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Does the method of consuming caffeine influence its effects?

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ABSTRACT

Caffeine is an integral part of the daily lives of many undergraduate students and is often used to increase cognitive wakefulness and as a tool to help the learner maintain their focus throughout a long day of studying. The researchers sought to understand the objective physiological and cognitive effects of the caffeine found in coffee, where they specifically focused on heart and respiratory rates, cognitive wakefulness, and the possible moderating influence of temperature and milk. Methodology: Both the correlational and the experimental study utilized a longitudinal within subject design, and the experimental study utilized a double-blind procedure. The correlational study showed the following results: (1) Heart rate and caffeine consumption had statistically significant results in the pooled raw data but insignificant in the pooled standardized data. (2) Respiratory rate and caffeine consumption had insignificant results. (3) Milk percentage and cognitive wakefulness had insignificant results. (4) Temperature of caffeine and cognitive wakefulness had insignificant results. Caffeine consumption and cognitive wakefulness showed statistically significant results in the standardized pooled data. The experimental design utilized a double-blind procedure to test if caffeine influences heart rate. However, it showed statistically insignificant results. This research study provides a solid foundation for other likeminded students to expand upon.

1. Introduction

1.1 Research Problem

Undergraduate students frequently utilize caffeinated products for a multitude of reasons. Caffeine is primarily used to increase cognitive arousal and to assist the individual in maintaining their focus. According to a study by Mahoney et al. (2019), among a sample of 1200 university students 92% reported using caffeinated products at least once in the past year, which exemplifies caffeine's popularity. Due to caffeine's prevalent use, the researchers wanted to discern whether the stimulating effect of caffeine is merely a placebo effect or if there is merit to the continued use of caffeine. Furthermore, if caffeine consumption does have a significant effect, the researchers wanted to discover what method of consuming coffee acts the quickest and provides the most effective delivery system for caffeine. Should one choose hot coffee or cold brew? Does adding milk into one's coffee lessen its stimulating impact? Will drinking one's beverage quicker result in a faster onset of caffeine's stimulating effects? As caffeine is one of the most widely used drugs on the legal market, these questions are important ones that hold relevance to most who enjoy it in any of its varied forms.

1.2 Literature Review

Contrary to public perception, consuming a caffeinated beverage does not cause statistically significant changes in vital signs. Brothers et.al (2016) investigated the effect of caffeine from both coffee and energy drinks on heart rate, blood pressure and QT interval (electrical activity of the heart) in a population of fifteen normotensive (normal blood pressure), non-smoking young adults. Their study was comprised of two components: During component 1, participants were given strictly controlled caffeine quantities that were titrated to the individual based on body weight. For component 2, caffeine was administered in quantities that an individual would normally consume (e.g., one serving of coffee, or one can of energy drink.). Brothers et. al, recognized that most people will not carefully titrate the amount of caffeine they consume to their body weight. Instead, people are more likely to measure their caffeine usage based on the serving size of the beverage. Therefore, component 2 examined the effects of caffeine being consumed in a practical dose. In this case, the participants were given one serving of coffee, and another set of participants were given a whole can of energy drink to consume. For both the caffeine-controlled study and the normal use study, the results did not find that caffeine had any measurable effect on the heart rate, blood pressure or the QT intervals.

Also contrary to what would be expected based on pharmacokinetics, neither the temperature of the beverage, the type of caffeinated beverage, nor the length of time it takes to consume it has any effect on caffeine concentration in the blood plasma. According to White et al. (2016), there is actually little to no variation in the peak concentration of caffeine in the participants' blood plasma after consuming hot coffee, cold coffee or chilled energy drink. Furthermore, the peak effects of caffeine manifest within 50 minutes post-consumption regardless of which of these drinks were used. Their study contained 24 participants (n=12 men, n=12 women) and measurements of caffeine plasma concentrations were extracted from blood samples taken prior to drink administration and then at intervals of five minutes until 480 minutes post-administration. The drinks taken included hot coffee, cold coffee and sugar-free energy drink. These drinks were consumed over both 20-minute periods and 2-minute periods, with the exclusion of hot coffee, which was taken only over a 20-minute period due to safety concerns. However, although there were no significant differences in caffeine area under the curve from time zero to infinity, cold coffee consumed in a 2-minute period exhibited the highest caffeine plasma concentrations in the participants caffeine concentration-time profile.

There is a possibility that other factors, such as the amount of milk added to the caffeinated beverage, moderate the immediate physiological effects of caffeine. Quinlan, Lane, & Aspinall (1997) examined the effect of adding milk into hot beverages, which included tea, coffee and hot water (which had 100mg/400ml caffeine added, so the caffeine concentration was equivalent to the coffee and tea). The dependent variables measured were skin conductance and temperature; heart rate; blood pressure; salivary cortisol concentration subjective anxiety levels and overall mood. The sample group consisted 16 individuals (n=8 men, n=8 women), who had a median age of 35.5 at the time of this study. The participants were non caffeine-naïve, who habitually consumed their coffee with milk. Furthermore, none of the participants smoked and were otherwise healthy individuals. When drinking coffee, the participants showed acute spikes in their heart rate and skin conductance. The participants who consumed coffee with milk added, had a heart rate spike of 9.4 bpm 10 minutes post consumption. When the beverages without the presence of milk were consumed, participants showed a spike of 11.7 bpm from their baseline heart rate. The participants skin conductance levels had a similar spike. Notably, the caffeine levels found in the saliva of the participants remained consistent regardless of the presence of milk which indicates the bioavailability of caffeine is not altered by the presence of milk. However, the researchers hypothesized that milk acts as a mediating influence on the subjective experience of drinking coffee, and the acute physiological effects may be explained by a sensory reaction to coffee's natural bitterness, although more research would be required to substantiate that claim.

1.3 Hypotheses

During the literature review, it was noted that the aforementioned studies did not adequately control for the placebo effect, which could have been a confounding variable influencing the results of the participants. Furthermore, drinking their caffeinated beverages in a foreign environment may have increased anxiety levels in the participants, which could potentially have influenced the outcome of their trials. This led the researchers of this paper to create the following five hypotheses for testing in a longitudinal correlational study and a follow-up double-blind experimental study.

Main effects of caffeine:

Hypothesis #1: If caffeine intake increases, then heart rate will be unchanged.

Hypothesis #2: If caffeine intake increases, then respiratory rate will be unchanged.

Hypothesis #3: If caffeine intake increases, then cognitive wakefulness will be unchanged.

Moderators of caffeine effects:

Hypothesis #4: If the temperature of coffee decreases, then cognitive wakefulness will be unchanged.

Hypothesis #5: If the quantity of milk in a caffeinated beverage increases, then cognitive wakefulness will decrease.

2. Methods

2.1 Participants

Three participants were tested in these studies, with ages ranging from 19 to 32 years old and with an average age of 24.5 years (n=1 men, n=2 women) The participants were all students in Psychology 245 at Camosun College and grouped together due to a mutual interest in the effects of caffeine. All the participants were regular caffeine users and the caffeine amounts that the participants consumed fell within their normal levels.

2.2 Correlational Study Methods

2.2.1 Materials

Each participant measured the temperature of their coffee with an Accutemp Compact Folding Thermometer immediately prior to consumption. The participants used a French Press style coffee maker with 400ml of 60.0 C water. They documented cognitive wakefulness by using the Simple Reaction Time box target test from the “Psych Lab 101” mobile phone app (Neurobehavioral Systems, Inc).

2.2.2 Procedure

Self-reported data was collected by each participant on 12 consecutive days. Upon first waking up, the participants recorded their baseline heart and respiratory rates. Once their physiological data was recorded, the participants took the Simple Reaction Time test (SRT) as a measure of their cognitive arousal. The participants agreed to record the first set of data between the hours of 7:00 AM and 10:00 AM, prior to consuming any caffeinated products.

First, the participants measured their Heart Rate (HR) by manually counting their radial pulse for 30-sec. They calculated their Beats Per Minute by multiplying their findings by 2. Second, they recorded their Respiratory Rate (RR) by counting the number of breaths they took for 30-sec and then multiplying this number by two to get the rate of breaths per minute. Third, participants completed a Simple Reaction Time test (SRT) on their mobile device to measure cognitive arousal. All three of the data points were recorded into their personal journal which accompanied them throughout the trial.

Upon completion of the SRT, the participant prepared their morning coffee. Prior to consumption, the participant recorded the quantity of caffeine in each serving of their coffee, the temperature of the beverage, and the quantity of milk added. All of this was added to their daily journal. Once the coffee was prepared, the participants had 30-min to consume their beverage, and after one hour, participants collected their post-consumption HR, HR and SRT scores. This sequence was repeated any time a participant drank coffee on a given day. At the end of the day, the participants calculated the change in their HR, RR and SRT scores to find the difference between baseline and post-consumption levels.

2.3 Experimental Study Methods

2.3.1 Materials

The researchers purchased two large bags of Alex Campbell’s Arabica bean from Thrifty Foods. Bag 1 contained caffeinated coffee grounds and bag 2 contained decaffeinated coffee grounds.

Bags 1&2 were subdivided into 36 individual clear plastic bags, which acted as portion-controlled servings. Each serving consisted of 15g (3tsp) of dry ground coffee. Each serving of caffeinated coffee grounds contained approximately 180 mg of caffeine, and the decaffeinated coffee contained approximately 21 mg of caffeine per serving. Every day each participant used one serving of coffee and 400 ml of boiling water in a French Press, which they allowed to sit for 2 minutes before compressing and pouring into a cup for consumption.

2.3.2 Procedure

Six bags were comprised of caffeinated coffee grounds and six bags were comprised of decaffeinated coffee grounds. Each bag was labeled 1-12 by another team member and given to another participant. The numbers associated with the caffeinated or decaffeinated coffee were selected at random, without a clear pattern to avoid the participants inadvertently guessing which control variable they were being exposed to. Each group member privately noted on a notepad which bags they filled with caffeinated coffee and which bags they filled with decaffeinated coffee prior to giving their labeled bags to another group member. Each group member noted who received the bags of coffee they filled. Pre-measuring coffee grounds controlled for possible placebo effects, as the participants were not aware of whether they were consuming caffeinated or decaffeinated coffee on a given day.

Following this, the individuals took home their premeasured bags of coffee and used those bags to make their coffee every morning. They used 350ml of 60.0 C water in a French Press or drip style coffee machine, and the individuals drank their coffee with no milk, sugar, or other additives to control for possible effects of the other additives. Furthermore, the coffee was consumed in the morning between the hours of 7:00 AM to 10:00 AM, which controlled for the individual expectations of increased wakefulness later in the day. During the Experimental study, the heart rate, respiratory rate, and cognitive wakefulness were all measured immediately prior to the consumption of caffeine, and directly after the coffee was consumed. The Correlational study likewise studied these effects and the same format was utilized to measure the change of psychological and cognitive functions.

The experimental design continued with the same procedure from the correlational method. Prior to drinking coffee in the morning, each participant measured their HR, RR, and conducted the SRT test. After the participant finished their coffee, they waited one hour before completing the same procedure. The participant pool for both the Correlational and Experimental studies entirely consisted of the three researchers, who all gave informed consent prior to conducting the study on themselves. Furthermore, on conclusion of the study, the participants conducted an informal debriefing with one another, and discussed the results and subjective experiences of each participant throughout the experiment.

3. Results

3.1 Correlational Study Results

3.1.1 Main Effects of Caffeine

Using raw data pooled across participants we found a statistically significant correlation (r = 0.61) between caffeine intake and heart rate (see Figure 1), although this relationship was not statistically significant when using data standardized for each participant (see Table 1). No statistically significant relationship was found between caffeine and respiratory rate, although unfortunately we were only able to test this hypothesis with one participant. However, we did find a statistically significant correlation between caffeine intake and cognitive wakefulness using pooled data across participants in either its raw (r = 0.48) or standardized (r = 0.43) form.

3.1.2 Moderators of Caffeine Effects

Using the pooled raw data there was a statistically significant correlation between the temperature of coffee and the level of cognitive wakefulness seen (r = 0.45), although no statistically significant correlation was seen when using data standardized for each participant (r = 0.21). Using either the pooled raw or standardized data, there was no statistically significant correlation was found between the quantity of milk in the caffeinated beverages consumed and the level of cognitive wakefulness seen.

3.2 Experimental Study Results

The results arising from the experimental manipulation of caffeine amount consumed

Figure 1. Scatterplot of changes in heart rate across levels of caffeine intake (Correlation study)

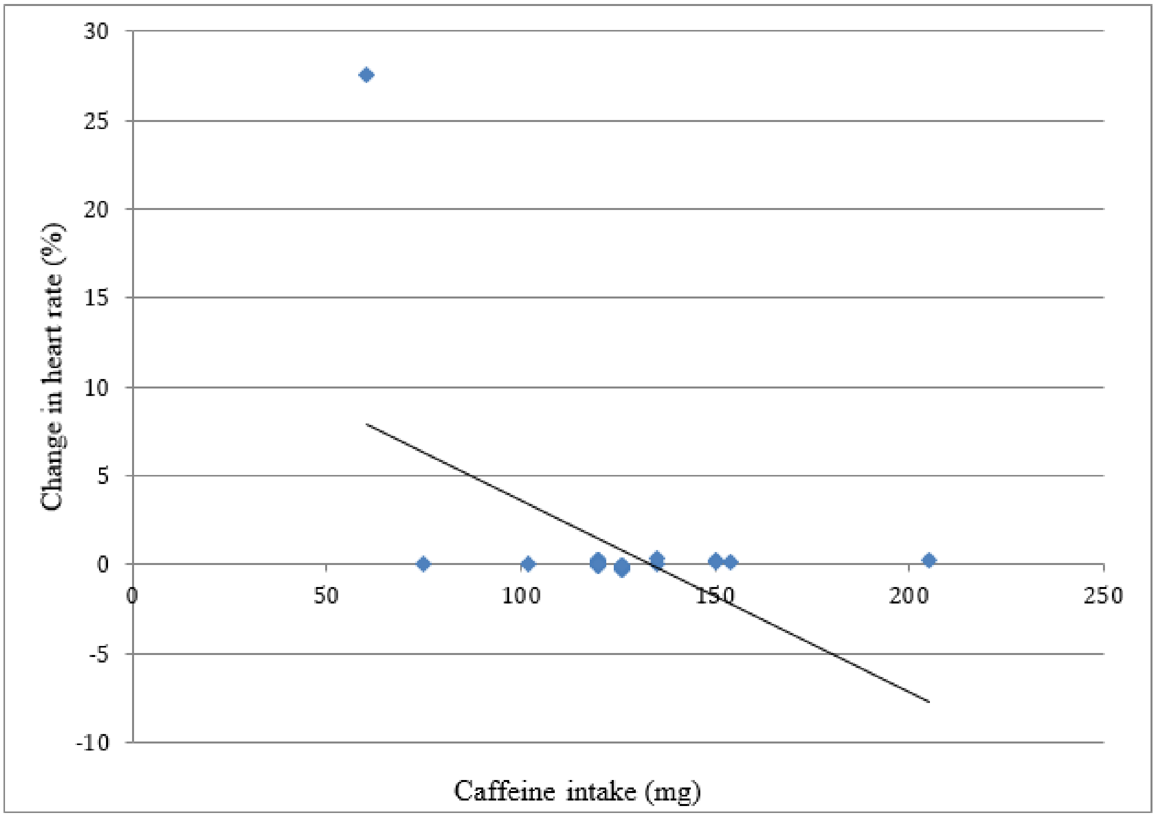

Figure 2. Bar graph of average (± 95% C.I.) change in heart rate across caffeine consumption conditions (pooled raw data from the Experimental study)

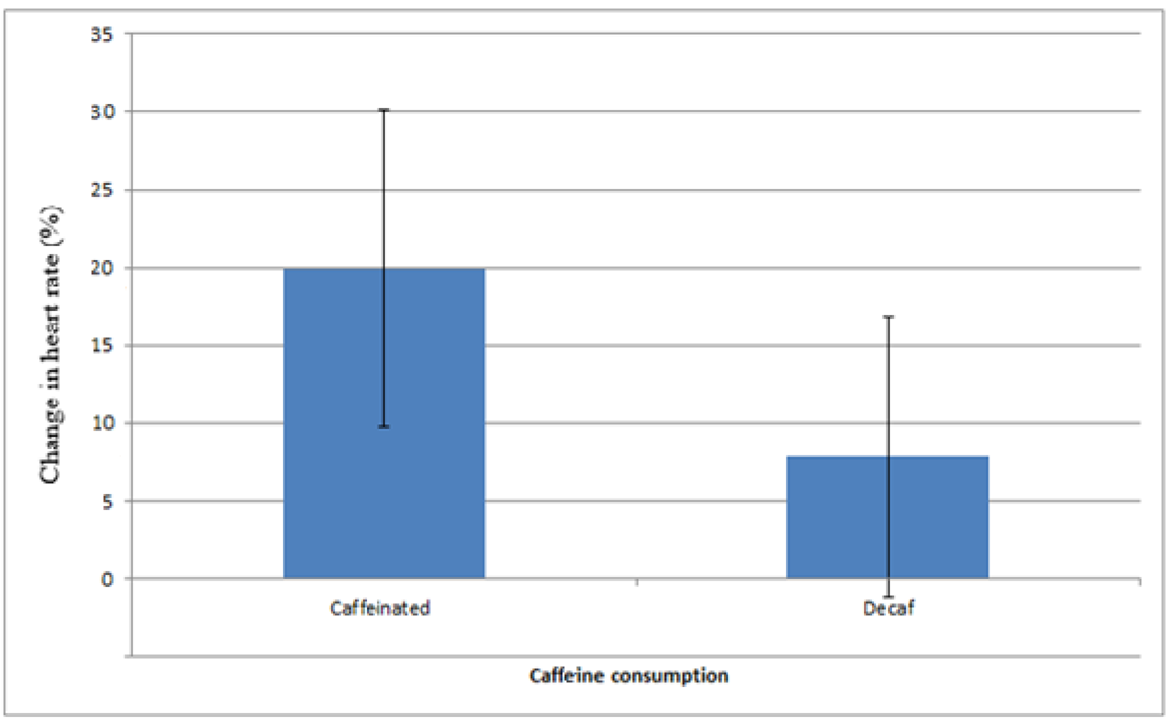

Table 1. Correlation coefficient (*r*) values from the Correlational Study, with number of trials (n) per correlation shown in brackets.

Relationship examined	Participant #1	Participant #2	Participant #3	Pooled raw data	Pooled standardized data
Heart rate and caffeine consumption	0.22(12)	-0.36(12)	0.07(12)	-0.51(36)*	0.09 (36)
Respiratory rate and caffeine consumption	0.54(12)	-	-	0.54(12)	0.54(12)
Milk percentage and cognitive wakefulness	-0.54(12)	.90(12) *	-	0.08(24)	0.18(24)
Temperature of caffeine and cognitive wakefulness	-0.06(12)	0.35(12)	0.13(12)	0.45(34)*	0.21(34)
Caffeine consumption and cognitive wakefulness	0.27(12)	0.91(12) *	.12(12)	0.48(36)*	0.43(36) *

*$p<.05$.

showed a statistically insignificant change in HR (p = 0.138; see Figure 2).

4. Discussion

The main purpose of this study was to discover the physiological effects of drinking caffeinated beverages. Furthermore, the researchers sought to understand any moderating influences of caffeine, including additives and temperature, to discover the most effective method of caffeine consumption. The data indicates that there is a mild positive correlation between caffeine intake and increased heart rate, respiratory rate and cognitive wakefulness. The data from the experimental portion of the study was not statistically significant.

4.1 Hypothesis #1 - As caffeine intake increases, the heart rate will remain the same.

During the correlational study, there was a statistically significant positive correlation in the raw pooled data (r = -0.51). One of the participants showed a mild negative correlation between heart rate and caffeine consumption, which differed from the positive correlation shown by the other two participants. The standardized data was not statistically significant and represented a very low correlation (r = 0.09). These findings are perplexing and have several possible explanations: there may have been collection problems for the HR data, and it is possible the data were not synthesized properly. It is also possible that the HR data should have been collected at multiple points after caffeine consumption. Quinlan et.al (1997) indicated that there was a minor increase in HR almost immediately post-consumption, which rapidly disappeared. Therefore, it is possible collecting the HR data one-hour post consumption could have missed the acute spike in HR. In the double-blind experimental study there was not a significant change in HR after coffee was consumed. The methods for physiological data collection in the experimental study were identical to those in the correlational study and, for the reasons listed above, it is likely the researchers missed the acute spike in HR, if one occurred at all.

4.2 Hypothesis #2 - As caffeine intake increases, the respiratory rate will remain the same.

Although the results were not statistically significant, there was a minor correlation (r = 0.51) exhibiting a relationship between caffeine consumption and increased respiratory rate. However, the sample size was only a single individual, and this may indicate a sensitivity to caffeine or experimenter bias causing these results. For further investigation, the participant pool should be larger, as the results of a single individual cannot be generalized to a population.

4.3 Hypothesis #3 - If caffeine intake increases, cognitive wakefulness will increase.

The testing of this hypothesis resulted in one of the highest raw pooled correlations for all the participants (r = 0.43). However, it should be noted that two participants showed very low correlations (r = 0.27 and r = 0.12) respectively, while one participant had an extremely high positive correlation (r = 0.91) which was statistically significant.

4.4 Hypothesis #4 - Colder coffee will not change the response to caffeine.

The results of testing this hypothesis showed very little correlation between temperature of coffee and cognitive arousal or any other physiological metric. However, the participants never consumed iced coffee, which means there is a possibility the coffee consumed was never cold enough to elicit this phenomenon. The researchers in White et al. (2016) kept their chilled beverages at 4C, while the researchers in Brothers et al. (2019) never deviated below 50C. Therefore, because the array of temperatures of coffee was severely limited, subsequent studies should examine the effect of iced coffee >0.0C alongside hot coffee in order to draw any conclusions about the correlation between temperature and physiological effect.

4.5 Hypothesis #5 - The consumption of caffeinated beverages with milk decreases the cognitive wakefulness-enhancing effects of caffeine within a beverage.

Interestingly, the results of testing this hypothesis varied greatly between participant one and two. This study examined the cognitive arousing effect of caffeine, which was measured via a simple reaction time test, courtesy of an app called Psych Lab 101. Participant one found a moderate negative correlation between increased milk quantity in a caffeinated beverage, and decreased reaction time scores, which indicated a higher level of cognitive arousal. However, participant two had the opposite results, and had a statistically significant, high positive correlation between increased milk solute in coffee and increased reaction time scores, which supports the initial hypothesis. If milk causes caffeine to be absorbed slower, it stands to reason the cognitive arousing effects of caffeine would be equally hampered. Unfortunately, the dataset is incomplete, as participant three did not conduct this correlational variable. The differences between participants one and two could be for a multitude of reasons, but a possible explanation could be the types of milk that were added to the beverages: Participant one is lactose intolerant, and thusly used non-dairy milk. The 'milk' participant one added to their coffee included: almond, coconut, soy and rice milk, which all have different fat and calorie contents to conventional cow milk. Also, for the duration of the baseline study, participant number one had varying brands and methods of consuming coffee, which ranged from espresso shots to drip style coffee, with varying amounts of 'milk' added. However, participant number two consistently consumed Starbucks brand Lattes with 2% cow milk added and had very little variation outside of this beverage. Subsequent studies should compare different kinds of milk analogues to examine the potential effects each one will have on metabolizing caffeine. This limited data may suggest that plant based milks are metabolized faster than animal milks, which suggests that people who avoid dairy may feel stronger effects from coffee than those who use traditional milk. Furthermore, other studies may compare skim milk to cream or whole milk, to look for a relationship between increased milk fat, and longer metabolism time.

4.6 Variations Between Participants

Notably across all of the variables, participant number three consistently had the lowest correlations, participant number two had the highest correlations, and participant number one had consistently moderate correlations.

4.7 Limitations

This study would benefit from several adjustments as there were several limiting factors that may have affected the outcome of this study. First, the quantity of caffeine used may not have been strong enough to elicit a strong response from the participant group. Due to the participants habitual caffeine use prior to the study, the quantity of caffeine consumed may not have been high enough to elicit a physiological effect.

Second, in subsequent studies, the researchers should utilize a similar methodology as Brothers, et.al (2017) study, where the baseline physiological data was recorded from seated participants who rested for 28 minutes, after which point their resting physiological data was recorded for 2-min. Post caffeine consumption the physiological data was automatically recorded at 30 intervals for 6 hours. This controls for user error, inadvertent bias and allows for an accurate representation of potential physiological changes. Participants in the current study were responsible for manually recording their own radial pulse. This method of data collection has several potential issues: Firstly, the baseline HR was recorded for 30s and the total was doubled to get the BPM. This collection period is significantly shorter than the procedures conducted by Brothers et al. (2017) and Quinlan et al. (1997) which took an average of HR data for 2-3 minutes respectively. Secondly, manually recording HR is a procedural skill that is easily miscalculated or misinterpreted. Furthermore, the participants should not manually record their vital signs, as the individual taking their own pulse allows for experimenter bias, which may inadvertently affect the reading and may produce inaccurate results.

In future research, the participant pool should be larger so that the sample size is more representative of the broader population. Furthermore, the other studies cited all contained samples ranging from 15-24 participants (Brothers et al., 2017; Quinlan et al., 1997; White et al., 2016).

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