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**Research article**

# Impact of Taurine and Caffeine on the Cognitive Performance of Healthy Older Adults

## Walter S. Marcantoni[*]

Department of Psychology, Bishop's University, Sherbrooke, Quebec, Canada

[*]**Corresponding author:** Walter S. Marcantoni, Department of Psychology, Bishop's University, 2600 College Street, Sherbrooke, Quebec, Canada. Tel: +15148482424; Fax: +18198229661; Email: wmarcant@ubishops.ca

## Abstract

Energy drink manufacturers imply that the addition of caffeine and taurine will enhance cognition; however, these claims have only been studied in young healthy adults. The goal of the present experiment was to examine whether oral administration of taurine, or a combination of taurine and caffeine (ingredients found in most energy drinks) would have a beneficial impact on the cognitive functions most susceptible to the effects of normal aging: processing speed, working memory and attentional capacity. Sixteen healthy older individuals (57 - 82 years) were tested using a double-blind, within-subjects experimental design with four conditions (taurine/caffeine, caffeine only, taurine only, and a placebo drink), and two cognitive tasks (N-back working memory/processing speed task and Rapid Serial Visual Presentation (RSVP) attentional task). Results show that administration of caffeine significantly enhanced performance in the N-back task, but that performance was significantly reduced following taurine/caffeine administration when task demands were high, in both the N-back and RSVP tasks. The results suggest that any beneficial effects energy drinks have on cognitive performance, may be due to the presence of caffeine, and that the addition of taurine may actually attenuate the effects of caffeine if cognitive task demands are high.

## Introduction

Energy drink manufacturers claim that, because of certain ingredients, their products will produce behavioural benefits. In particular, it is implied that the addition of caffeine and taurine will enhance cognition [1]. However, the empirical evidence supporting this claim is mixed [2-5]. Caffeine on its own, in the low to moderate doses (approximately 100 mg) that are found in most energy drinks, has been shown to produce a variety of positive effects includingenhanced cognitive functioning [6-12]. However, at higher doses, caffeine can produce negative effects such as increased anxiety [13-14].

In contrast, and unlike caffeine, there is a little evidence with regards to the putative influence of ingesting taurine on cognition. The absence of any taurine effect on cognitive performance may be due in part to its already high levels in the brain under normal conditions [15]. The brain is able to synthesize taurine [16], and cerebral levels of taurine are tightly regulated by the blood-brain barrier [17]. The sodium and chloride dependent taurine transporters in the blood-brain barrier are only transcribed as an acute response to neuronal crisis, such as an ischemic episode [18]. Therefore, it is questionable whether any taurine crosses the barrier under normal conditions, and if any does cross whether the small amount found in most energy drinks (approximately 1000 mg in the average energy drink), would have any effect on mental processes by itself or in combination with caffeine [19].

To date, the effects of taurine and caffeine on cognitive performance have been studied exclusively in young healthy adults. Current evidence suggests that healthy older adults are more likely to benefit from the performance-enhancing effects of caffeine than are younger adults [8]; however, little is known with regards to the potential effects of taurine or a combination of taurine and caffeine on the cognitive performance of this population. However, there are several reasons why the cognitive performance of older adults may benefit from the addition of taurine. First, there is evidence that cerebral levels of taurine decrease with advanced age [20-22], and that low levels of cerebral taurine have been shown to have an adverse effect on mental processes [23]. Decreased levels of taurine in the cerebrospinal fluid have been found in patients suffering from Alzheimer's [24]. Second, while individuals with

normal cerebral levels of taurine may not benefit cognitively through the oral administration of taurine, the same may not be true of individuals with low cerebral levels of taurine. In fact, studies have shown that aged mice experiencing normal age-related decline in cognitive functions may actually benefit from taurine supplementation [25-26]. Furthermore, taurine has been used for centuries in the Orient, where it is used to treat dementia [27]. Finally, age-related changes in the permeability of the blood brain barrier [28] may facilitate the entry of orally administered taurine into the brain. Thus, the goal of this study was to examine whether oral administration of taurine, or a combination of taurine and caffeine (ingredients found in most energy drinks) would have a beneficial impact on the cognitive functions most susceptible to the effects of normal aging: processing speed, working memory and attentional capacity [29].

Based on the current evidence we hypothesized that participants exposed to caffeine or taurine would perform significantly better than participants exposed to a placebo on tasks measuring working memory/processing speed (the N-back task) and attentional capacity (Rapid Serial Visual Presentation (RSVP) task). Furthermore, we hypothesized that participants exposed to a combination of caffeine and taurine would perform better on the different cognitive tasks than those exposed to caffeine or taurine alone.

# Method

## Design

The hypotheses were tested using a double-blind, within-subjects experimental design with four conditions of a single independent variable (taurine and caffeine, caffeine only, taurine only, and a neutral drink) providing a measure on three dependent variables of cognitive function (attention, memory and reaction time). The four experimental conditions consisted of: 1) placebo (no caffeine, no taurine); 2) 1000 mg of taurine; 3) 80 mg of caffeine; 4) 1000 mg of taurine and 80 mg of caffeine. Participants received each of the experimental conditions over four different testing sessions. Memory and and processing speed were were evaluated using the N-back task, and attentional capacity was evaluated using the RSVP task. The differing experimental conditions and cognitive tasks were counterbalanced across participants.

## Participants

There were 16 healthy, non-smoking participants, aged between 57 - 82 years (M = 63.1, SD = 7.9, 6 females) who gave informed consent prior to testing. The experiment was open to all those who volunteered and who passed two screening tests during their initial visit. The Mini Mental State Examination (MMSE) was administered in order to screen participants with cognitive impairments. A health screening questionnaire was also used to assess the participant's level of physical health (history of cardiovascular

and neurological disorders) and life style (history of alcohol or drug abuse). All sixteen participants were free of any cognitive or physical impairments that otherwise would have prevented them from participating. Furthermore, none of the participants were using prescription medication. In addition to the above screening tests, participants were also asked to answer a questionnaire regarding their caffeine consumption. All participants reported consuming some form of caffeinated beverage on a daily basis, with coffee being the beverage of choice among all of our participants. Three participants reported occasionally substituting tea for coffee, and only one participant reported consuming soft drinks from time to time. None of our participants had ever consumed energy drinks. The average daily caffeine intake was 213 mg (range 80 mg to 400 mg). When asked if they drank caffeinated beverages to help keep them awake, eleven of the sixteen participants responded in the negative. The main reason they drank caffeinated beverages was the taste. Project approval was granted by Bishop's University Research Ethics Board.

## Materials

The juice was No Name berry punch made at 5/6th of directed dilution to increase the flavor of the drink and to mask any bitterness from the chemicals, namely the caffeine. One serving size of the juice, 250 mL, contains 15.44g of sugar, which is actually less than the 27g found in a similar serving size of Red Bull. The caffeine level was set at 80 mg and the taurine level was set at 1000 mg. The concentrations of the active chemicals and the volume ingested are the values found in a 250 mL can of Red Bull.

All tasks were performed on a 17-inch monitor. The N-back task was introduced is a continuous performance task used to assess working memory [30]. Participants are presented with a series of stimuli, usually numbers and letters [31], and the task consists of indicating when the current stimulus matches the one from n steps earlier in the series. In the current study we chose unfamiliar symbols as the stimuli, as opposed to letters and numbers, making it more difficult for participants to keep track of stimuli by simple sub-vocal repetition, thus increasing task demands on memory. Consequently, participants were presented with a series of unfamiliar symbols that flashed for 500 ms duration, with a 1375 ms delay between symbols. Each block contained three conditions. The 0-back required participants to respond when they saw "?" in the sequence of symbols. This condition was used as a baseline measure of processing speed, simple choice reaction time, because it minimized both stimulus and response uncertainty. The subject was told to answer as accurately and quickly as possible when they saw the "?" appear on the screen. For the 1-back condition, participants responded when they saw the same symbol back to back in the sequence. The cognitive demands of the task were highest with the 2-back condition which required that participants respond when they saw the same symbol that had been shown two

symbols previously. Each condition was presented three times within a given block, and their order of presentation was random. Within each condition, the target was presented three times, for a total of nine targets per block. Instructions were presented at the beginning of each condition, 2000 ms duration with an 8000 ms delay, informing the participants of the condition. Participants were asked to respond by clicking with the right mouse key. Accuracy of response was emphasized over speed of response. The N-back test had 8 blocks, each of which was used once.

Task specifications for RSVP required the participant's eyes to be placed 42cm away from the screen. To obtain the required visual degree of 17 degrees for the RSVP, the stimuli (uppercase letters) were 4mm high, equivalent to Arial 9. Each stimulus was presented for 100 milliseconds with no delay. Each series contained two targets (T1 and T2). Seven to ten letters preceded T1, and 1 to 5 letters followed T2. Participants to were asked to identify both T1 and T2, and the rate of T2 detection was used as the measure of attention. When participants try to identify a pair of target stimuli (T1 and T2; targets are characterized by different attributes, i.e. color) that are partially masked by distractors which follow them in the stream, attention to T1 often impairs attention to T2 when the targets appear within 500ms of each other. The greatest impairment usually occurs around 200 ms (an inter-target delay of one letter) when task difficulty, and hence cognitive demands, are at their highest [32]. This effect appears to have an attentional basis because it only occurs when subjects allocate attention to the first target [33]. Therefore, in our experiment we used two inter-target delays: 200 ms and 1000 ms. The number of intervening letters between T1 and T2 at an inter-target delay of 200 ms was one (high task demands), and the number of intervening letters between T1 and T2 at an inter-target delay of 1000 ms was nine (low task demands). All stimuli were shown on a grey uniform background and, with the exception of T1, which was white, all letters were black. Each block consisted of sixty RSVP sequences, with each inter-target delay being represented six times. Four RSVP blocks were presented.

## Procedure

During their initial visit, participants were told they were taking part in a study that examined the effects of energy drink ingredients on cognitive performance, and that they would be exposed to each of the four conditions over the course of four experimental sessions. All participants were tested in the morning. Participants were asked to refrain from drinking any caffeinated beverages within twelve hours of their test appointment. In order to ensure no carry-over effects from one testing session to the next, participants were tested at one-week intervals over the course of their participation. Testing of each participant lasted four weeks,

and all participants completed all four conditions in the alloted time. At the start of each experimental session the participant drank 250mL of the No Name berry juice, with the addition of the active chemical as indicated above. Using the average of time recommendation by most energy drink manufacturers for maximal results (twenty minutes) and time required for peak concentration of caffeine in the brain (thirty minutes) [34], participants waited twenty-five minutes after ingestion before being tested on the RSVP and N-back tests. During the twenty five minute wait participants practiced the tasks in order to increase familiarity and minimize learning effects. The order in which the tests were presented were counterbalanced.

## Results

Working memory was evaluated by recording the percentage of targets correctly identified in the N-back task. Descriptive statistics are presented in Table 1. A 4 x 3 repeated measures ANOVA that examined the effects of four levels of treatment condition (taurine, caffeine, taurine/caffeine, and placebo) across three levels of the N-back test (delay period of 0, 1, and 2) on the percentage of correct target responses revealed a significant main effect of treatment, $F(3,45) = 3.98$, $p = .013$, $\eta^2 = .210$, a significant main effect for delay, $F(2,30) = 36.05$, $p < .001$, $\eta^2 = .706$, and significant treatment by delay interaction effect $F(6,90) = 2.97$, $p = .011$, $\eta^2 = .165$. Post-hoc comparisons of both main and interaction effects were conducted using paired t-tests with a Bonferroni correction. Only significant post-hoc results will be reported. Post-hoc comparisons of the treatment main effect revealed that participants exposed to caffeine only correctly identified significantly more targets than those exposed to a combination of taurine and caffeine, $t(15) = 3.15$, $p = .007$, $d = .79$, 95% CI [1.98, 10.23]. Post-hoc comparisons of the delay main effect revealed that participants correctly identified significantly more targets in the 0-back condition than the 1-back condition, $t(15) = 4.06$, $p = .001$, $d = 1.01$, 95% CI [1.99, 6.37], and the 2-back condition, $t(15) = 6.21$, $p < .001$, $d = 1.55$, 95% CI [23.06, 47.19]. Furthermore, participants correctly identified significantly more targets in the 1-back condition than the 2-back condition, $t(15) = 4.06$, $p < .001$, $d = 1.46$, 95% CI [19.62, 42.36]. Post-hoc comparisons of the treatment by delay interaction revealed that in the 2-back condition, participants exposed to caffeine correctly identified significantly more targets than those exposed to a combination of taurine and caffeine, $t(15) = 3.04$, $p = .008$, $d = .75$, 95% CI [4.31, 24.65]. Of note, participants exposed to caffeine correctly identified more targets than those exposed to a placebo, $t(15) = 2.05$, $p = .058$, $d = .43$, 95% CI [-0.37, 19.90], and taurine, $t(15) = 2.06$, $p = .057$, $d = .35$, 95% CI [-0.29, 17.63], however these results did not quite reach significance. These trends are illustrated in Figure 1.

| N-back | Placebo | | Taurine Only | | Caffeine Only | | Caffeine and Taurine | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD | M | SD |
| 0-back | 99.61 | 0.75 | 97.97 | 4.3 | 99.61 | 0.6 | 99.45 | 0.64 | 99.16 | 1.57 |
| 1-back | 95.63 | 6.99 | 96.41 | 8.72 | 95.78 | 4.28 | 92.11 | 7.94 | 94.98 | 6.98 |
| 2-back | 62.5 | 21.92 | 63.59 | 25.94 | 72.27 | 23.71 | 57.79 | 26.34 | 64.03 | 24.47 |
| Overall | 85.91 | 9.88 | 85.99 | 12.98 | 89.22 | 9.53 | 83.11 | 11.64 | | |

**Table 1:** Means and Standard Deviations for the Percentage of Correct Target Detections across Three Levels of the N-back Task.
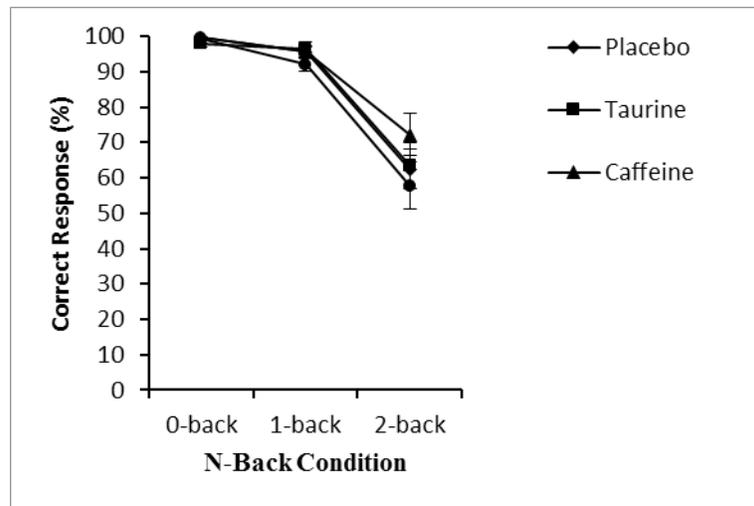


**Figure 1:** Correct response rates (%) for the N-back task. Exposure to taurine/caffeine significantly reduced task performance compared to caffeine exposure in the 2-back condition.

Processing speed was evaluated by recording response times, measured in milliseconds (ms), in the 0-back condition of the N-back task. Descriptive statistics are presented in Table 2. A one-way within ANOVA that examined the effects of four levels of treatment condition (taurine, caffeine, taurine/caffeine, and placebo) on processing speed was not statistically significant, $F(3,45) = .294$, $p = .830$, $\eta^2 = .019$.

| Placebo | | Taurine Only | | Caffeine Only | | Caffeine and Taurine | |
|---|---|---|---|---|---|---|---|
| M | SD | M | SD | M | SD | M | SD |
| 562.68 | 142.17 | 549.64 | 132.1 | 557.18 | 146.21 | 555.18 | 145.08 |

**Table 2:** Means and Standard Deviations for Response Times, Measured in Milliseconds (ms), in the 0-Back Condition of the N-back Task.

Attentional capacity was evaluated by recording the percentage of targets correctly identified in the RSVP task. Descriptive statistics are presented in Table 3. A 4 x 2 repeated-measures ANOVA that examined the effects of four levels of treatment condition (taurine, caffeine, taurine/caffeine, and placebo) across the two inter-target delays (200 ms or 1000 ms) on the percentage of correct target responses revealed no significant main effect for treatment, $F(3,45) = .630$, $p = .599$, $\eta^2 = .040$, a significant main effect for delay, $F(1,15) = 85.42$, $p < .001$, $\eta^2 = .851$, and no significant treatment by delay interaction effect $F(3,45) = 6.17$, $p =$ .001, $\eta^2 = .292$. The main effects of delay using revealed a significant increase in target detection as the inter-target delay increased ($p < .001$). Post-hoc comparisons of the interaction effect, using paired t-tests with a Bonferroni correction, showed that at an inter-target delay of 200 ms participants exposed to a combination of taurine and caffeine identified significantly fewer targets than the caffeine only condition, $t(15) = 4.61$, $p < .001$, $d = 1.15$, 95% CI [8.82, 23.99], the taurine only condition, $t(15) = 3.82$, $p = .002$, $d = 0.96$, 95% CI [7.95, 27.99], and the placebo condition, $t(15) = 2.82$, $p = .013$, $d = 0.71$, 95% CI [3.84, 27.42]. These trends are illustrated in Figure 2.

| Delay | Placebo | | Taurine Only | | Caffeine Only | | Caffeine and Taurine | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD | M | SD |
| 200 | 50 | 12.08 | 52.34 | 17.21 | 50.78 | 17.36 | 34.38 | 16.77 | 46.88 | 15.86 |
| 1000 | 82.81 | 19.83 | 85.94 | 24.1 | 85.94 | 24.1 | 93.75 | 11.18 | 87.11 | 19.8 |
| Overall | 66.41 | 15.96 | 69.14 | 20.66 | 68.36 | 20.73 | 64.07 | 13.98 | | |

**Table 3:** Means and Standard Deviations for the Percentage of Correct Target Detections across 2 Inter-Target Delays of the RSVP Task.
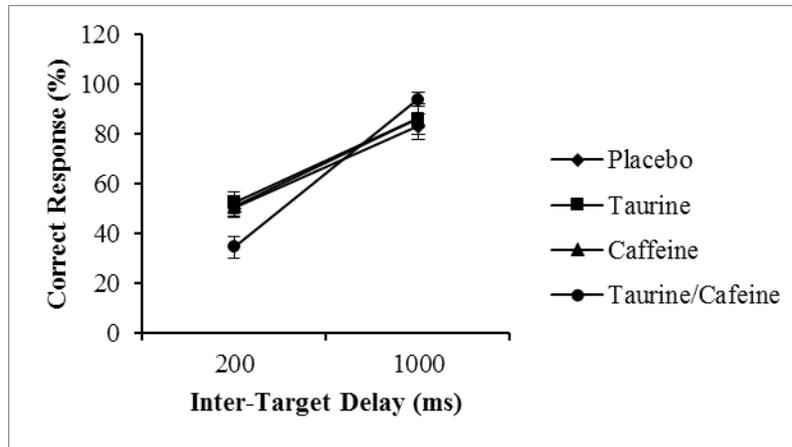


**Figure 2:** Correct response rates (%) for the RSVP task. Exposure to taurine/caffeine significantly reduced task performance compared to all other conditions at the 200 ms inter-target delay.

## Discussion

The goal of this study was to examine whether independent oral administration of caffeine, taurine, or a combination of taurine and caffeine (ingredients found in most energy drinks) would have a beneficial impact on the cognitive performance of older, healthy individuals. For caffeine alone, the only significant effect was improved working memory performance when compared to combined administration of taurine and caffeine, and this was most notable within the N-back task condition where target detection was at its most difficult (the 2-back). Furthermore, when compared to the placebo or taurine alone condition, caffeine administration alone enhanced working memory performance during the 2-back task of the N-back, but it just failed to meet significance. In all, these results provide support for the notion that caffeine alone had a positive effect on working memory performance. Caffeine alone did not significantly influence processing speed and attentional performance. For taurine alone, there were no significant effects on any of the cognitive measures. For the combined administration of taurine and caffeine, compared to the caffeine only conditions, performance was significantly poorer on the N-back task, but only when task demands were at their most difficult (2-back). A similar result was observed in the RSVP task when comparing performance between the two conditions when task demands were at their highest. The administration of taurine/caffeine produced significantly lower target detection rates at an inter-target delay of 200 ms than were observed following caffeine only administration. These differences in performance between the two conditions were not observed in measures of processing speed.

The results observed in the caffeine condition are in line with those observed in previous studies that examined the independent administration of the active ingredients found in energy drinks in that the administration of caffeine had a positive effect on cognitive performance [2,4,35]. Cognitive enhancement has also been reported in older adults following caffeine administration [36,37].

In contrast, there was no evidence that taurine improved performance on any of the cognitive tasks, and this too accords with previous studies using young adults [4,35]; however, Giles et al. [2] reported that taurine alone enhanced cognitive performance. Little evidence exists with regards to the impact of taurine supplementation on the cognitive performance of healthy older adults. Studies with healthy older mice have reported that chronic administration of taurine (eight months prior to and during testing) can enhance memory functions [25]. In our study, exposure to taurine occurred only prior to testing, and was administered only once. Thus it appears that potential benefits of taurine in an older population could result from chronic, rather than, acute administration. Another possible explanation for a lack of taurine effect may be due to the fact that taurine reaches its peak 60

minutes post-intake [38]. Participants began the tasks 25 minutes following treatment administration (when caffeine is reaching its peak plasma concentration), and testing lasted approximately 35 minutes. The absence of any taurine effects on task performance may be due to the fact that testing was completed prior to taurine reaching its peak plasma concentration.

The combination of taurine and caffeine appeared to attenuate the effects of caffeine, resulting in diminished performance across both working memory and attentional tasks when compared to all other conditions. However, these changes only took place when cognitive task demands were high. In the N-back task, caffeine administration resulted in a significantly better task performance than what was observed following taurine/caffeine ingestion, but only when task difficulty was at its highest (the 2-back condition). Similar results were observed in the RSVP. An inter-target delay of 200 ms produced a high level of attentional impairment across all experimental conditions. However, attentional impairment was greater following the taurine/caffeine administration than just the caffeine administration. Again it appears that taurine seems to attenuate the effects of caffeine, but only when cognitive task demands are high. Peacock et al. [4], also reported that the combined administration of both caffeine and taurine negatively impacted task performance. In other words, the addition of taurine seemed to attenuate the positive effects of caffeine. One possible explanation for this is taurine has been shown to act as an agonist of gamma-amino butyric-acid ($GABA_A$) receptors [39-40]. The naturally occuring neurotransmitter for these receptors is GABA. GABA is the main inihibitory neurotransmitter found throughout the central nervous system. Therefore, by binding to, and activating $GABA_A$ receptors, taurine may actually enhance widespread inhibition within the central nervous system,resulting in a more relaxed state. Jia et al. [41] reported that taurine acts as a potent activator of $GABA_A$ receptors located in the thalamus which is involved in a variey of functions including the regulation of consciousness, sleep and wakefulness [42-43]. The authorsreported that taurine diminished the activity of the thalamocortical relay neurons thereby providing support for the notion that taurine may assist in relaxation and sleep via the boosting of the GABA nerve transmission, and would thus explain how it could attenuate the effects of caffeine.

Thus, it would appear from the present results that any beneficial effects the active ingredients in energy drinks have on cognition is due to the caffeine in the beverage, and that taurine adds very little, or may actually counteract the effects of caffeine when both are combined. These results contrast with earlier findings claiming that the combined effect of both taurine and caffeine enhanced cognitive performance in young adults [5,44,45]. However, these studies did not attribute the effects to any particular compound, but rather to the whole drink, and it may be possible that other factors, such as the presence of glucose in the drink [46,47], or the possibility of participant expectancy [46,48-51], may have influenced their results.

One concern with the current experiment is the large inter-subject variability that was observed. Inspection of the tables shows high variability in the 2-back of the N-back task, and all lags within the RSVP task, across all conditions. An earlier experiment carried out in our lab, using the same conditions and tasks, but young healthy participants, produced much lower inter-subject variability [35]. The large variability observed in our older participant's scores might be due in part to the disparity in their ages. Ten of our participants were aged between 57 and 64 years, four between the ages of 65 and 70 years, one of 78 years, and one of 82 years. All participants were free of any cognitive or physical problems that might have hindered their performance; however, studies show inter-individual differences in cognitive functioning increases among healthy older individuals [52-53]. Individuals who are 57 will be experiencing cognitive changes that are different from those who are 82, and these differences could explain the large discrepency observed in our participant's performances. Another limitation of the study is the small sample size, which, in combination with the large performance variabilityofour participants, lowered the power of the study. A suggestion for future studies would be to examine the effects on larger, differing subsets of older individuals thereby minimizing the interindivual differences within the samples. For example, target groups within the older population could be separated into young-old (ages 65 -74), old-old (ages 75 - 84)and oldest-old (ages 85 and older) [54]. Yet another limitation of the study is the limited evaluation of cognitive functions. It is possible that a more extensive evaluation of other cognitive functions affected by the aging process, such as problem solving and inhibitory control [55] would have yielded different results. Finally, there was a lack of physiological measuressuch as plasma caffeine, or plasma taurine, concentrations. These measures would have allowed us to more accurately assess the impact of these ingredients on observed performance.

## Conclusion

The current study is a first step in understanding the independent effects of taurine, as well as its interaction with caffeine, on the cognitive functioning of healthy older adults. Although the results are somewhat inconclusive, the use of ecologically meaningful doses of caffeine and taurine on the cognitive performance of older adults across multiple levels of task difficulty provide a framework for future studies such as examining how different subsets of the older population would respond to the ingredients, and whether these effects would be the same or different over a wide spectrum of cognitive functions affected by the aging process. For the moment it appears that older individuals who are looking for a little cognitive boost, especially

when confronted with heavy task demands, should stick to the tried and tested cup of coffee, because not only has it been shown to be effective, it will certainly cost them less.

## Acknowledgement

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