration comparison of the present year to a year when they were one-quarter or one-half their current age. Although lacking the rigor and exactitude of short-term duration judgements (seconds to minutes), several researchers have investigated these very long-term retrospective estimates on a time scale of years (Gallant *et al.*, 1991; Lemlich, 1975; Walker, 1977). These types of estimates do not involve an internal clock, but they may involve recall processes that caffeine may affect (Smith *et al.*, 1993).

METHOD

Participants

Participants were 25 males and 81 females who volunteered for the experiment. They ranged from 18 to 81 years old ($M = 45.8$). Each participant was randomly assigned to one of four experimental conditions in a 2×2 factorial design. This was done separately for males and females.

Methods and procedure

Participants were told that they were participating in an experiment testing the effect of caffeine on a tactual performance task. They were queried as to weight, age and caffeine (coffee, tea and cola) intake. Caffeine intake was recorded as cups/day of espresso coffee, tea and cola.

Participants were given a pill (200 mg caffeine or a placebo) and were instructed to take it 1 h prior to their arrival on another day. Because the cognitive effects of caffeine can vary with time of day (Anderson and Revelle, 1994; Kelemen and Creeley, 2001), all testing was conducted at approximately the same time of day (the afternoon). Participants were also instructed to abstain from caffeine for 4 h prior to the experiment and to not eat or drink anything for 1 h before arriving.

Upon arrival, participants were asked to take a test of impulsivity (30-item Barratt impulsiveness scale, or BIS; Patton *et al.*, 1995). Previous research has shown that an individual's level of impulsivity can influence caffeine's cognitive effects (Anderson and Revelle, 1994). Therefore, participants' impulsivity scores were included for a possible covariate in the statistical analyses.

The apparatus used for the duration-judgement task was similar to that of Zakay (1993). It consisted of a wooden box ($20 \times 40 \times 40$ cm) with an opening (12×8 cm) through which the participant could place his or her hand. The box was located in a quiet, lighted room. A 17-sided polygon (all sides of different length and identical to that used by Zakay) was presented in 1 cm relief on a 10×10 cm cardboard card. The task was to determine, using touch alone, the exact number of angles of the polygon. A relief of a circle and ellipse (for practising) was located on the side of the box. A small, red light bulb was located on the top of the box, and a buzzer was located in the back of the box, both of which were under the control of the experimenter who also had a timer.

Participants were told that within the box there was a relief of a polygon and that their task was to count as accurately as possible the number of angles. They were instructed to perform the task with the index finger of their dominant hand, and they were asked to place their non-dominant hand beneath the table. (This was intended to keep them from looking at their watches.)

Each participant was presented with two consecutive intervals. The first interval, a practice interval, lasted for 10 s, and it was marked by the lighting of the red bulb during which time participants could practice feeling the reliefs on the side of the box. The onset and termination of the practice interval was demarked by the onset and termination of the red light. Participants were told that during the lighting of the red light bulb they could practice recognizing shapes by touching reliefs of a circle and an ellipse placed outside the box.

After the light was extinguished, participants received further instructions that varied according to the experimental group. Participants in the prospective condition were told to determine the number of angles after hearing the first buzz, and at the sound of the second buzz that they would have to judge the 'length of time' that their hand was in the box. The phrase *length of time* was repeated and emphasized so that there was no doubt that they were going to be asked to estimate the duration. (These instructions were emphasized because the pilot study suggested that some prospective participants forgot that they were given instructions to estimate duration.) Participants in the retrospective paradigm were told to determine the number of angles, but no mention of duration was made. For both prospective and retrospective conditions, the TI was 15 s, during which the tactual task was performed. The onset and termination of the TI was demarked by two buzzes (each 0.5 s).

Following removing their hands from the box, participants estimated the total number of angles. Then they made duration estimates on paper that contained two parallel 26 cm horizontal lines separated by 3 cm. The left half (13 cm) of the upper line was a thick 1 mm bold face line (representing a duration of 10 s) whereas the right half was thin. The entire lower line (along which the estimate of the TI was to be drawn) was thin. The length of lines provided equal probabilities for the participants to mark the second interval as longer or shorter than the standard interval. Those few participants who wanted to indicate a duration greater than the entire length of the bottom line (representing 20 s) were permitted to draw a third line parallel to the second line. They were told that the 13 cm bold section on the upper line represented a duration of 10 s. They were asked to mark a line length on the lower line that represented the duration of the TI. Finally, they verbally estimated the duration of the TI in seconds.

Immediately following completion of the short-term duration judgement, all participants received a test of very-long-term retrospective duration comparison (Gallant *et al.*, 1991). They were asked the following questions:

> Did one year seem to pass more rapidly or more slowly when you were one-half your present age? Using 12 subjective units (as in 12 months per year) as the standard for the length of one year right now, how long did one year seem to be when you were one-half your present age [referred to hereafter as *half-age*]? If the time seemed to pass more slowly when you were younger assign a number larger than 12. If one year seemed to pass more quickly when you were younger, your estimate should be less than 12.

The first question served as a validity check for the response to the second question:

> Did one year seem to pass more rapidly or more slowly when you were one-quarter your present age? Using 12 subjective units (as in 12 months per year) as the standard for the length of one year right now, how long did one year seem to be when you were one-quarter your present age [referred to hereafter as *quarter-age*]?

Statistical analysis

Data on the estimate of number of polygon angles, the verbal estimate of duration, the analogue estimate of duration, and the very long-term duration comparison were analysed by conducting separate $2 \times 2 \times 2$ (drug $\times$ paradigm $\times$ sex) factorial analyses of variance (ANOVAs). Additional t tests were used or planned comparisons of interest. Unless a nonsignificant effect ($p > 0.05$) is particularly important, only the significant effects and interactions are reported, and for each significant effect, the effect size, d, is reported. Cohen (1977) called $d = 0.2$ a small effect, $d = 0.5$ a medium effect and $d = 0.8$ a large effect. Because some of the measured variables were correlated, a multiple-regression analysis was conducted to identify the significant predictors of verbal estimates of duration.

RESULTS

The participants' mean weight was 144.4 pounds ($SD = 33.3$). Their mean caffeine consumption was 1.66 cups/day ($SE = 0.14$). Using approximations from the Center for Science in the Public Interest (1997; see also Stine *et al.*, 2002), the number of milligrams of caffeine per day was calculated by assuming that a cup of espresso contains 170 mg, a cup of coffee contains 120 mg, a cup of tea contains 46 mg, and a cup of cola contains 45 mg. The overall mean reported caffeine consumption was 201.5 mg/day (*SE* = 17.4). The overall mean reported caffeine consumption was 201.5 mg/day (*SE* = 17.4). The participants' mean BIS score was 59.9 (*SE* = 1.0). Their overall mean estimate of number of angles was 9.63 (*SE* = 0.11), which is an underestimate of the actual number (17). On these measures, there were no significant effects or interactions of the different conditions (all $F_{(1,98)} < 1.16$, $p > 0.28$).

Verbal estimate of duration

The mean verbal estimate of duration (along with the standard error of the mean) in each combination of duration-judgement paradigm and drug condition is shown in Figure 1. The effect of drug condition was significant: Estimates were larger in the placebo condition than in the caffeine condition ($F_{(1,98)} = 6.10$; $p = 0.02$; $d = 0.52$). The effect of paradigm was not significant ($F_{(1,98)} = 2.35$, $p = 0.13$, $d = 0.27$), although as expected estimates were slightly larger in the prospective paradigm than in the retrospective paradigm. The interaction of drug condition and paradigm was significant, $F_{(1,98)} = 4.56$, $p = 0.04$. In the retrospective paradigm, estimates did not differ between the placebo and caffeine conditions ($t_{(51)} = 0.61$, $p = 0.54$, $d = 0.16$). However, in the prospective paradigm, estimates were significantly greater in the placebo condition than in the caffeine condition ($t_{(51)} = 2.72$, $p = 0.009$, $d = 0.74$). The effect of sex was not significant ($F_{(1,98)} = 0.72$, $p = 0.40$, $d = 0.20$), although as expected females' estimates ($M = 13.0$, $SD = 7.3$) were slightly larger than were males' estimates ($M = 11.6$, $SD = 6.0$).

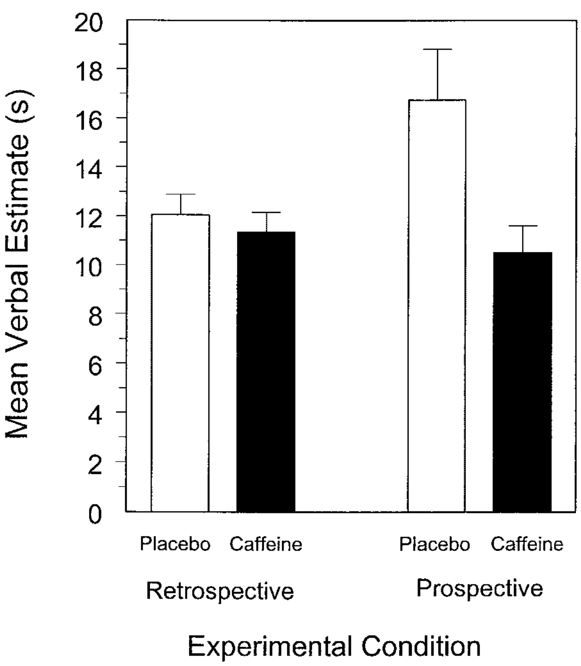

Figure 1. Mean verbal estimate (and *SE*) is displayed for each combination of paradigm (retrospective and prospective) and drug (placebo and caffeine). In the prospective paradigm, verbal estimates were significantly greater in the placebo condition than in the caffeine condition ($p = 0.009$). In the retrospective paradigm, verbal estimates did not differ between the placebo and caffeine conditions ($p = 0.54$)

Analogue estimates of duration

The overall correlation between verbal and analogue estimates of duration was large and significant ($r_{(105)} = 0.98, p < 0.001$), and the analogue-estimation data closely resembled the verbal-estimation data shown in Figure 1. As before, the effect of drug condition was significant ($F_{(1,98)} = 5.43$, $p = 0.02$, $d = 0.48$), with larger estimates in the placebo condition than in the caffeine condition. The effect of paradigm was not significant ($F_{(1,98)} = 1.68$, $p = 0.20$, $d = 0.27$). The interaction of drug condition and paradigm was only marginally significant ($F_{(1,98)} = 2.37$, $p = 0.13$). In the retrospective paradigm, estimates again did not differ between the placebo and caffeine conditions ($t_{(51)} = 0.85$, $p = 0.40$, $d = 0.23$). In the prospective paradigm, estimates were again significantly greater in the placebo condition than in the caffeine condition ($t_{(51)} = 2.38$, $p = 0.02$, $d = 0.64$). The effect of sex was not significant ($F_{(1,98)} = 0.50$, $p = 0.48$, $d = 0.17$), although as expected females' estimates ($M = 13.2$, $SD = 1.1$) were slightly larger than were males' estimates ($M = 12.0$, $SE = 0.9$).

Other variables

Drug, paradigm, the interaction of drug and paradigm, and sex (all dummycoded), along with age, body weight, caffeine consumption and BIS score were entered into a multiple-regression equation, using the stepwise-entry method. Only drug condition and the interaction of drug condition and paradigm were significant predictors of verbal estimates, although paradigm and BIS scores were marginally significant predictors. Simultaneously entering all four predictors into a multiple-regression equation revealed a significant prediction ($R = 0.37$, $F_{(4,101)} = 3.99$, $p = 0.005$), with drug significant ($\beta = 0.255$, $t_{(1)} = 2.75$,

$p = 0.007$), the interaction of drug and paradigm significant ($\beta = 0.189$, $t_{(1)} = 2.03$, $p = 0.04$), paradigm marginally significant ($\beta = 0.138$, $t_{(1)} = 1.49$, $p = 0.14$) and BIS score marginally significant ($\beta = 0.124$, $t_{(1)} = 1.34$, $p = 0.18$). The correlation between each of the other variables and the verbal estimate was not significant, all rs < 0.14, ps > 0.16.

Very long-term duration comparisons

Mean half-age estimate was 18.5 ($SE = 0.5$), and mean quarter-age estimate was 25.4 ($SE = 1.1$). Drug condition did not significantly affect either half-age comparisons ($F_{(1,96)} = 2.33$, $p = 0.13$, $d = 0.16$) or quarter-age comparisons ($F_{(1,73)} = 2.10$, $p = 0.15$, $d = 0.10$). (The *df*s are different because some participants did not make some estimates, particularly the quarter-age estimates.) As expected, quarter-age estimates were significantly larger than the half-age estimates ($t_{(80)} = 6.66$, $p < 0.001$). The correlation between half-age and quarter-age estimates was significant, $r = 0.76$, $p < 0.001$.

DISCUSSION

The major finding of the present experiment is that participants in the placebo condition made larger prospective verbal estimates of duration than did those in the caffeine condition. In addition, retrospective verbal estimates of duration did not differ between the two drug conditions.

Thus, both our study and that of Botella *et al.* (2001) show that caffeine reduces prospective duration timing. However, the results of the two studies are not totally comparable. Our study involved a verbal estimation task. Botella *et al.* asked their participants to press a key when they estimated that 10 s had elapsed after a beep. Two practice trials in which a computer demonstrated the 10 s interval preceded 10 of their experimental trials. Although Botella *et al.* referred to their task as one involving 'reproduction of time intervals' (2001, p. 538), it is actually a combination of production and reproduction tasks. In a purely reproduction task, no verbal reference is made to the length of the interval; and in a purely production task, participants are not given a sample of the target interval. Botella *et al.* referred to the duration estimates in the caffeine condition as an 'overestimation of time' (2001, p. 538). That term is vague, however, because the duration estimate was, in fact, smaller in their 300 mg caffeine condition than in their placebo condition, although only females showed this effect. Our finding that participants in the placebo condition gave larger verbal estimates of duration is consistent with Botella *et al.*'s finding that participants in the placebo condition gave shorter estimates of duration only if it is assumed that Botella *et al.*'s participants focused on the production aspect of the task. In other words, the two sets of findings are consistent only if the most salient aspect of the hybrid production-reproduction task for Botella *et al.*'s participants was that they should attempt to produce a '10 s' interval.

There were some other differences in the results between the two studies. Botella *et al.* noted an effect of caffeine at a dose of 300 mg but not at a dose of 150 mg. An effect at an intermediate dose, 200 mg was found. This difference may be attributable to the dose-related variability commonly seen with caffeine, to the fact that our experiment involved a purely verbal estimation paradigm, or both. Finally, only females were affected by caffeine in their study. In our study, males' and females' duration estimates did not differ, although there were relatively few males.

There are several potential explanations for why caffeine reduced prospective duration estimates in the present study. First, caffeine apparently did not produce its effect by a dopamine D_2-agonist property. That would have produced opposite results from what we and Botella *et al.* found. Another possibility is that caffeine produced an effect on GABAergic neurotransmission opposite to its agonistic effect on dopamine D_2 receptors as a result of its effect on adenosine A_{2A} receptors (Fuxe *et al.*, 1998; Zahniser *et al.*, 2000). This explanation is *post hoc* and speculative.

Another possible explanation focuses on the typical finding that caffeine enhances memory. This enhancement may decrease the apparent age of events (i.e. past events may seem more recent). Caffeine may have enhanced memory for the signal that indicated the start of the target interval, leading to a decreased verbal estimate (or production) of the target duration. The finding that caffeine did not influence retrospective estimates, which are usually considered to be heavily based on memory, weakens this explanation.

The most parsimonious explanation for our findings, as well as those of Botella *et al.* (2001), may be in terms of arousal effects: caffeine increases arousal and attentional resources (Smith and Tolla, 1998). Evidence that arousal and attention are important in prospective timing is compelling (Block *et al.*, 1998). Increased arousal leads to a narrowing of the focus of attention, with attentional resources predominantly allocated to the most salient information

(Easterbrook, 1959). The most salient duration in our study was the target interval, during which participants attempted to estimate the number of angles of a tactually felt object. Compared with participants in our placebo condition, participants in our caffeine condition may have attended more to nontemporal information (the tactual task) during the target interval and attended to time relatively less often. Attentional resources affect production in a manner that is opposite to that of verbal estimation (Block *et al.*, 1998). The most salient duration in Botella *et al.*'s study was the estimated duration, during which participants attempted to produce a '10 s' duration (or, possibly, to reproduce an 'empty' target duration). Compared with participants in their placebo condition, participants in their caffeine condition may have attended relatively more to temporal information during the reproduction duration. This explanation seems plausible considering that the most salient duration in their study was 'empty', with no information to process and therefore no salient information, other than temporal information, on which to focus attention.

Prospective duration estimates are usually larger than retrospective estimates (Block, 1992, 1996), which is what we found. In Zakay's (1993) experiment, which used essentially the same protocol, just the opposite was noted. The other significant difference between the two studies is that the instructions to the prospective participants in this experiment were repeated and emphasized. These differences aside, it is difficult to know why our findings are opposite to those of Zakay, although perhaps it can be attributed to the older-age participants in the present study (Block *et al.*, 1998).

Botella *et al.* (2001) found an effect of caffeine on females' duration estimates, but not on males' estimates; in fact, females' estimates were shorter than males in both their placebo condition and their 300 mg caffeine condition (although not in their 75 mg or 150 mg caffeine conditions). A recent meta-analytic review revealed that compared with males, females tend to make relatively shorter prospective productions and reproductions and relatively larger prospective verbal estimates (Block *et al.*, 2000). Although the present findings did not reveal larger prospective verbal estimates in females compared with males, the effect was in that direction, and the effect size was comparable to that of the reviewed studies. Botella *et al.*'s sex difference also agrees with that revealed by previous studies, although it is unclear why it was found in only two of their four conditions.

Other potential effects of caffeine on duration judgement

Other behavioural effects of caffeine may relate to the duration judgement effects that were seen. For example, caffeine seems to improve encoding of new information in humans (Smith *et al.*, 1999). Easterbrook (1959) predicted that the encoding of more information resulting from increased arousal also narrows a person's attentional focus. As a result, compared with the participants in the control condition, participants in the caffeine condition may have encoded more information about the primary task (counting polygon angles) but less information about the secondary task (attending to time). As a result shorter duration judgements were to be expected.

Yet another explanation for the results must be considered. Do they reflect reduced duration estimates after caffeine or increased duration judgements after caffeine withdrawal on the part of the placebo subjects? Hogervorst *et al.* (1998) evaluated the effect of caffeine on the cognitive performance of young, middle-aged and old volunteers. A caffeine withdrawal effect was hypothesized to be responsible for the reduced cognitive performance of middle-aged volunteers receiving placebo. In this study, some of the placebo subjects were caffeine users who went without it for 4 h before the test was administered. It could be argued, therefore, that the duration judgement scores they gave was more a reflection of a short abstinence from caffeine, and that there should be a difference between the placebo subjects who normally consume caffeine products and those who do not. However, as reported earlier, a multiple regression equation indicated that the caffeine consumption variable was not a significant predictor of verbal estimation in any of the groups.

Impulsivity and caffeine

Compared with non-impulsive people, impulsive people show poorer control of attention. One may expect impulsives to attend less often to a nontemporal information processing and more often to temporal information processing, which would mean that they would make larger prospective verbal estimates. Supporting that notion, a tendency was found for participants who scored high in impulsivity to make larger verbal estimates. Other researchers have also found that high impulsives make decreased duration judgements, but those experiments used reproduction and production tasks (Davidson and House, 1978), which may produce opposite effects. The effect of caffeine on impulsivity has also been studied, although to a limited extent. Caffeine appears to facilitate recall in high impulsives but not low impulsives (Gupta, 1991). This suggests that caffeine should increase duration estimates in the retrospective paradigm, in which recall may be a factor (see also Anderson and Revelle, 1982). However, we did not find an effect on retrospective estimates. Additional research is needed to clarify issues related to impulsivity.

Very long-term duration estimates

Our findings on very long-term duration estimates were similar to those in other studies (see Gallant *et al.*, 1991, for a summary). Participants in our placebo condition estimated the duration of a year at one-half their age to be about 1.5 times longer than the current year and estimated the duration of a year at one-quarter their age to be about 2.1 times longer than the current year. These findings are similar to those of Lemlich (1975). Our finding that caffeine did not affect this comparison indicates either that caffeine does not affect retrieval in very long-term comparisons or that very long-term duration comparisons do not depend primarily upon recall or retrieval. Memory for remote time intervals may be encoded in terms of a few subjective impressions (e.g. short, average or long year), not in terms of thousands of events that occur during any year.

SUMMARY

In summary, the present findings replicated and clarifiy the recent findings of Botella *et al.* (2001) on effects of caffeine on prospective duration estimation. Under the influence of caffeine, prospective duration experience decreases. The most parsimonious explanation is that caffeine increases arousal level, which leads to a narrowing of the focus of attention to the most salient information. We also extended the findings of Botella *et al.*, who did not study retrospective duration estimates. Our finding that caffeine did not influence retrospective duration estimates suggests that effects of caffeine on psychological time are not attributable to memory-enhancing properties of caffeine.

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