

The effect of habitual caffeine consumption on inhibition

Melissa Kuiper

2014715

Liberal Arts and Sciences

Cognitive Neuroscience, Humanities, Tilburg University

Wouter de Baene

Tineke Snijders

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Abstract

With caffeine being present in many beverages, it is one of the most commonly consumed psychoactive drugs worldwide. In this EEG study the effect of habitual caffeine consumption on inhibition during a Stroop Colour and Word Test (SCWT) was measured, using the N450 and late occipital-parietal positive activity ERPs. Previous studies have found that when people consume caffeine the amplitudes of ERPs show bigger differences between congruency settings, suggesting caffeine consumption increases brain activity in the regions that help with performing inhibition. However, these studies on the effects of caffeine included alleviation of withdrawal symptoms in their research, leading to a possible inflated result. This study aimed to replicate their findings based on caffeine alone, leaving out possible alleviation of withdrawal symptoms. The 35 participants between the ages of 19 and 53, of which 22 females, were asked to partake in the SCWT during which EEG was measured and fill in a questionnaire about their caffeine consumption habits. Using a repeated-measures ANOVA, no significant outcomes were found for the effect of habitual caffeine consumption on the ERP amplitudes for congruent and incongruent conditions, the difference of which reflected inhibition. This lack of significant results suggests that in past research the inclusion of withdrawal symptom alleviation could have inflated their results. Furthermore, it highlights the need for further research that controls for this withdrawal symptoms.

Keywords: Inhibition, Habitual, Caffeine, EEG, ERP, Stroop

Introduction

With caffeine being present in many beverages, it is one of the most commonly consumed psychoactive drugs worldwide (Dixit, Goyal, Thawani, & Vaney, 2012). Caffeine has been shown to increase alertness and research has found that even small amounts can counteract the effects of, for example, sleep loss or fatigue on performance (Smith, 2002). Furthermore, consuming caffeine is said to improve parts of cognitive functioning, such as reaction time and attention (Kennedy, 2014). These described effects are the result of caffeine binding to adenosine receptors and in result blocking them. Adenosine is an inhibitory neuromodulator that decreases overall neural activity and promotes sleep. This means that blocking the adenosine receptors causes increased brain activity and changes in the levels of neurotransmitters such as dopamine, adrenaline, serotonin and acetylcholine, as well as regulate vigilance and attentional processes (Dixit, Goyal, Thawani, & Vaney, 2012)(Kennedy, 2014) (Baur, et al., 2021).

Because caffeine has an influence on attention, it also has an influence on the brain functions that fall in this category. One of these functions is inhibition, which is a form of attention control that allows us to ignore automatic responses while trying to focus on a specific task (Schacter, Gilbert, Wegner, & Hood, 2016). The way the effect of caffeine on inhibition presented itself in previously completed behavioural studies is through a decrease in reaction time when faced with an inhibition task where, for example, participants were faster in correctly responding to tasks after they had consumed caffeine. On top of this, a decrease in error rate can be found in some studies, but this effect is not always repeated (Dixit, Goyal, Thawani, & Vaney, 2012). Studies have also found that the mentioned behavioural effects get bigger when the amount of caffeine consumed increases (Smith, 2002).

The effect caffeine consumption has on inhibition can also be studied on a neurological level. This can be done using electroencephalography (EEG) and looking at event-related potentials (ERP). EEG is a way to measure the electrical activity in the brain, which can be used to see which parts of the brain are active at a specific time. When this electrical activity is related to a stimulus, the presented EEG data can be averaged together in order to show the precise brain activity for the presented stimulus, which is an ERP (Light, et al., 2011). ERPs are a useful tool in studying inhibition, because it shows at what point in time the interference of automatic responses takes place (Hanslmayer, et al., 2008). For inhibition research the N450 ERP has shown to reflect the interference effect best. The N450 is a negative ERP, which can be seen through electrodes placed above the frontal-central brain regions. Previous research has shown that people have a larger N450 amplitude in tasks in which they have to inhibit automatically triggered false responses, compared to similar tasks in which the automatically triggered response is correct. This means that the higher neural activity at N450 reflects the extra brain activity in the parts of the brain involved in suppressing the automatic responses. Another ERP that reflects inhibition is the late occipital-parietal positive activity, a late positive complex ERP that is visible in the electrodes located above the occipital-parietal brain regions. This ERP also shows larger amplitudes during incongruent trials compared to congruent ones (Pires, Leiteo, Guerrini, & Simoes, 2014).

A previous study, performed by Dixit, Vaney and Tandon on the effect of caffeine on inhibition using EEG, has shown that caffeine promotes faster inhibition of false automatic responses. In this study, participants performed an auditory inhibition task before and after consuming caffeine (3 mg per kg of body weight). During these inhibition tasks EEG was used to measure the P3 ERP, a positive ERP related to decision making measured by electrodes placed

above the parietal lobe. The study found a significantly larger amplitude of the P3 between congruency conditions after caffeine was consumed. This led to the assumption that by blocking adenosine receptors, caffeine increases dopamine levels and has an effect on the dopamine receptors in the hippocampus and the prefrontal cortex which are positively related to acquisition and retention of working memory tasks. On top of this, the increased amplitude differences reflected increased information processing by a higher uptake of cortical neurons after caffeine (Dixit, Vaney, & Tandon, 2009). The found increase in P3 amplitude therefore shows that the effect caffeine has does not come from less interference from false automatic responses, but from having more resources available to inhibit these automatic responses faster.

In this study, however, participants were told to refrain from consuming caffeine 12 hours before partaking in the experiment (Dixit, Vaney, & Tandon, 2009). While the control of the caffeine intake in this study can be seen as a positive, because it isolates the effect of caffeine, it also has a clear negative side to it. The negative of controlling caffeine intake in a within-subjects study is that when you restrict caffeine intake, you allow caffeine withdrawal symptoms to hinder your results (Juliano, Kardel, Harrell, Muench, & Edwards, 2019). These withdrawal symptoms can present themselves in the form of fatigue or concentration issues, for example (Kennedy, 2014). Both symptoms can express themselves in a decrease in mental effort or engagement, and therefore would negatively impact one's performance during an inhibition task (Shou & Ding, 2013). The reason why taking withdrawal symptoms into account is important, is because the caffeine consumption during the study will alleviate the withdrawal symptoms, which leads to exaggerated findings (Kennedy, 2014).

The issue of including alleviation of withdrawal symptoms in caffeine studies, is a problem that is present in most research on this topic. Experimental studies done on people who

do not habitually consume caffeine do show positive effects similar to participants experiencing withdrawal symptoms (Kennedy, 2014). However, because habituation of caffeine consumption leads to tolerance building, these people who do not consume caffeine on a habitual level show bigger effects of caffeine than daily consumers (Lara, Ruiz-Moreno, Salinero, Del Coso, & Sandbakk, 2019). There currently is some research done on the effect of caffeine on people who consume it habitually, however most of these studies are done on physical health related topics, rather than neurological ones. This means that there is a gap in the current understanding of the way caffeine influences most people, as most people do not commonly fall in the withdrawal or rarely consuming caffeine categories.

Understanding more about the extent to which habitual caffeine consumption can influence inhibition is important as it gives more insight in inhibition and attentional processes, as well as filling the gap in common caffeine research. From a neurological perspective, understanding the effect long term use of caffeine has on inhibition can give a better insight in the workings of the adenosine receptors and how they respond to different daily amounts of caffeine. On top of this, because caffeine is so widely used and available to most people, understanding the possible extent to which its effects can help people make better decisions about their consumption habits.

Therefore, this study will focus on the effect habitual caffeine consumption has on inhibition. Similar to the aforementioned study, EEG will be used to measure ERP's during an inhibition task. The expectation is that in line with findings from the aforementioned EEG studies, people who habitually consume caffeine will have more variance in the ERP amplitudes between conditions, than people who do not consume caffeine on a daily basis. On top of this,

this study also expects to find that this effect will significantly increase when the level of habitually consumed caffeine gets larger.

Methods

Participants

For this study there were 35 participants between the ages of 19 and 53 (Mean age = 22); of these participants 26 were female. Most of the participants were recruited through the psychology bachelor at Tilburg University. These participants were rewarded for their participation in participation credits. The rest of the participants were acquaintances of fellow researchers and received no reward afterwards.

No specific inclusion criteria were defined. However, colour blindness was selected as the exclusion criterion. Since none of the participants claimed to be colour blind, all participants could take part in this study. The study was approved by the ethical committee of the Tilburg School of Social and Behavioral Sciences. After reading the information letter, the participants gave their written consent.

Measures

Questionnaire

In order to study caffeine consumption, the participants were asked to fill in a questionnaire about their daily caffeine use. This questionnaire was specifically designed for this study and consisted of five questions (appendix A). The questionnaire was constructed to give insight into the daily caffeine consumption of the participants by using questions such as ‘at what age did you start consuming caffeinated beverages’, ‘what type of caffeinated beverages do you

usually consume’ and ‘how many caffeinated beverages do you drink daily’. These questions consisted of categorical multiple choice answer options, such as coffee, tea (iced or hot) or soft drinks, and some had an added option for elaboration. Because this was a homemade questionnaire, its validity and reliability cannot be backed up by earlier research. However, since the questions were very simple in nature and only measured specific things of interest in this study, their validity and reliability were deemed to be sufficient.

The questions that were most relevant to this study were the questions on the amount of caffeine that is consumed daily by the participants. When estimating how much caffeine a participant consumes per day, the number and types of drinks were considered. Because different caffeinated drinks contain different amounts of caffeine, generalized amounts of caffeine mg per serving size have been assigned to the different drinks, namely: coffee 95 mg, tea 45 mg, soft drinks 34 mg, energy drink 80 mg, pre-workout drink 225 mg (Wartenberg, 2019) (What is caffeine, 2022) (Red Bull Energy Drink Ingredients, n.d.) (Caffeine in Workout Supplements, n.d.). The average mg of caffeine in the selected types of drinks were multiplied by the number of drinks consumed.

Computer task

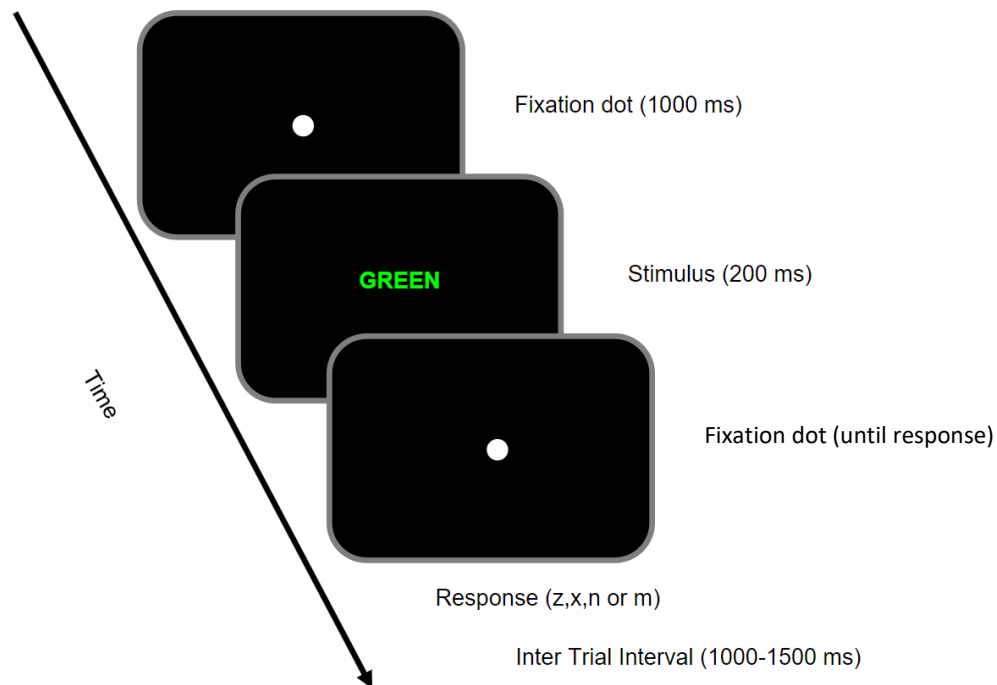
Inhibition was studied by use of a Stroop Colour and Word Test (SCWT), which was run using the OpenSesame program (Mathod, Schreij, & Theeuwes, 2012). Participants were shown different combinations of stimulus text (RED, GREEN, BLUE and YELLOW) and stimulus colour (#ff0000, #00ff00, #ffff00 and #0000ff). These stimuli were presented in font size 100 at the centre of the screen on a grey background (#aaaaaa). In total there were 16 possible word-colour combinations that could be presented to the participant. These combinations consisted of

four congruent trials, where the written word and its colour matched, and twelve incongruent trials, in which the written words and their colours did not match. Each trial started with a fixation dot which was shown for 1000 ms, then the stimulus was presented for 200 ms (figure 1). After that, another fixation dot was shown until the participant responded by pressing one of the response keys (z, x, n or m), as instructed before the experiment. For this fixation dot no maximum response time was set. An inter trial interval was placed between the trials, which lasted for 1000-1500 ms.

The participants were tasked with naming the stimulus colour by pressing dedicated buttons. In this experiment the dedicated buttons that could be pressed were 'z', 'x', 'n' or 'm', which were linked to the stimulus colours red, green, blue and yellow respectively.

Figure 1.

The trial procedure of the SCWT



Procedure

During the data collection of this within-subjects experiment, first the participants were fitted with an EEG cap and additional EOG and ECG flat sensors were placed on various parts of the face and chest. Once the participants were ready, they were led to a cabin in which the experiment would be run. Besides having sound-reducing walls and being dimly lit, the cabin was also provided with a CCTV camera that made it possible for the participants to be observed during the tasks. The monitor in the cabin was placed at approximately 60 centimetres in front of the participant and had a screen resolution of 1920px x 1080px. Before starting the experiment, the participants received the instructions to stay as still as they could, in order to limit the amount of noise picked up by the EEG recording system.

Before the experiment was run, two practice sessions were completed. The first practice session introduced the participants to the set-up of the experiment and the way stimuli were presented. It was also meant to help the participants memorize the different buttons they had to press when being presented with a colour. This colour-response mapping session showed a combination of the letters XXX with one of the four earlier mentioned colours (e.g., XXX and XXXXX). These four different stimuli combinations were repeated 25 times each, 100 trials in total, for optimal remembering of the functions of the buttons. Once the first practice task was completed, a shorter second practice session was presented. This session worked in the same way as the real experiment and showed 24 trials (12 congruent and 12 incongruent) to help introduce the participants to the real experiment.

The actual experiment followed after the two practice sessions. Similar to the practice sessions, the real experiment started by showing the participants the instructions of the task they were supposed to complete and allowing the participant to press start whenever they felt ready.

The experiment was split up in three blocks of 96 trials. In these blocks every congruent colour-word combination was repeated 12 times, while all the incongruent combinations were repeated 4 times. This made a total of 48 congruent and 48 incongruent trials per block. The stimuli were presented in a random order. In between the trial blocks, participants were given the option to take a small break.

Because this experiment was in collaboration with other experiments, the participants remained in the cabin for two additional tasks after finishing the SCWT. After completing all the tasks, the participants filled out several questionnaires, including the questionnaire on caffeine consumption that was used in this study.

EEG recordings

The EEG was recorded using a BioSemi Active-Two amplifier system (BioSemi, Amsterdam, The Netherlands). There were 32 active electrodes placed on the electric cap, following the 10/20 system. Two electrodes were placed on the left and right mastoids, in order to gain an offline reference. On top of this, a reference electrode (common mode sense: CMS) was fixed on the cap between Cz and C4 during measurement. Furthermore, four EOG and two ECG electrodes were placed. The EOG electrodes were positioned so they could detect horizontal and vertical eye movements. The vertical eye movements were measured by two electrodes placed above and below one of the eyes, while the horizontal movements were measured by two electrodes on the outer canthi of both eyes. The ECG electrodes were positioned in the middle of the sternum and at the same height on the left ribcage, under the armpit. The ECG data was not analysed in this study. The signals were digitized at a sample rate of 512 Hz.

EEG data analysis

The data analysis was performed using the program Brain Vision Analyzer 2.1 (Brain Products GmbH, Germany). The data were re-referenced offline using the average of the left and right mastoids, after which the data were filtered offline (.01-30 Hz bandpass filter, 50 Hz notch filter). The data were divided into 1100 ms epochs corresponding to the beginning of the presented stimuli, this included a 100 ms prestimulus baseline. The epochs in which at any EEG channel the contrast between the most negative and positive values was larger than 150 microV were rejected. The epochs were averaged individually for each condition and baseline corrected (-100 to 0 ms). On top of this, data were corrected for eye movements making use of the method by Gratton & Coles (Gratton, Coles, & Donchin, 1983).

Statistical analyses

The statistical analyses focused on the comparing the amplitudes of congruent and incongruent trials of the ERP components N450 and the late occipital-parietal positive activity. The amplitudes were computed as the average amplitude within the 325-465 ms and 600-900 ms time windows respectively, making these the time frames selected for analysis. As the topographical maximum for the N450 was found at the Cz electrode, this electrode was analysed. For the late occipital-parietal positive activity the average amplitude of the Pz, P03 and P04 electrodes was studied. Additionally, two statistical analyses were done on behavioural data, namely the reaction times and the percentage of correct responses.

Caffeine consumption data were included in this study as the independent variable. This variable was continuous and on a ratio scale. The dependent variables in this experiment were the amplitude differences between the congruent and incongruent trials of the N450 and of the

late occipital-parietal positivity, which reflected the level of inhibition. These variables were on a ratio scale. The dependent variables for the behavioural data were reaction times and percentage of correct responses. These variables were also on a ratio scale

For the behavioural data, the reaction times were corrected for outliers. The outliers, defined as any reaction time slower than 150 ms or longer than 2600 ms, were removed from this study. These values were chosen because a response time lower than 150 ms was too fast to be a genuine response, while 2600 ms was 2.5 standard deviations away from the mean. Visual inspection of the EEG data did not indicate outliers, but for one participant the EEG data was missing. This participant was left out of all the statistical analyses, which meant that only 34 participants were included in this study.

In order to study the hypotheses that people who habitually consume caffeine are better at inhibiting the Stroop effect than people who don't consume caffeine and that this effect increases when people habitually consume more caffeine, four repeated measures ANOVAs were run in SPSS (IBM SPSS Statistics for Windows, version 27.0, 2020). Two ANOVAs examined the effect of habitual caffeine consumption on reaction time and accuracy. Whereas the other analyses examined the effect of habitual caffeine consumption on ERP amplitudes in congruent and incongruent trials. In these repeated measures ANOVAs, congruency (congruent vs incongruent) was set as the factor and caffeine use was the covariate. A main effect of congruency was expected, but this study mainly focused on the interaction between caffeine and congruency.

Before running the actual analyses, the assumptions of repeated measures ANOVA were checked for each separate analysis. The assumptions of independence of observations, normality and sphericity were all met.

As this study only focused on inhibition and ERPs, only the correctly answered trials have been included in the statistical analysis. Because, this study only had one p-value per analysis, no post hoc corrections were performed.

Results

The participants had an accuracy rate of 94.61% when completing the SCWT, leaving an average of 134.15 congruent and 132.24 incongruent trials to be analysed. The standard deviations were 9.42 and 9.38 respectively. The amount of correctly answered congruent trails had a range of 110 to 144, whereas for the incongruent trials the range was 103 to 144 correctly given responses. The outcomes of the questionnaire showed that on average the participants consumed 136 mg caffeine daily, with a standard deviation of 132.9. The range of caffeine consumption was 0 to 440 mg.

As mentioned in the methods section, four separate repeated measures ANOVA's have been performed in order to analyse the data. The first two analyses regarded the behavioural data of both the reaction times and correctly given responses during the experiment. Whereas the latter two regarded the amplitudes of the N450, measured through the Cz electrode, and the late occipital-parietal positive activity, measured through the averages of the P03, P04 and Pz amplitudes.

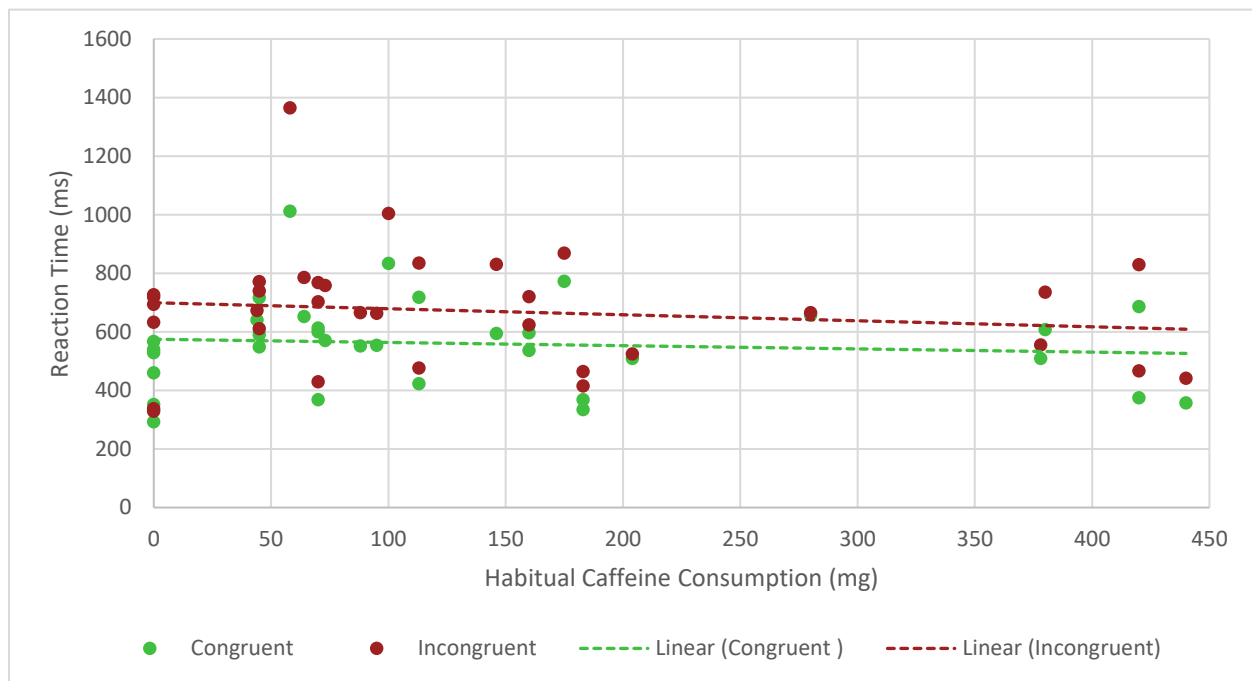
Reaction times and correct responses

In the first analyses, two components of behavioural data, reaction time and correct responses, were studied using repeated measures ANOVA. The reaction times had an average of 546.79 ms for the congruent setting and 660.26 ms for the incongruent one. The standard deviations were 145.39 and 187.97 respectively. The distribution of reaction times compared to

habitual caffeine consumption can be seen below (figure 2). The main effect of congruency on reaction time was significant and of medium size [$F(1,32) = 61.42, p < 0.001, \eta = 0.66$]. The main effect of caffeine was not significant [$F(1,32) = 0.41, p = 0.53, \eta = 0.01$]. The interaction effect between congruency and caffeine use on reaction times was also not significant [$F(1,32) = 1.64, p = 0.21, \eta = 0.05$].

Figure 2.

Reaction times of correctly answered congruent and incongruent trials in relation to caffeine consumption

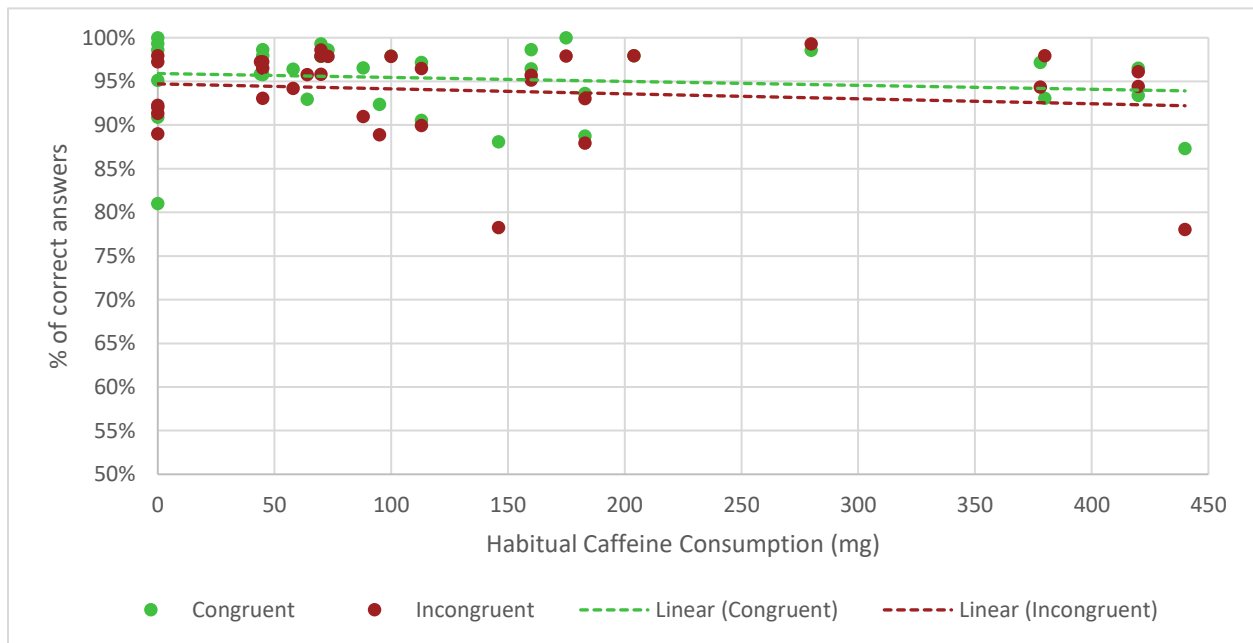


Note: The reaction times of correctly answered congruent and incongruent trials visualized against the habitual caffeine consumptions of participants. A trend line is shown for both congruency conditions.

When it comes to accuracy, the averages were 95.28% correctly answered congruent trials and 93.94% correctly answered incongruent ones. The standard deviation for the congruent trials was 4.30% and for the incongruent ones it was 5.06%. Similar to the previous analyses the distribution of scores can be seen in the added figure (figure 3). The analysis showed no significant results for the main effects of either congruency or caffeine consumption on the percentage of correctly answered trials [$F(1,32) = 1.52, p = 0.23, \eta = 0.05$] [$F(1,32) = 0.83, p = 0.37, \eta = 0.03$]. The interaction effect of congruency and caffeine was also nonsignificant [$F(1,32) = 0.05, p = 0.82, \eta = 0.00$].

Figure 3.

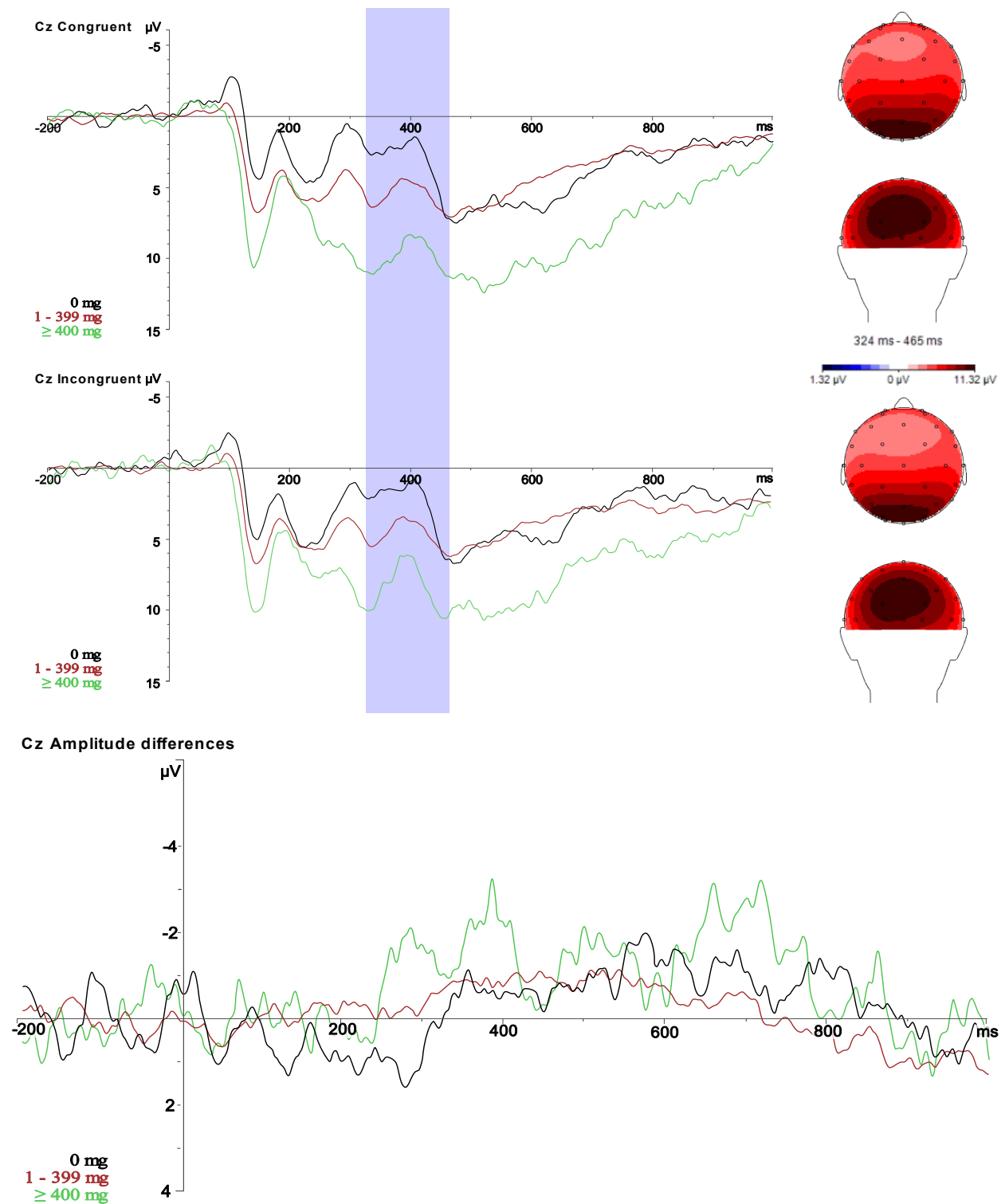
Percentages of correctly answered trials in relation to habitual caffeine consumption



Note: The percentage of correctly answered congruent and incongruent trials visualized against the habitual caffeine consumptions of participants. A trend line is shown for both congruency conditions.

The N450 and late occipital-parietal positive activity

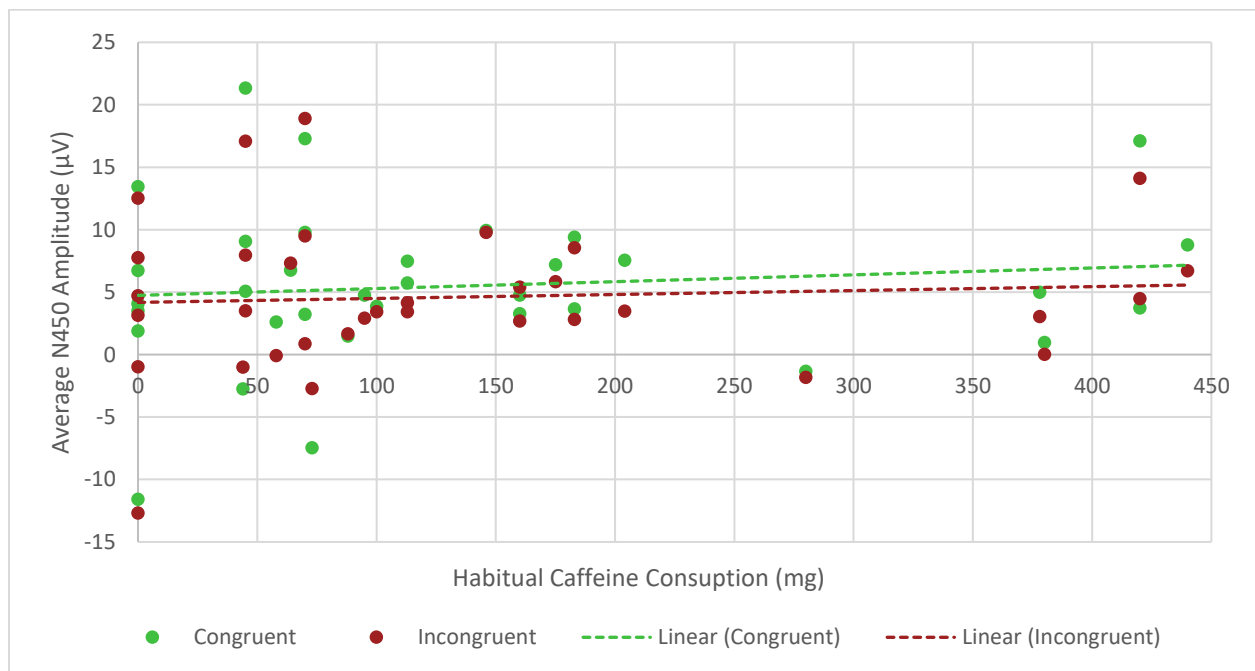
Just as for the behavioural components of this study, the ERPs were analysed using two separate repeated measures ANOVA's. The first analysis was done for the N450 amplitudes (figure 4 & 5). The main effect of congruency on the N450 amplitude was not significant [$F(1,32) = 1.53$, $p = 0.23$, $\eta = 0.05$]. The main effect of caffeine consumption on the N450 amplitude was also not significant [$F(1,32) = 0.29$, $p = 0.60$, $\eta = 0.01$]. On top of this, for the interaction between congruency and caffeine no significant effect was found [$F(1,32) = 0.94$, $p = 0.34$, $\eta = 0.03$].

Figure 4.*The N450 ERP amplitudes per condition*

Note: ERPs are shown at electrode CZ for congruent trials and incongruent trials, and their scalp topography of the time range studied in this analysis (325 - 465 ms). The studied time range is marked in purple. The bottom graph shows the amplitude differences between congruency settings. For illustration purposes three categories have been formed. The cut-off values have been set at 0 and 400 mg, based on the EFSA regulations who consider a daily amount of 400 mg to be the limit of safe caffeine consumption (EFSA Panel on Dietetic Products, 2015).

Figure 5

The N450 amplitudes relative to habitual caffeine consumption

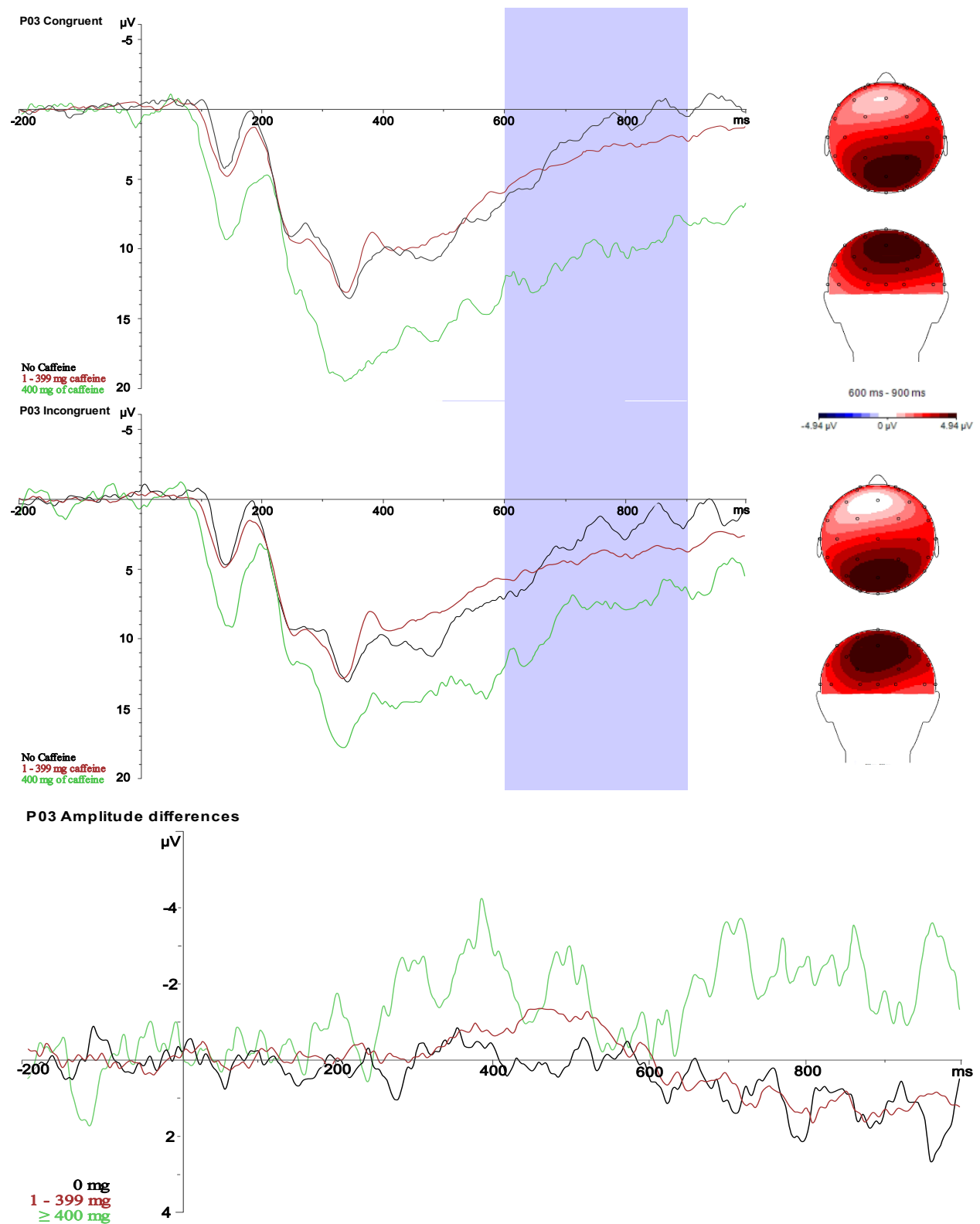


Note: The average N450 amplitudes of the Cz electrode for both congruent and incongruent trials are plotted against mg of habitual caffeine consumption. A trend line is shown for both congruent and incongruent settings.

The last analysis that was done was for the amplitudes of the late occipital-parietal positive activity (figures 6 & 7). A large significant main effect of congruency on the amplitude of the late occipital-parietal positive activity was found [$F(1,32) = 4.74, p < 0.05, \eta = 0.13$]. The main effect of caffeine on the late occipital-parietal positive activity, as well as the interaction effect between congruency and caffeine on this ERP, were nonsignificant [$F(1,32) = 0.65, p = 0.43, \eta = 0.02$] [$F(1,32) = 3.84, p = 0.06, \eta = 0.11$].

Figure 6.

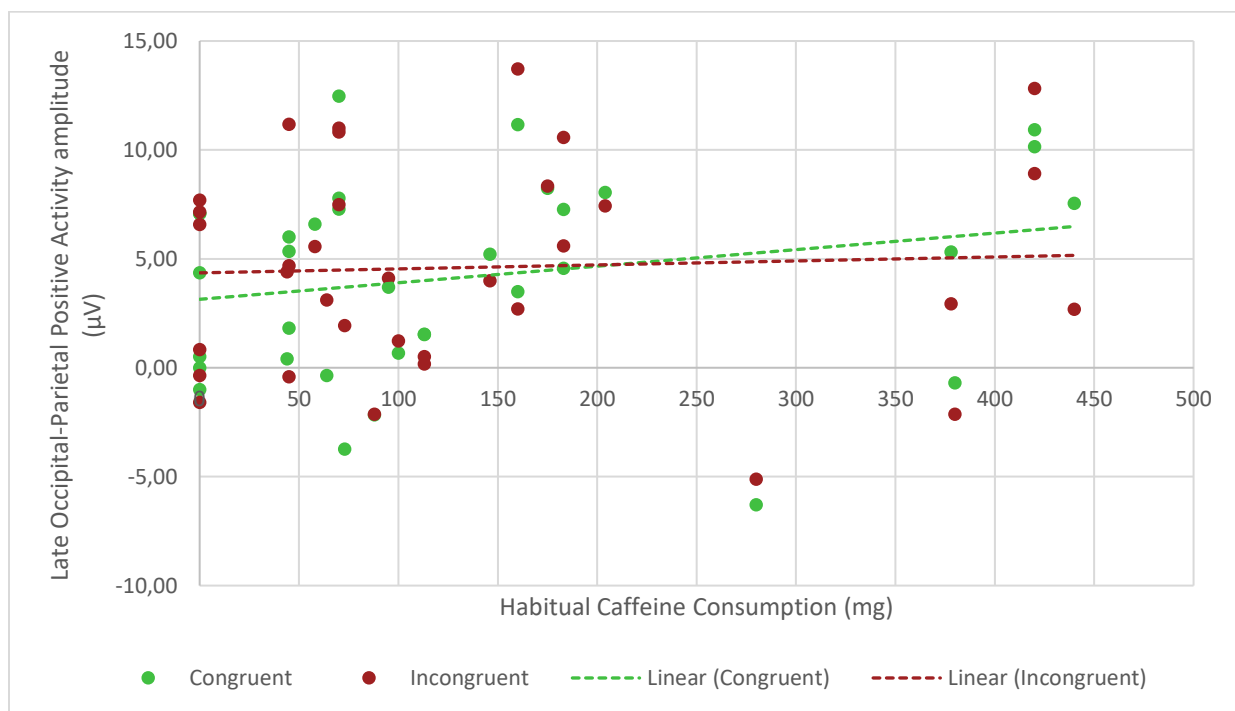
The late occipital-parietal positive activity ERP per condition



Note: ERPs at electrode P03 for congruent trials and incongruent trials and their scalp topography of the time range studied in this analysis (600 - 900 ms). This time range is marked in purple. The bottom graph showed the amplitude differences between congruency settings. For illustration purposes three categories have been formed. The cut-off values have been set at 0 and 400 mg, based on the EFSA regulations who consider this to be the limit of safe caffeine consumption (EFSA Panel on Dietetic Products, 2015).

Figure 7.

The late occipital-parietal positive activity amplitudes relative to habitual caffeine consumption



Note: The average late occipital-parietal positive activity amplitudes of the P03, P04 and Pz electrode for both congruent and incongruent trials plotted against mg of habitual caffeine consumption. A trend line is shown for both congruent and incongruent settings.

Discussion

This study examined the difference in N450 and the late occipital-parietal positive activity amplitudes between congruency settings in a SCWT for people who habitually consume caffeine in different amounts. The study expected to find a larger amplitude difference for people who habitually consume caffeine compared to people who do not, as well as an increase in amplitude difference among participants who habitually consume higher amounts of caffeine.

The results showed no significant effect of habitual caffeine consumption on the amplitude differences between congruency settings for the N450 and the late occipital-parietal positive activity. Additionally, no significant increase in effect for participants who consumed more caffeine was found.

This lack of significant results related to the hypothesis in this study, compared to previous research, shows the importance of taking withdrawal symptoms out of caffeine studies. As mentioned in the introduction, studies in which caffeine consumption was controlled have found significant effects of caffeine on inhibition, but these effects could very well be inflated because of the alleviation of withdrawal symptoms included in them. The fact that this study has found no effect, implies the legitimacy of the aforementioned statement.

An alternative explanation for the discrepancies between the outcomes of this study and the aforementioned research is that this study focussed on the N450 and the late occipital-parietal positive activity, whereas the mentioned study by Dixit, Vaney and Tandon focussed on the P3 ERP (Dixit, Vaney & Tandon, 2009). This means that it could be possible that the effect of caffeine on inhibition would be visible for the P3, but not for the two ERPs studied in this experiment.

Additionally, the difference in outcomes could be caused by the fact that in previous studies many variables were controlled for, that this study could not take into account. In the study by Dixit, Vaney and Tandon for example, all participants consumed a relatively equal amount of caffeine at a similar time before starting their inhibition task (Dixit, Vaney, & Tandon, 2009). This leads to a very precise insight in the effect of caffeine at a specific moment in time after it is consumed, regardless of whether alleviation of withdrawal symptoms is taken into account. In this study, caffeine consumption was not controlled and participants only had to report on their daily consumption. This means that for this experiment participants could have participated in the inhibition tasks while they were no longer experiencing effects from the caffeine they had consumed or were in the window of caffeine withdrawal. The results from these participants could show a deflated result, which could account for the lack of significant caffeine interaction found in this study.

Additional to the nonsignificant effects related to the hypothesis, two significant main effects of congruency were found. The results showed that congruency has a large effect on the amplitude of the late occipital-parietal positive activity and a medium effect on reaction time. These effects both proved there was an interference from automatic responses present in this study. In line with previous research the inhibition of automatic responses presented itself in higher levels of brain activity and slower response times in the incongruent condition, where inhibiting for these responses was necessary. This proves that the SCWT did work, but inhibition in this study could not be related to caffeine consumption in either the amplitude differences or the behavioural data.

While not controlling caffeine consumption is one of the strengths of this study, as it allows a realistic insight into the effect of caffeine as it would present itself in most caffeine

consumers, the lack of control is also one of its limits. As mentioned, the lack of control of caffeine consumption before partaking in the experiment might have caused deflated interaction results. On top of this, because the habitual caffeine consumption was reported on using a questionnaire, the actual amounts participants consumed were estimates rather than known quantities. The possible deviation between reported caffeine consumption and the true amount consumed, could negatively influence the results as well.

The difference in findings of this study compared to controlled caffeine studies, shows the importance of taking alleviation of withdrawal symptoms into account when studying caffeine. Most of what we know now about the effects of caffeine comes from controlled studies, so there is still a gap in knowledge about habitual consumption. A way to start filling this gap in further research is to look into the alleviation of withdrawal symptoms and find how much of the found effects in caffeine research can be explained by it. This can be done, for example, by performing a controlled study in which there are three groups made up of participants who do not consume caffeine, participants who habitually consume caffeine and are told to withdraw before the experiment and a group of participants who habitually consume caffeine and do not have to withdraw. This would make it possible to study the effects of caffeine in isolated consumption and for people who either do or do not commonly consume it.

In short, this study has found no significant effect of habitual caffeine consumption on inhibition. When comparing these results to the significant results found in studies that control caffeine intake, it shows a clear discrepancy. The lack of overlap in findings expresses the need for more research on habitual caffeine consumption and the effect alleviation of withdrawal symptoms has on the findings of existing studies.

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Appendix A

Questionnaire on caffeine consumption

CAFFEINE

1. Do you consume caffeinated drinks? (i.e. coffee, tea, energy drinks)

Yes - Please continue.

No - Please move to last question.

2. At what age do you start consuming caffeinated beverages?

Under 8 years old

8 - 12 years old

12 - 16 years old

16 - 18 years old

Over 18 years old

3. What type of caffeinated beverage do you usually consume?

Coffee or Coffee specialty drink

Tea (iced or hot)

Soft drink

Energy drink (ie. Red Bull, Monster, etc.)

Pre-workout drink

Other, please specify:

4. About how many caffeinated beverages do you consume daily?

<1

1

2 - 3

3 - 5

5 - 7

7 or more

5. For what purpose would you consume a caffeinated beverage? (Please select all that apply.)

To feel more awake

To stay up late

To help with focus and concentration

To be more alert

To be more productive

To improve physical performance

No specific purpose

Prefer not to answer