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Daniel Mayorido-Alvarez

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The Effects of Caffeine on Attention Span and Reaction Time among Young Adults, Middle-aged Adults, and Older Adults: A Two-part Meta-Analysis and Research Proposal

This Senior Project is approved as acceptable

Project Co-Director

Dr. Aaron Allen

Project Co-Director

Dr. Jay Quinan

Committee Member

Dr. Greg Preuss

Honors Program Director

Dr. Bill Yankosky

Honors Program Assistant Director

Dr. Fred Sanborn

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The Effects of Caffeine on Sustained Attention and Reaction Time among Young Adults, Middle-aged Adults, and Older Adults: A Two-part Meta-Analysis and Research Proposal

Daniel Roberto Mayorido-Alvarez

Dr. Jay Quinan & Dr. Aaron Allen

North Carolina Wesleyan University

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Abstract

Caffeine is shown to improve sustained attention and reaction time by inhibiting the effects of adenosine, yet its effects across age groups still remain unclear. Though young adults show moderate cognitive improvements, middle-aged and older adults likely do not experience these same benefits as a result of tolerance and metabolic differences. This study aims to propose a meta-analysis and an experimental study to examine the age-related and dose-dependent effects of caffeine on simple reaction time and sustained attention. The proposed meta-analysis will synthesize research currently available in the literature, in which the proposed experiment will use a double-blind, 3x2 mixed factorial design to assess performances across all three age groups. These findings will be optimal for the development of age-specific caffeine intake recommendations.

Chapter 1: Review of the Literature

1.1 – Background:

Caffeine is one of the most widely used drugs in the world, and it is a purine alkaloid base naturally in plants, including coffee beans, cacao beans, cola, and tea. Due to its psychoactive properties, caffeine is shown to improve and arouse several internal functions of the body, including the parasympathetic nervous system, memory, physical performance, and wakefulness (McLellan et al., 2016). It is because of these benefits that caffeine is responsible for the growing industry of caffeine-containing food products for consumer use.

In pure form, caffeine appears as a bitter white powder, and its mean half-life in healthy individuals is about 5 hours, but it can range from 90 minutes to 9.5 hours due to individual differences and external factors, including pregnancy, obesity, smoking, and altitude (Institute of Medicine, 2001). Caffeine is rapidly and completely absorbed, with 99% absorption within 45 minutes (Institute of Medicine, 2001).

In addition, significant behavioral effects have been found and studied from the consumption of caffeine, due to its antagonistic resemblance to adenosine, as seen in Figure 1.

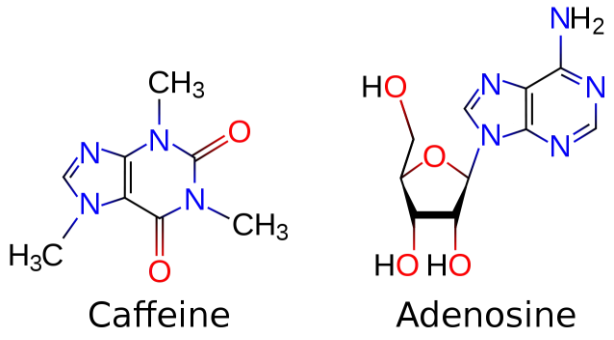

Fig. 1: Structure of Caffeine and Adenosine (Stroma, 2020).

Caffeine is an antagonist of adenosine, a central nervous system depressant responsible for promoting sleep and suppressing arousal (Mandal, 2019). By blocking adenosine's inhibitory effects, caffeine indirectly influences neurotransmitter release, including norepinephrine,

dopamine, serotonin, glutamate, and GABA (Institute of Medicine, 2001). Exposure to caffeine also shows neuroprotective effects, for caffeine reduces oxidative stress and decreases reactive oxygen species production (Kolahdouzan & Hamadeh, 2017). It protects against cognitive decline and improves memory retention, particularly in Alzheimer's disease models (Kolahdouzan & Hamadeh, 2017).

1.2 – Introduction:

Decades of research have shown that caffeine has a net positive effect on several cognitive and behavioral functions and is present in the diets of billions of individuals worldwide. Typically, the main motivations for the consumption of caffeine include taste, mood enhancement, alertness, socialization, health benefits, and habit formation (Choi, 2020). Among college-aged students (20 years or older), coffee and energy drinks were associated with motivation by the desire for alertness, habit, and health benefits, while more nuanced beverages, such as caffeinated teas were significantly motivated by socialization (Choi, 2020). In older adults between the ages of 25 and older, motivations for the consumption of caffeine differ from that of college students (Ágoston et al., 2018). Among older men, the leading desire for the consumption of caffeine is habit, while the leading desire in women is socialization (Ágoston et al., 2018). In the same study (Ágoston et al., 2018), younger participants (18 to 24 years) were more likely to consume caffeine for alertness, while older participants (25 to 68 years) generally scored higher on the desire by habit and symptom management.

It is, however, unclear if health benefits, one of the overlooked and inconclusive motives for consuming caffeine, may have an effect on a person's active behaviors, namely in simple reaction time and sustained attention. Moreover, it is unclear if age has a significant role in the effectiveness of caffeine consumption on these factors.

1.3 – Simple Reaction Time:

Simple reaction time is the time it takes for an individual to respond to a single, expected stimulus with a predetermined action. This action can be as simple as the press of a button, and it is fundamental for the measure of cognitive speed and alertness. These are influenced by the factors of fatigue and caffeine intake. Among university students, 60 mg doses of caffeine are shown to slightly increase reaction times (Smith, 2023). However, the findings tend to become unclear, as the range among ages increases. It is unclear if caffeine intake among older adults holds a similar effect to that of a younger individual and if the dosage has a role in that discrepancy or gap in knowledge. Chronic caffeine intake is shown to lower the effect of improvement on simple reaction time among varying dosages (Carpenter, 1959), which is an antiquated finding that has yet to be explored.

1.4 – Sustained Attention:

Sustained attention is the ability to maintain focus on the task at hand without being affected by any internal or external factors (Virginia Tech, 2024), which can include factors such as fatigue. While caffeine generally decreases reaction time, research suggests that this decrease also coincides with increased sustained attention. Dose-dependent effects show that caffeine increases sustained attention at levels of 3 mg/kg of caffeine more than 1 mg/kg of caffeine in adolescents (Cooper et al., 2020). It is yet to be discovered if this dose-dependent difference is generally constant among the following age groups. Individuals between the ages 18 and 40 were found to have decreased alpha-band oscillatory brain activity by approximately 12 percent after the first hour of caffeine ingestion, indicating an increased cortical arousal (Foxe et al., 2012). This finding supports that ingesting caffeine can increase sustained attention marginally over a wide age range that is still yet to be narrowed down.

1.5 – Thesis:

Caffeine, a widely consumed psychoactive drug, has been shown to enhance cognitive and behavioral functions, such as simple reaction time and sustained attention. However, there are still uncertainties that are unclear across different age groups. While younger individuals tend to receive many noticeable improvements in alertness and response speed, the benefits caffeine provides over time likely diminish as age increases over time. Given the inconsistencies of the existing research, a comprehensive meta-analysis is necessary to synthesize the current findings while bringing into light what is yet to be discovered. Additionally, an experimental study should be followed to examine the cognitive effects of low doses of caffeine on simple reaction time and sustained attention in different age groups. Future research can test whether higher or more specific doses of caffeine have distinguished effects on age groups.

Chapter 2: Meta-Analysis Proposal

2.1 – Search Strategy:

This systematic review and meta-analysis will be conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines designed to help researchers follow a structured, 27-item listed framework to systematically collect, analyze, and report data that is comprehensive and free from bias. The most essential criteria for composing a comprehensive and relevant literature search are to consider the following: the title, the abstract, the introduction, the methods, the results, and the discussion. Each criterion includes a subset of items that will help the researcher determine if a research article consists of relevant and similar information needed for a meta-analysis. These include, but are not limited to, a rationale, an objective, a search strategy, eligibility criteria, a risk of bias assessment, the data collection process, the synthesis methods used, the results of syntheses, and the interpretation, limitations of the evidence, and implications of the discussion. Additionally, this meta-analysis will be pre-registered with PROSPERO, a database for registering reviews and meta-analyses to reduce research duplication and minimize reporting bias so that researchers may ensure accountability for any reported findings while allowing other researchers access to knowledge that has already been explored.

The databases that will be used for a literature search will include PsychInfo, Biological Sciences, and PubMed for the published articles to be used in this meta-analysis. Articles published in English from January 1, 2000, to March 1, 2025, with keywords and operators (“caffeine”) AND (“simple reaction time” OR “sustained attention”) AND (“young adults” OR “middle-aged” OR “elderly” OR “old”) will be used for the literature search.

2.2 – Inclusion and Exclusion Criteria:

The inclusion criteria will be identified by the following: (1) scientific articles with clear information regarding the administration of caffeine; (2) caffeine that is administered by a pill, beverage, coffee, energy drink, or gum; (3) articles that include a placebo-control condition; (4) articles that have clear age distinctions among young adults, older/middle-aged adults, or elderly adults; (5) articles that measure the effect of caffeine on cognitive or behavioral tasks including simple reaction time and sustained attention; and (6) articles that are in English.

The exclusion criteria will consist of studies identified by the following: (1) articles that include ill, injured, or medically compromised individuals; (2) participants who are not adults; (3) articles that lack a placebo condition; (4) articles that do not clearly state the age groups of young, middle-aged, and elderly adults; and (5) articles in which caffeine doses are administered at a constant dose rather than a milligram per kilogram rate.

2.3 – Meta-Analysis

Due to the overwhelming number of studies in the literature with too tight of a time constraint, this meta-analysis cannot yet be conducted. Nevertheless, for this meta-analysis, the average simple reaction time (via the Psychomotor Vigilance Task) and average sustained attention (via the Digit Symbol Substitution Test) scores will be extracted from each study for statistical analysis via calculated effect sizes. This quantitative measure will describe to what extent caffeine improves simple reaction time and sustained attention in comparison to the control group.

For each effect size of a study, a 95% confidence interval will be used. Forest plots will also be implemented to compare both effect sizes and confidence intervals for each study, and they will also combine all effect sizes to show the overall effect of caffeine on these tasks. Another value for forest plots is to display the variability of each effect size. Through the use of meta-analysis software, such as Revman, Stata, or Comprehensive Meta-Analysis, funnel plots can be created for determining bias. If a plot appears symmetrical, there is little to no risk of bias, though an asymmetrical funnel plot may indicate some bias.

Chapter 3: Research Proposal

3.1 – Hypotheses & Rationale:

Many years of research have been dedicated to measuring reaction time and sustained attention among individuals of all ages, even without the introduction of caffeine. In general, both simple and choice reaction times significantly slow down as age increases in a person, even with the presence of practice effects, where repeated testing improves reaction times (Fozard et al., 1994). Reaction time tests have also found and supported the hypothesis that younger adults tend to have quicker responses than older individuals at the cost of accuracy (Fozard et al., 1994). On average, simple reaction time has been measured to slow with age at the rate of 2 to 6 milliseconds per decade (Hardwick et al., 2022). For this experimental study, it is expected for the results to follow a similar trend of reaction times measuring higher as the age group increases. Additionally, errors are more likely to occur among younger adults than middle-aged or older adults.

The purpose of this study will be to analyze individual differences among three notable age groups: young adults (YA), middle-aged adults (MA), and elderly adults (EA). Significant differences among age groups may show that there is a potential for optimal caffeine dosage depending on the age group, and this research may be essential for the development of age-specific recommendations for caffeine intake.

3.2 – Methods:

This study will recruit a total of 120 participants, with an equal number of participants in the three subject groups, and all subjects will participate in two conditions: the experimental condition (1 mg/kg of caffeine) and the placebo/control condition (no caffeine). The YA subjects will range between the ages of 18 to 34 years, while MA subjects will range between the ages of 35 to 59 years, and EA subjects will range between the ages of 60 years and above. For each age group, a total of 40 participants will be recruited for this study. Young adults, middle-aged

adults, and elderly adults will be recruited through North Carolina Wesleyan University announcements and emails aimed toward enrolled students in the traditional day program and adult studies, faculty, and staff administrators. Alumni will also be eligible for recruitment for the study via announcements sent by the Office of Alumni Relations. Depending on the age of the prospective subject, one will be assigned to the age group based on the aforementioned criteria. To facilitate the recruitment of elderly individuals, announcements of this study will be distributed at local independent living homes in close range of North Carolina Wesleyan University's main campus. Prospect subjects will be asked for informed consent for the participation of this study, and each participant will be medically screened and measured for their weight at the Wellness Center of the NC Wesleyan Campus for the proper caffeine dose administration of this study.

Men are shown to metabolize caffeine more efficiently than women (Dillon et al., 2019). Due to this discrepancy in the effects of caffeine and for simplicity, only men will be included in this study; though, replications of this study can also be done with women. In addition to this exclusion, nicotine users will not qualify to participate in the study, for nicotine increases caffeine metabolism by up to 50 percent (Choi, 2020). This precaution will be taken to guarantee that every subject's body is given an equal amount of time to onset the effect of caffeine. Caffeine is also known to have a variety of physiological adverse effects, including but not limited to arrhythmia, heart palpitations, trouble sleeping, anxiety, and nausea (Berg, 2024). The exclusion criteria will thus extend to those who undergo metabolic or endocrine disorders, heart conditions, diabetes, medications with interactions to caffeine metabolism, and daily caffeinated beverage intake.

A psychomotor vigilance task (PVT) will be used to measure a subject's simple reaction time using the *PVT Research Tool* application available only on Apple iOS devices. Images and

procedures are shown in Appendix A. Recorded data will be transferred onto an Excel file and sent to the researchers for statistical analysis. All subjects will be required to perform a three-minute test. The second task to measure sustained attention utilizes the Digit Symbol Substitution Test (DSST), which will be prescribed on paper and pen. Appendix B displays the DSST along with the instructions that will be provided for the subjects.

3.3 – Procedure:

After recruiting participants fit for the experiment, they will schedule a testing session with the researchers at the North Carolina Wesleyan University main campus at 10 am. It will be required for all participants to abstain from caffeine or excess sugar intake 24 hours prior to the testing session. The experimental treatment (1 mg/kg caffeine) will be prepared in a cup of filtered water alongside a normal glass of water that will represent the placebo/control treatment (no caffeine). Caffeine is shown to have a distinguished bitter taste (Poole & Tordoff, 2017) in its pure, powder form, but research suggests that low doses of caffeine in water pose no noticeable taste. Therefore, the placebo will not be masked to match the experimental treatment. In future studies, it will be necessary to mask the higher doses of caffeine in water to eliminate the bitter taste.

On the day of a visit, a researcher will administer a random cup, both labeled “A” or “B”, to a subject, and the cup consumed will be annotated for the lead researcher so that they may prepare the opposing treatment for the subject’s next visit (unbeknownst to the other researcher). After a subject consumes the treatment on any visit, they will proceed to take a 45-minute absorption period to account for the onset time of caffeine. During these 45 minutes, participants will be allowed to relax and read a book, scroll on their phone, and perform any activity that is not physically or mentally overwhelming, such as going for a walk, solving a complex puzzle, or playing mobile games that demand fast reaction times. Afterward, testing will begin, and the

subject will be free to leave after completing both the PVT and the DSST, which should conclude no later than 11 am. All participants, after both visits, will be compensated twenty dollars for their time and commitment. In the case of any adverse effects of caffeine occurring on a subject, the campus physician assistant will be on stand-by to examine the subject. A subject will also have the right to see any physician of their choosing. In case of a medical emergency beyond the control of the PA, the researchers will contact 911 for emergency medical services. The following study will be reviewed by the North Carolina Wesleyan Institutional Review Board and will be approved after considering the experimental boundaries and ethical standards.

3.4 – Design:

This experiment will include two independent variables, those being the three age groups (young, middle-aged, and older) and the two treatment groups (caffeine and placebo). Since a person's age cannot be transferred across other age groups, the former independent variable is known as a between-subjects variable. Moreover, since all subjects will participate in a caffeine and placebo condition, the latter variable is known as a within-subjects variable. Given this description, the following study will be organized as a double-blind, placebo-controlled, 3x2 mixed factorial design, as shown in Figure 2. The dependent variables measured in this study will consist of the scores obtained by the PVT and DSST results.

		I.V. 1: ***Age Groups***		
		Young Adults	Middle-aged Adults	Older Adults
I.V. 2: ***Treatment Groups***	Experimental	Dependent Variable	Dependent Variable	Dependent Variable
	Placebo-Control	Dependent Variable	Dependent Variable	Dependent Variable

Figure 2: Table layout of IV and DV groups.

PVT results will indicate individual, mean, and median successful scores based on time in milliseconds. False scores (< 150ms) or errors will not be collected or analyzed. DSST results will be tallied by the correct number of scores, as well as the incorrect number of scores, over the total number of responses for each participant at the discretion of the researchers. Based on the means of scores, normality of the results will be assessed by histograms. Due to the multiple number of cells in this design, an appropriate statistical analysis method is to perform a two-way, mixed analysis of variance (two-way, mixed ANOVA) to analyze the between-subjects factors with the within-subjects factors. The percent error $p < 0.05$ will be used to measure the statistical significance of the obtained results. To reduce the risk of concluding the false existence of statistical difference among between-subject factors, a post-hoc test, namely Tukey's HSD (Honestly Significant Difference), will be performed after analyzing the two-way, mixed ANOVA. Microsoft Excel will be the tool used to analyze the obtained data.

In accordance with the hypotheses of this experimental study, PVT cell means are expected to be lowest in all categories among younger adults due to naturally quicker hand-eye dexterity than in middle-aged to older adults. In turn, the highest PVT cell means are likely to occur among older adults. As for the DSST, cell means are likely to be highest among younger adults and lowest among older adults, though it is expected that young adults are likely to have more error rates across the board.

3.5 – Significance and Conclusion:

Based on the found research and what is already known about caffeine, it is likely that a higher dosage of caffeine will be necessary for a middle-aged to elderly adult to experience the same benefits that a young adult would consume, though one must consider the health risks

involved. These health risks may include, but are not limited to insomnia, nervousness, restlessness, nausea, increased heart rate, anxiety, and chest pain (Travers, 2017).

On a more practical basis, the test for simple reaction time is essential for everyday tasks that involve strong precaution, such as driving. The introduction of optimal caffeine doses may show improvement in this task and possible prevention of car collisions on the road. The measurement of sustained attention is significant to test for any everyday task that involves consistent focus, such as writing or typing, whether it be recreational, professional, or educational. Caffeine may show that its consumption at an optimal dose is likely to prevent little, yet consistent errors. By identifying the optimal caffeine dose range with respect to age, this research will help develop a path for age-specific caffeine intake recommendations for all individuals.

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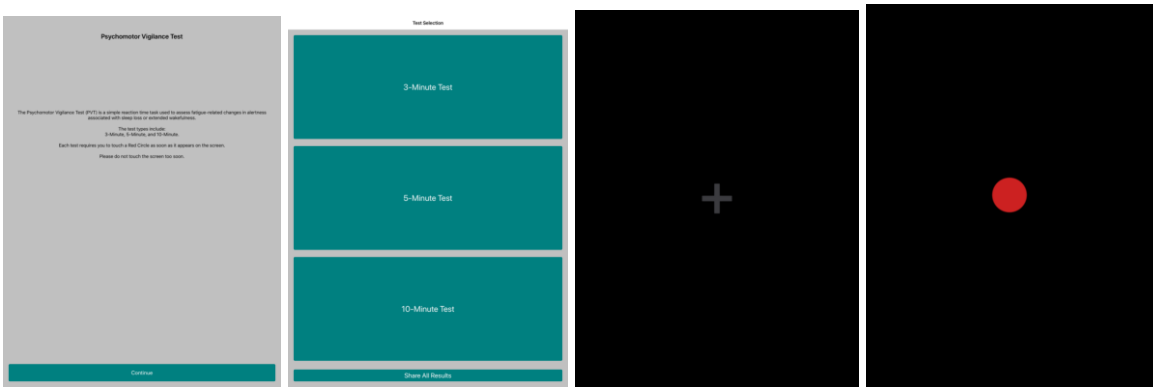
Appendix A

Psychomotor Vigilance Task

The following images display the mobile application *PVT Research Tool*, developed by The Texas A&M University System CSE, and are provided by the Apple App Store on its main page (PVT Tool, 2019). One can choose to take either a three-minute test, a five-minute test, or a ten-minute test. Upon beginning the task, a person will see a dark grey plus sign. Between intervals of two to fifteen seconds, a red circle will appear and act as the stimulus. A person must press on the screen as quickly as possible after noticing the stimulus. Reaction time will be recorded in milliseconds. False starts (< 150 ms) and failed reactions will also be recorded. Results will be inscribed on an Excel sheet and can be downloaded on the mobile device used.

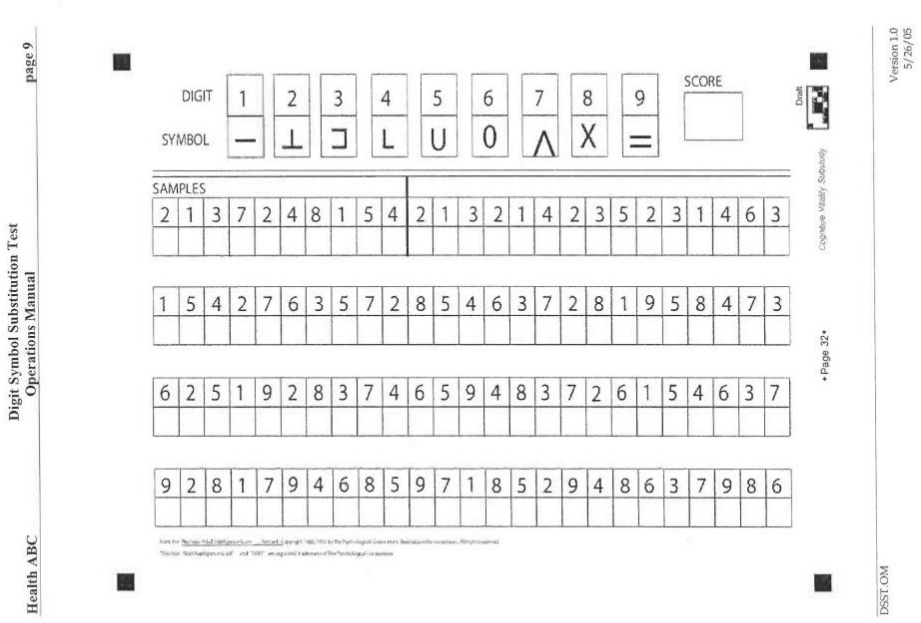


Screenshots of the *PVT Research Tool*.

Appendix B

Digit Symbol Substitution Test

The Digit Symbol Substitution Test is a neuropsychological test used to assess processing speed and attention. The DSST is a core subtest of the Wechsler Adult Intelligence Scale (WAIS), often used in clinical neuropsychological settings. Below is the test that will be administered in this study. At the top of the landscaped page, there is a key made up of integers 0 to 9 with a symbol labeled below it. Below is the workspace where a line of integers in no particular order are above empty boxes for the subject to fill. The subject will be tasked to write down as many matching symbols to its corresponding integer as possible in a 90-second time span. The results will be collected from each subject after the 90 seconds conclude, and only correct responses, per the discretion of the researchers, will be used for data analysis.



Actual *DSST* worksheet used to measure sustained attention.