CATÓLICA
FACULDADE DE EDUCAÇÃO E PSICOLOGIA

PORTO

THE COGNITIVE AND NEUROPSHYSIOLOGICAL IMPACT OF COFFEE CONSUMPTION

Dissertation presented to Universidade Católica Portuguesa in order to obtain a Master's Degree in Psychology

- Specialization in Clinical and Health Psychology -

Maria Inês Santos Pereira

Porto, July 2020

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This work was supervised by:

Professora Doutora Patrícia Oliveira-Silva

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Abstract

The objective of this within-subject study is threefold: to explore the self-reported cognitive impact of coffee intake (compared to decaf); to characterize the physiological profile of coffee consumption (compared to decaf) through a Wavelet analysis in regular consumers; to validate whether the heart rate could be a good physiological signature of the coffee effect at the physiological level. The sample (*n*=13) ranges between 18 and 50 years old. Participants were instructed to consume a randomly selected substance (coffee or decaffeinated) and had their cardiac activity continuously monitored for 45 minutes after consumption. In order to analyze the two conditions, a Discrete Wavelet Transform (DWT) was applied, followed by the Wilcoxon test. Our results showed a significant difference between the two conditions, confirming this approach's applicability to overcome the difficulty of analyzing continuous measurement, especially the peripheral neurophysiological measures). Also, the self-reported cognitive data are consistent with the neurophysiological results. Results imply that the Wavelet analysis might shed light on this field in order to find a more reliable way to assess the effect of psychoactive substances in clinical settings.

Keywords: coffee, decaffeinated, cardiac activity, Wavelet analysis, cognitive performance

Resumo

O objetivo deste estudo intra-sujeitos é triplo: explorar o impacto cognitivo do consumo do café (em comparação com o descafeinado) através do autorrelato; caracterizar o perfil fisiológico do consumo de café (em comparação com o descafeinado) através de uma análise de Wavelet em consumidores regulares; validar se a frequência cardíaca pode ser uma medida fisiológica do efeito do café no nível fisiológico. A amostra (*n*=13) tem idades compreendidas entre os 18 e 50 anos. Os participantes foram instruídos a consumir uma substância selecionada aleatoriamente (café ou descafeinado), a sua atividade cardíaca foi monitorada continuamente durantes os 45 minutos após o consumo. Para analisar as duas condições, foi aplicada a Discrete Wavelet Transform (DWT), seguida pelo teste de Wilcoxon. Os nossos resultados demonstraram uma diferença significativa entre as duas condições, confirmando a aplicabilidade desta dabordagem em superar a dificuldade de analisar a medidas contínuas, principalmente as medidas neurofisiológicas periféricas). Relativamente aos dados cognitivos recolhidos através do autorrelato, estes são consistentes com os resultados neurofisiológicos. Os resultados sugerem que a análise da Wavelet pode ser inovadora e contribuir para a exploração de uma forma mais eficaz de avaliar o efeito psicoativo de substâncias em contexto clínico.

Palavras-chave: café, descafeinado, atividade cardíaca, análise Wavelet, desempenho cognitivo

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Introduction

The history of the word “coffee” is still uncertain. It is known that coffee is found in 63 plant species called *Coffea Arabica*, naturally present in its leaves, seeds and fruits. The origin of the word comes from Arabia, where they call it “qahwah” (Cappelletti et al., 2015).

Coffee is the second most popular drink in the world; the only drink to surpass it is water. Every day we consume an impressive amount of 1.6 billion cups of coffee globally (Cappelletti et al., 2015). The Portuguese population consumed 15 tons of coffee only in 2018, spending 433 million euros in total. A Portuguese study concluded that 71.7% of their sample consumed caffeine from tea, coffee or barley (Pinhão et al., 2016).

In Portugal, a regular coffee has, on average, 28 ml, a “short” coffee has 17 ml, and a “full” coffee contains approximately 47 ml. A low-moderate consumption of coffee is from 1 to 3 / 4 cups of coffee per day (AICC, 2016). Usual caffeine consumers may be tolerant and develop withdrawal symptoms when they cease consuming caffeinated products after a long time of regular consumption (Irons et al., 2016). It is also well documented that individuals aged 35 to 64 years are the largest consumers, with an average intake of 250 mg/day (Registo, 2019).

There is a perception that caffeine is harmless because it is legal, so the consumers might not understand its potential effects, or due to the lack of valid and reliable methods of assessment (Irons et al., 2016). Authors have highlighted that individuals might tend to overestimate the caffeine content on soda, energy drinks and also on filter coffee, Starbucks coffee, and expresso (Mackus et al., 2016). The same authors describe that the reason for this confusion might be explained by the absence of information on the labels of products that naturally contain caffeine (e.g., coffee and tea). However, beverages with added caffeine, such as energy drinks, are obligated to inform the caffeine content of the item (Mackus et al., 2016).

The domestic environment was identified as the main place of coffee consumption (71%), followed by snack bars (19%) and work environments (8.6%). Surprisingly, coffee shops are the places where less coffee is consumed. Individuals also consume more coffee in the morning (50.5%), while 38% said they use the product during breakfast, 20.5% extend its use until lunchtime. This habit is justified by the perception of the product as a stimulant. They say that it is necessary to "start the day". The same behavior was not repeated in the afternoon (5.7%) and significantly decreased after dinner because it might "disturb their sleep". Most consumers (38.1%) associated coffee with a habit, pleasure, family, friendship and work demonstrating that coffee is present in almost every domain of their daily life (Arruda et al., 2009). This association also indicates that the motivations for its consumption reflects the social meaning of drinking coffee, whether at home, work or in the circle of friendship. In this way, coffee seems to be used worldwide to satisfy consumers' physiological and psychological needs (Arruda et al., 2009).

According to the statistics, the Portuguese population will double their coffee consumption over the next decade. It is expected that by the year 2021, every Portuguese will consume eight kilograms of coffee per year (Oliveira & Dias, s.d.). The coffee consumption at home is expected to rise by 20% more (Oliveira & Dias, s.d.). Given the implications of caffeine use and inconsistency of measurement methods from previous studies, it seems important to have a thorough and precise way of measuring caffeine consumption (Shohet & Landrum, 2001).

Considering the immense growth of these beverages in our culture and focusing on young adults, it is important to start new research lines that allow us to explore new ways to analyze the impact of coffee on the individuals' physiological activity. It is now crucial to develop new measures, other than self-report questionnaires, in order to obtain more objective indices. Thus, this study aims to understand the impact of caffeine consumption through a self-reported cognitive measure, compared to decaffeinated, but also through a peripheral neurophysiological measure, namely heart rate, using an innovative approach called Wavelet analysis.

Theoretical Framework

The Coffee Consumption

The most popular mood-altering, psychoactive drug in the world is caffeine (Babwah et al., 2018). Usually, this beverage is consumed as filtered coffee, boiled unfiltered coffee, and decaffeinated coffee. Many protective effects have been attributed to coffee intake, such as psychoactive responses (e.g., improving concentration, alertness, mood regulation); reducing mental and physical fatigue; giving a boost to perform day-to-day activities; the prevention of some chronic diseases (e.g., Parkinson's disease, cardiovascular diseases); protecting against some cancers; diminishing depression among women; providing powerful anti-oxidants; attenuating inflammation; reducing cognitive decline in the elderly; to cite a few (Heckman, Weil & Gonzalez de Meija, 2010; Alves, Casal & Oliveira, 2009; Nehlig, 2010).

In fact, coffee drink is safe. However, when consumed in high doses (500–1000 mg) coffee may produce some detrimental effects, namely, hypertension, cardiac arrhythmia, anxiety, tachycardia, insomnia, detrimental effects on working memory, anxiety, jitteriness, restlessness, ringing in the ears, confusion, tremors, fever, photophobia, vomiting, and diarrhea (Irons et al., 2016; Alves, Casal & Oliveira, 2009).

In the past ten years, there has been a tremendous growth of caffeine consumption in adolescents and young adults, and not only due to the increased intake of coffee, but also due to the increased consumption of other caffeinated products (El-Nimr, Bassiouny & Tayel, 2019). It was reported by the same authors that 44% of young adults (18 to 34 years old) drank coffee every day. For instance, more than 90% of college students claim to have consumed caffeine at least once in the previous year (Mahoney et al., 2019), many of them assumed to drink more than once a day. Interestingly, some reports showed that females consumed more caffeine than males, however, it is also warned that both males and females are exceeding the safe levels of caffeine consumption (El-Nimr, Bassiouny & Tayel, 2019). Continuous and excessive use of caffeine may happen due to the young people's (and even adults') lack of understanding of the amount of caffeine in the products they consume and view them as "soft products/drinks" (Babwah et al., 2018; Mahoney et al., 2019).

The Coffee Absorption

After being ingested, caffeine is of rapid absorption. It goes from the gastrointestinal tract into the circulatory system after approximately 30 to 60 minutes of ingestion, when it reaches the plasma concentrations peak (Cappelletti et al., 2015). The authors also found that the caffeine has been found to sometimes peak between 15 and 120 min after consumption. They have determined that this lack of homogeneity can occur due to inter-individual differences and delayed gastric emptying. Generally, the half-life of the caffeine is between 4 to 6 hours on adult population (Irons et al., 2016).

The caffeine exerts its psychoactive effects by blocking adenosine receptors. Adenosine is a neurotransmitter that produces inhibitory effects in both the central and peripheral nervous systems. Caffeine works by blocking the adenosine receptors, promoting its inhibitory effects, and originating the drug effect (Sands et al., 2014). After this step, several systems are affected, such as the neuropsychiatric, cardiovascular, endocrine, and gastrointestinal systems (Cornelis, 2006).

The Coffee Cognitive and Physiological Impact

According to the Institute for Coffee Studies, coffee has a positive impact on the central nervous system: caffeine acts on the cerebral cortex, exerting an excitatory effect on the neurons, favoring mental faculties such as attention, concentration, alertness, memory (Romeiro & Delgado, 2012) and also on neural networks that accounts for the emotional response (Giles et al., 2018). Caffeine is considered to improve performance, reaction time, and mental and visual processing, which are prerequisites for practicing any sport (Romeiro & Delgado, 2012). Caffeine has a positive impact in both cognitive and affective dimensions (Attwood, Higgs & Terry, 2007).

In the study carried out by Sands et al. (2014), the authors assessed the impact of caffeine on mood and psychomotor performance in consumers and nonconsumers alike and concluded that a typical cup of coffee does influence mood and psychomotor performance in both conditions. In the same line, the authors explored if coffee compared to a placebo (cornflour placebo, containing 0 mg of caffeine) would produce significant changes on the expected areas. During the experiment the participant´s attended three sessions, with an overnight caffeine abstinence of 12 hours. According to Snel, Lorist & Tieges (2004) the consumption of one to four cups of coffee can influence cognitive activity. Their research concluded that caffeine is able enhance an individual´s performance, during multiple mental tasks such has cognitive, learning, memory and attention tasks. The authors also described that there is also the possibility that caffeine might impact the performance of the participant during vigilance tasks.

In the study of Smith, Christopher, and Sutherland (2013), the authors confirmed that, in tasks typically impaired by reduced alertness (e.g., variable fore-period simple reaction time tasks, vigilance tasks, and choice reaction time tasks) participants showed better performance after the consumption of caffeine, compared to decaffeinated coffee or tea. However, accordingly to Nehlig (2010) the performance in learning and memory tasks were not commonly affected by caffeine consumption. It was proven that on few occasions, caffeine could affect memory learning, and also have facilitatory or inhibitory effects due to complex interactions with dose, subject, and task variables. The author confirmed that a variety of mental tasks performance can be improved by the consumption of caffeine, directly or indirectly, by decreasing decrements in performance under suboptimal alertness conditions.

Assessment of Coffee Effect´s

The coffee effect has been studied almost exclusively using self-report measures. However, this approach might have limited validity because of many factors: individual expectancies, learning impact, and the inability to detect subtle effects on the cognitive and affective domains.

In fact, few studies have intended to explore the effect of caffeine intake in the physiological systems (Pradhan et al., 2020; Sargent et at., 2020; Uddin et al., 2014), which can represent a previous step in order to understand the individual differences and its impact on brain functioning. Uddin et al. (2014) study intended to explore the effects of caffeinated beverage consumption through the electrocardiography (ECG). The participants (all male, from 19 to 27 years old) of their study refrain from smoking and drinking up to 6 hours prior to the experiment. The ECG signal was recorded through the BIOPAC. Afterwards, the effects of the caffeinated beverage consumption were analyzed by peak amplitude variation of different waves and their corresponding intervals of ECG signal. The authors found that the consumption of caffeinated beverage has significant influence on peak amplitude of the waves and the different intervals of the ECG signal. However, the study also found negative impacts on peak amplitude and heart rate that in the future might contribute to the development of any type of heart abnormality. Due to these findings, it would be wise to avoid caffeine consumption so as not to develop cardiac irregularities.

Thus, a more objective measure, such as using peripheral neurophysiological measures (i.e., based on cardiac, respiratory, or electrodermal systems) to index individual reactivity, might be useful.

The cardiovascular system seems to be a good candidate and a reliable signature of the coffee impact in the body functioning. The cardiac activity is a very complex physiological system that depends on multiple regulatory subsystems, which interact with the central and peripheral autonomic controls and humoral influences (Berntson, Cacioppo & Tassinary, 2017). In other words, to control the heart, an individual needs to count on a very sensitive neurobehavioral process.

The cardiovascular system is controlled by the sympathetic and parasympathetic branches of the autonomic nervous system. There are both local intrinsic auto-regulatory processes and extrinsic regulatory processes that are linked to autonomic and hormonal systems. According to Berntson and colleagues (1995), any substance increasing the sympathetic influence on the cardiovascular system will produce similar increase in heart rate.

One potent substance modulating the sympathetic nervous system, namely, increasing its excitability, is the caffeine (Glade, 2010).

Although we may find useful measures to monitor drinking coffee's effect over time, it is worth noting that this step is not enough. It is also needed to have a good measurement method strategy to extract relevant information from the data. A common approach to quantification of heart activity is by calculating mean values for interval of interests. Therefore, processing heart rate signals have been the focus of many researchers for a long time, and many authors have discussed the limitations underlying this approach (Berntson, Cacioppo & Tassinary, 2017; Nasrolahzadeh et al., 2019). Many authors have warned about the need to invest in developing and testing new approaches that would allow more reliable information to be extracted from neurophysiological signals, especially in long records that exceeded a few minutes. It has been warned that nonsignificant results might occur because of large measurement error (mainly caused by using only mean values) and the poor consideration of different elements (i.e., high and low frequency waves) that compose the signal (Laborde, Mosley & Thayer, 2017; Seraganian et al., 1985; Stern et al., 2001).

Thus, the present within-subject study was conducted to (i) to explore the self-reported cognitive impact of coffee intake (compared to decaf) ; (ii) investigate whether the continuous cardiac monitoring using an adjusted Lead II configuration can differentiate the caffeine intake from the decaf intake when analyzed through a continuous wavelet transform, and therefore, can be used for assessment in the clinical practice; and (iii) validate whether the heart rate could be a good physiological signature of the coffee effect at the peripheral neuro physiological level.

Methods

This study aimed at comparing the impact of a cup of coffee intake (compared to the decaffeinated intake) at the cardiac activity over 45 minutes after the intake, using a Wavelet analysis to explore the differences between the conditions, in a double-blinded within-subject design. The proposal was submitted to and approved by the Internal Ethics Committee. As expected, participants were not obliged to complete the procedure, meaning that they could leave at any time without experiencing any adverse effects.

This study followed a quantitative methodology, and the main objective is to assess the impact of caffeine and decaf intake on the pattern of peripheral neurophysiological reactivity (namely, cardiac frequency) of regular consumers, using a wavelet transform.

The inclusion criteria were to consume coffee regularly (at least once a day), to be 18 years old or older, to have signed the informed consent and not having any clinical condition that prevents drinking coffee (as reported by the participants themselves). The exclusion criteria were as follows: self-reported history of mental disorders, current irregular sleep disorder (especially during the night before the data collection), being on any medication regularly, and substance abuse. The participants are between 18 to 50 years old. No participant dropped out or was excluded from the study.

Sample

A convenient sample of thirteen participants (5 male; 8 female; ranging in age from 18 to 46 years old: *mean* ± *SD* = 24.15 ± 7.71 years; regarding qualifications, 7.7% had middle school, 61.5% finished high school, 23.1% had a degree, 7.7% had Master's Degree) were involved in this study after being recruited through social media and student associations. The frequency of coffee intake ranged from one to six expressos per day in working days, and one to three expressos in weekend days. Regarding participants' profession, 84.6% declared to be students, 15.4% were working. Still, regarding civil status, 93.3% were single, 7.7% divorced.

Instruments

The instruments administered to the participants during the study were the following:

Sociodemographic Data

A questionnaire collected sociodemographic information regarding the participants' sex, age, academic formation, coffee consumption habits (e.g., how many cups of coffee they consume on a regular basis, why do they consume coffee, on which occasions they consume coffee), and also if they had coffee before the experiment (see appendix A). Since this study is part of a bigger project, some of the questions will not be presented or discussed here.

Peripheral Neurophysiological Data

The BIOPAC MP160 (Santa Barbara – CA, USA) data collection system was used to collect the peripheral neurophysiological data during both the baseline and the experimental procedure. The ECG100C amplifier was used to record the electrical activity generated by the heart, namely recording an electrocardiogram (ECG). The ECG was registered through an adjusted Lead-II configuration using three electrodes (one electrode placed in the middle of both clavicles and a third at the top of the left shoulder). The software that accompanies the BIOPAC system (i.e., AcqKnowledge) was programmed to calculate online the Heart Rate, the metric used for this study.

Cognitive Data

A self-report measure was applied throughout the experiment in order to evaluate the cognitive performance of the participants. This instrument evaluated the participants perspective of their cognitive performance with a 5-point Likert Scale (1 very sleepy - 5 very focused) at four different moments (baseline/before condition taking; and 15, 30 and 45 minutes after the condition intake) for both coffee and decaffeinated coffee conditions.

Synchronization Software

The Psycho-Py (Peirce et al, 2019) was used to synchronize all the procedure with the peripheral neurophysiological data recording. The Builder interface was used to provide the needed platform to write scripts in order to create the behavioral paradigm, deliver the stimuli, synchronize with the AcqKnowledge including markers related to the task performance, and control the procedure.

Procedures

Data Collection

The data was collected at the Human Neurobehavioral Laboratory by trained research assistants (two researcher assistants were involved in each data collection to ensure that the conditions were double-blinded, i.e., the researcher interacting directly with the participants were not aware of the condition being applied at that moment. After being recruited, participants were scheduled to make two visits to the lab. In one of the appointments, they had to randomly and fully blinded, drink a cup of coffee, and in the other, they had to consume a decaf coffee.

When arriving in the lab for the data collection, participants signed the declaration of informed consent (see appendix B), and filled the sociodemographic questionnaire before having the setup of the electrodes to record the peripheral neurophysiological signals. Before consuming the substance, participants participated in a baseline recording and learned how to perform some cognitive tasks that were presented during the 45 minutes of monitoring of the substance's effect. However, those data (baseline, cognitive and affective assessments) are not part of the current study, but instead, part of a more extensive project.

Data Treatment and Analysis

This section explains the wavelet transform (WT), which versatile applicability has fascinated researchers from different fields. The WT will be used in this study as a feature extraction method. Over the last decade, psychologists have worked more and more with physiological signals. Subsequently, they have struggled to apply sophisticated techniques to biosignals, such as advanced signal processing and machine learning. One recent method used when analyzing peripheral psychophysiological signals is the WT, a linear transformation of the signal from time to frequency domain (Gomes & Velho, 2015). Much of the interest related to Wavelet analysis is due to its flexibility in handling multiple nonstationary signals. The WT allows the experimenter to do a sub-band decomposition based on a downsampling process (Addison, 2017).

There are multiples advantages of working with the WT, such as, probing the chosen signal at different scales, obtaining more information for other types of post-processing methods, and also, the WT-based analysis can match to the local variations of the input time sequence, resulting in a more detailed representation of the signal (Vetterli, & Herley, 1992). The wavelet-domain feature space can improve the identification of the performance during a variety of human activities through the signals created by body responses. This means that it can improve the classification of the performance because of the distinctive feature space produced (Feng, Golshan & Mahoor, 2018). Additionally, it is also possible to quantify the results of the WT using traditional statistical analysis (Issartel, 2015).

Usually, researchers use three types of WT, namely the Continuous WT, Discrete WT, and Wavelet Packet Decomposition. Decomposing the signal means, in the first level, to run the DWT process through a decomposition of the signal into approximation and detail components. In other words, this process means to apply a low-pass and a high-pass filter, and subsequently, repeat the decomposition in the same process (Issartel, 2015). The DTW requires the use of two functions presented in Figure 1.

There are currently several studies in the psychology field that choose to adopt the wavelet transform (WT) methodology such as, Slewa-Younan et al.. These authors demonstrated differences between males and females with schizophrenia in their brain functional connectivity. Other examples are studies on music, body movement coordinated with the melody by Jones, recognition of emotional facial expression by Knyazev et al., or interpersonal motor coordination by Issartel et al., and the list goes on (as cited in Issartel, 2015).

In their studies Slewa-Younan et al.; Jones; Knyazev; and Issartel, recognize the massive potentiality of this method and its increasing application in a remarkably wide variety of Psychology fields, demonstrating the importance for psychology to explore the WT method in the peripheral neurophysiological data (as cited in Issartel, 2015). Some authors have been even more emphatic about the role of the WT method, saying that it allows us to collect information on any complex synchronization between time-series in most Psychology areas (Issartel, 2015).

Figure 1

Wavelet Transform functions

$$\varphi[n] = \sum_k h[k] \cdot \varphi[2 \cdot n - k]$$

$$\psi[n] = \sum_k g[k] \cdot \varphi[2 \cdot n - k]$$

Note. This figure demonstrates the two set of functions required for the Wavelet Transform analysis (adapt from Rodrigues et al., 2018). From "Electroencephalogram hybrid method for alzheimer early detection", by P. M. Rodrigues et al., 2018, *Procedia computer science*, *138*, 209-214.

Another concept important to clarify is the Cepstral Analysis (CA). The CA is a competent tool to analyze the time lags in replicas in conventional frequency bands. The CA consists of a signal analysis technique that results from a homomorphic transformation named cepstrum (functions showed in Figure 2). The cepstrum allows at least two signals deconvolution in the time-domain, making it suitable to split the source and filter the components. For this reason, is tremendously applied in speech signal processing (Rodrigues et al, 2018).

Figure 2

Cepstral Analysis function

$$c_i = c_j = IDFT\ (\log(|DFT(x_i\,(\mathrm{n}))|))$$

Note. This figure demonstrates the Cepstral Analysis function (adapted from Rodrigues et al., 2018). From "Electroencephalogram hybrid method for alzheimer early detection", by P. M. Rodrigues et al., 2018, *Procedia computer science*, *138*, 209-214.

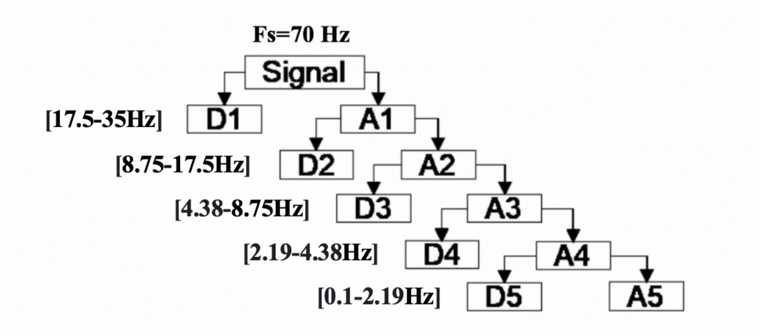
Finally, the last two steps consist on the ECG features extraction and the statistical analysis between the study groups (coffee and decaf).

The sampling frequency of the data was 70 Hz, processed in the AcqKnowledge, without the preprocessing application of any digital filters. The ECG (electrocardiogram) signal was segmented in sections of 5 seconds to be analyzed using a toolbox developed in Matlab environment for the WT. The wavelet used in this study was the Symlet 4 with five levels. Each signal (coffee and decaf) was decomposed at 5 levels, has demonstrated in Figure 3, which allows us to localize the bands where we can find differences between the two conditions.

The same time frame was previously used in other studies with ECG signals and proved to be reliable (Sharma & Acharya, 2019).

Figure 3

ECG Wavelet decomposition



Note. This figure demonstrates the Wavelet decomposition of the ECG signal (adapted from Rodrigues et al., 2018). From "Electroencephalogram hybrid method for alzheimer early detection", by P. M. Rodrigues et al., 2018, *Procedia computer science*, *138*, 209-214.

Finally, the last two steps consist on the ECG features extraction and the statistical analysis between the study groups (coffee and decaf). The statistical analysis, was conducted through the Statistical Package software for the Social Sciences (IMB SPSS) v.26. The cepstral distances (CD) parameters homoscedasticity were analyzed through the *Paired-samples test* and through the normality with the *Shapiro-Wilk*. The data distribution did not meet the parametric test hypotheses. We then analyzed the differences between groups by using the *Wilcoxon test* and the *Sign test*, which produced the same results. Since the results were identical, the *Wilcoxon test* was selected to conduct the data analysis (Martins, 2011). Since the data fulfilled the *Wilcoxon test's assumptions, it was used* to compare the differences in the ECG signal data of the participants (within-subjects factor) on two different conditions (intake of a cup of coffee and a cup of decaf).

Regarding the levels of statistical significance, a level of $p < .05$ was considered.

Results

The results of the present study will be presented according to the research question: *Are there differences in the pattern of autonomic activation at the level of the cardiac activity between coffee and decaf consumption*?

The Table 1 presents the statistical differences between the consumption of coffee and decaffeinated found on the CD^1 and CD^2 bands through a 5 second segment in ECG signals.

Table 1

Wilcoxon test results – rectangular window

WT family	Features	Z	*p*
	CD^1	-1,712[a]	.087**
	CD^2	-1,992[a]	.046*
Symlet 4	CD^3	-1,083[a]	.279
	CD^4	-1,153[a]	.249
	CD^5	-,734[a]	.463

There are marginally significant differences between coffee consumption and decaffeinated consumption in the band CD^1, $Z(13)=-1{,}712$, $p=.087$ (Table 1), and significant differences between coffee consumption and decaffeinated consumption in the band CD^2, $Z(13)=-1{,}992$, $p=.046$ (Table 1). It was also discovered that the bands CD^3, CD^4, and CD^5 do not allow the identification of differences between these two conditions ($p > .05$). Compared to the decaffeinated drink, coffee influence the different energy bands in which the signal was decomposed, especially the CD^1 and CD^2.

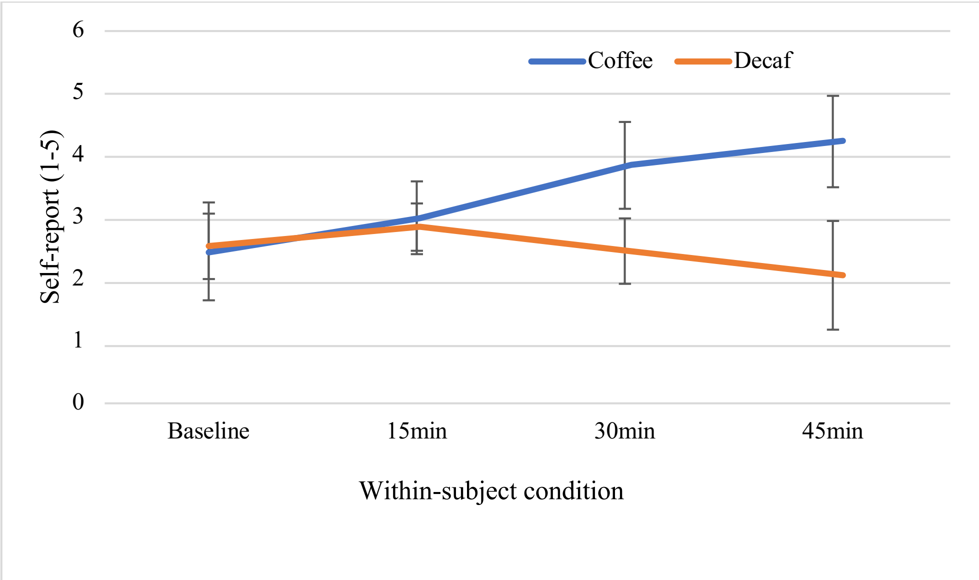
It was discovered that the bands CD^3, CD^4, and CD^5 do not allow to identify differences between coffee consumption and decaffeinated consumption ($p > .05$). At the same time, the CD^2 proved to be a promising measure to identify those differences.

Results showed that the heart rate is an excellent candidate to differentiate the impact of psychoactive substances, namely caffeine, through the monitoring of peripheral measures. In fact, the cardiac measure has shown to be differentially affected by the intake condition. In this study, the ECG signal associated with the coffee intake showed significantly more energetic than the signal related to the decaf intake in two energy bands.

There are also differences between coffee consumption and decaffeinated consumption accordingly to the self-report measure. As showed on Figure 4, during the baseline tasks (before substance consumption) the participants perception of cognitive performance was remarkably similar, both substances scored between 2 and 3. After the baseline tasks and during the 15 minutes after substance consumption, the participants indicated an increase in their cognitive performance. However, the perception of the participants who had consumed decaf reached its peak slightly before reaching a score of 3, while the perception of the participants who had consumed coffee continued to rise. At 30 minutes after the substance consumption, the participants who had consumed coffee scored close to 4, demonstrating a steady increase, while the participants who had consumed decaf showed steady decrease, scoring between 2 and 3. A similar outcome to the baseline tasks. At the 45-minute mark, the participants who had consumed coffee demonstrated a continuous increase, scoring over 4. On the other hand, the participants who had consumed decaf demonstrated a continuous decrease, scoring only 2. During the 45-minute mark the perception of the participants who consumed coffee reached the highest score (a little over 4) recorded while the perception of the participants who consumed decaf was at his lowest (close to 2).

Figure 4

Cognitive Performance Results



Note. The graphic demonstrates the participants perception of the substances impact in the cognitive performance, throughout the 45 minutes of the experiment.

The Figure 2 allows us to understand that due to the participants unawareness of the nature of the substance they are consuming, the baseline task for both substances begins with very similar results, demonstrating that the substance consumption acted has a stimulus. However, through the course of the cognitive tasks it becomes clear that the participants presented better results when they consumed coffee. As presented in Figure 4, the perception of the participants is that coffee increases cognitive performance since, 45 minutes after the substance consumption the coffee score reached double the score of the decaf.

Dicussion

This study intends to contribute to the development and validation of innovative and more objective data analysis approaches to investigate the impact of psychoactive substances at the physiological level. There is a need to provide new diagnostic tools for this field in order to avoid relying exclusively on self-report measures.

Here, in a within-subject design, we randomly administered a cup of coffee and a cup of decaf (in different days) on a sample of 13 participants, who had their cardiac activity monitored for 45 minutes and a monitored of their cognitive functioning through a self-report measure. Finally, a WT was applied to the dataset to explore different energy patterns between the two conditions. Coffee was chosen because it is the most consumed psychoactive substance in the world and contains many compounds that influence the cognitive and affective functioning (Farah, 2009; McLellan, Caldwell &Lieberman, 2016). We tested whether splitting the physiological wave associated with each condition (coffee or decaf), using a wavelet decomposition approach to extract additional features from the biosignal, could signal the potential effect that the coffee might have in the brain functioning. During the data treatment, the ECG signal was processed by the WT in order to reconstruct the bands components. Then we proceeded to analyze the band components through the CA, in order to evaluate the 5 second lag between the bands. The results demonstrated that, significant statistical differences were found in the CD^2 and marginally significant statistical differences were found in the CD^1.

In fact, the analysis conducted demonstrated that a hybrid method (the WT and CA) can detect differences on the ECG signal after the consumption of coffee and decaffeinated. The proposed approach takes into account a wavelet coefficient that extracts features in different levels of resolution, representing a powerful tool for peripheral neurophysiological measures decomposition.

Much like the ECG signal treatment through the WT, the self-report measures also demonstrated differences between the consumption of coffee and decaffeinated. The participants who had consumed coffee presented a continuous increase in their perception of cognitive performance during the 45 minutes of the experience. However, the participants who had consumed decaf initially demonstrated an increase, up until the 15-minute mark. Then, the score preceded to decline until the 45-minute mark, ending with half the caffeine consumption score.

For future research, some of the limitations not addressed in this study must be considered. For instance, the focus should be placed on obtaining a larger sample of the population to ensure generalization, and on using other modalities of the peripheral neurophysiological activity, such as the electrodermal activity or respiratory frequency, in combination with self-report measures, to compare the accuracy and synchrony of those two measures. Besides, since comparing caffeinated and decaffeinated coffee can have many limitations related to the product itself (e.g., differences on the roasting and brewing processes or the quality and the exact quantity of beans used to prepare the product, the grinding technique applied, the temperature and preparation of the drink) all of this might implicate differences in the potential impact that the substance might have. Therefore, to control for these variables, we suggest to compare different brands.

In conclusion, this study helped to overcome three limitations in this field: the difficulty of analyzing continuous measurement (especially when recording peripheral neurophysiological measures); the participants' difficulty on being aware, or even their unwillingness to precisely report the effect of psychoactive substances; the challenge of capturing discrete differences in the signal that could not be obtained using means or other mean scores or central tendency measures.

References

Addison, P. S. (2017). *The illustrated wavelet transform handbook: introductory theory and applications in science, engineering, medicine and finance*. CRC press.

Alves, R. C., Casal, S., & Oliveira, B. (2009). *Benefícios do café na saúde: mito ou realidade? Química Nova, 32*(8), 2169–2180. https://doi.org/10.1590/s0100-40422009000800031

Arruda, A. C., Minim, V. P. R., Ferreira, M. A. M., Minim, L. A., da Silva, N. M., & Soares, C. F. (2009). Justificativas e motivações do consumo e não consumo de café. *Ciência e Tecnologia de Alimentos*, *24*(4), 754-763. https://doi.org/10.1590/s0101-20612009000400009

Associação Industrial e Comercial do Café (AICC). (2016) *Consumo de café em Portugal: Tipologia e Volume*. Programa Café e Sade, Associação Industrial e Comercial do Café. http://aicc.pt/wp-content/uploads/2016/01/Newsletter-3.pdf

Attwood A. S., Higgs S., Terry P. (2007). Differential responsiveness to caffeine and perceived effects of caffeine in low and high regular caffeine consumers. *Psychopharmacology*, *190*(4), 469-477. https://doi.org/10.1007/s00213-006-0643-5

Babwah, T. J., Ramcharan, C., Ramgoolam, C., Sookoo, N., Creese, W., Pamassar, M., & Ramdin, R. (2018). Most Major Side Effects of Caffeine Experienced by Young Adults Are Acute Effects and Are Related to Their Weekly Dosage Ingested. *Journal of Caffeine and Adenosine Research*, *8*(1), 18-26. https://doi.org/10.1089/caff.2017.0008

Berntson, G. G., Cacioppo, J. T., & Tassinary, L. G. (Eds.). (2017). *Handbook of psychophysiology*. Cambridge University Press.

Cappelletti, S., Daria, P., Sani, G., & Aromatario, M. (2015). Caffeine: cognitive and physical performance enhancer or psychoactive drug?. *Current neuropharmacology*, *13*(1), 71-88. https://doi.org/10.2174/157015913666141210215655

Cornelis MC, El-Sohemy A, Kabagambe EK, Campos H. (2006) Coffee, CYP1A2 genotype, and risk of myocardial infarction. *JAMA, 295*(19), 1135. https://doi.org/10.1001/jama.295.10.1135

El-Nimr, N. A., Bassiouny, S. H., & Tayel, D. I. (2019). Pattern of Caffeine Consumption among University Students. *Journal of High Institute of Public Health*, *49*(3), 154-161. https://doi.org/10.21608/JHIPH.2019.56579

Farah, A. (2009). Coffee as a speciality and functional beverage. *Functional and Speciality Beverage Technology*, 370–395. https://doi.org/10.1533/9781845695569.3.370

Feng, H., Golshan, H. M., & Mahoor, M. H. (2018). A wavelet-based approach to emotion classification using EDA signals. *Expert Systems with Applications*, *112*, 77–86. https://doi.org/10.1016/j.eswa.2018.06.014

Giles, G. E., Spring, A. M., Urry, H. L., Moran, J. M., Mahoney, C. R., & Kanarek, R. B. (2018). Caffeine alters emotion and emotional responses in low habitual caffeine consumers. *Canadian Journal of Physiology and Pharmacology*, *96*(2), 191–199. https://doi.org/10.1139/cjpp-2017-0224

Glade, M. J. (2010). Caffeine-not just a stimulant. *Nutrition*, *26*(10): 932–938. https://doi.org/10.1016/j.nut.2010.08.004

Gomes, J., & Velho, L. (2015). *From Fourier analysis to wavelets*. Springer.

Heckman M.A., Weil J. & Gonzalez de Mejia E. (2010). Caffeine (1, 3, 7- trimethylxanthine) in foods: a comprehensive review on consumption, functionality, safety, and regulatory matters. *Journal of Food Science*, *75*(3), 77-78. https://doi.org/10.1111/j.1750-3841.2010.01561.x

Irons, J. G., Bassett, D. T., Prendergast, C. O., Landrum, R. E., & Heinz, A. J. (2016). Development and initial validation of the caffeine consumption questionnaire-revised. *Journal of Caffeine Research*, *6*(1), 20-25. https://doi.org/10.1089/jcr.2015.0012

Issartel, J., Bardainne, T., Gaillot, P., & Marin, L. (2015). The relevance of the cross-wavelet transform in the analysis of human interaction - a tutorial. *Frontiers in Psychology, 5.* https://doi.org/10.3389/fpsyg.2014.01566

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research–recommendations for experiment planning, data analysis, and data reporting. *Frontiers in psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00213

Mackus, M., van de Loo, A. J., Benson, S., Scholey, A., & Verster, J. C. (2016). Consumption of caffeinated beverages and the awareness of their caffeine content among Dutch students. *Appetite, 103*(1), 353-357. https://doi.org/10.1016/j.appet.2016.04.038

Mahoney, C. R., Giles, G. E., Marriott, B. P., Judelson, D. A., Glickman, E. L., Geiselman, P. J., & Lieberman, H. R. (2019). Intake of caffeine from all sources and reasons for use by college students. *Clinical Nutrition, 38*(2), 668-675. https://doi.org/10.1016/j.clnu.2018.04.004

Martins, C. (2011). *Manual de análise de dados quantitativos com recurso ao IBM SPSS: saber decidir, fazer, interpretar e redigir*. Psiquilibrios

McLellan, T. M., Caldwell, J. A., & Lieberman, H. R. (2016). A review of caffeine's effects on cognitive, physical and occupational performance. *Neuroscience & Biobehavioral Reviews*, *71*, 294–312. https://doi.org/10.1016/j.neubiorev.2016.09.001

Nasrolahzadeh, M., Mohammadpoory, Z., & Haddadnia, J. (2019). Analysis of heart rate signals during meditation using visibility graph complexity. *Cognitive neurodynamics*, *13*(1), 45-52. https://doi.org/10.1007/s11571-018-9501-5

Nehlig, A. (2010). Is caffeine a cognitive enhancer?. *Journal of Alzheimer's Disease, 29*(1), 85-94. https://doi.org/10.3233/JAD-2010-091315

Oliveira, T. & Dias, R. R. (s.d.). Tendências Económico-sociais no Consumo de Café em Portugal para 2021 D issertação de Mestrado, Instituto Português de Administração de Marketing. IPAM Repositório.

Phan J.K., Shah S.A. (2014). Effect of caffeinated versus noncaffeinated energy drinks on central blood pressures. *Pharmacotherapy, 34*(6), 555-560. https://doi.org/10.1002/phar.1419

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Hchenberger, R., Sogo, H., K astman, E., Lindelv, J. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*. https://doi.org/10.3758/s13428-018-01193-y

Pinhão, S., Poínhos, R., Franchini, B., Afonso, C., Teixeira, V. H., Moreira, P., ... & Correia, F. (2016). Avaliação da ingestão energética e em macronutrientes da população adulta portuguesa. *Revista Portuguesa de Saúde Pública, 34*(3), 220-235. https://doi.org/10.1016/j.rpsp.2016.06.004

Pradhan, B. K., Tarafdar, K. K., Nayak, S. K., Khasnobish, A., Chakravarty, S., Ray, S. S., & Pal, K. (2020). Dataset for EEG signals used to detect the effect of coffee consumption on the activation of SSVEP signal. *Data in brief*, *29*, 105174. https://doi.org/10.1016/j.dib.2020.105174

Registo (2012, Junho 21). *Mais Cafeína!*. http://dspace.uevora.pt/rdpc/bitstream/10174/22596/1/Registoedicao212.pdf

Rodrigues, P. M., Freitas, D., Teixeira, J. P., Bispo, B., Alves, D., & Garrett, C. (2018). Electroencephalogram hybrid method for alzheimer early detection. *Procedia computer science*, *138*, 209-214. https://doi.org/10.1016/j.procs.2018.10.030

Romeiro, S. & Delgado, M. (2012). A sade numa chávena de café. *Revista Nutrícias*.

Sands, H. R., Downey, L. A., Wilson, R. P., Abbott, L. R., Tysse, B., & Parrott, A. C. (2014). Mood and psychomotor tremor changes following acute caffeine consumption in moderate and minimal caffeine consumers. *Journal of Caffeine Research*, 5(1), 42-49. https://doi.org/10.1089/jcr.2014.0020

Sargent, A., Watson, J., Topoglu, Y., Ye, H., Suri, R., & Ayaz, H. (2020). Impact of tea and coffee consumption on cognitive performance: an fNIRS and EDA study. *Applied Sciences*, *10*(7), 2390. https://doi.org/10.3390/app10072390

Seraganian, P., Hanley, J. A., Hollander, B. J., Roskies, E., Smilga, C., Martin, N. D., ... & Oseasohn, R. (1985). Exaggerated psychophysiological reactivity: Issues in quantification and reliability. *Journal of Psychosomatic Research*, *29*(4), 393-405. https://doi.org/10.1016/0022-3999(85)90025-

Sharma, M., & Rajendra Acharya, U. (2019). A New Method to Identify Coronary Artery Disease with ECG Signals and Time-Frequency Concentrated Antisymmetric Biorthogonal Wavelet Filter Bank. *Pattern Recognition Letters*, *125*(1), 235-240. https://doi.org/10.1016/j.patrec.2019.04.014

Shohet, K. L., & Landrum, R. E. (2001). Caffeine consumption questionnaire: a standardized measure for caffeine consumption in undergraduate students. *Psychological reports, 89*(3), 521-526. https://doi.org/10.2466/pr0.2001.89.3.521

Smith, A. P., Christopher, G., & Sutherland, D. (2013). Acute effects of caffeine on attention: a comparison of non-consumers and withdrawn consumers. *Journal of psychopharmacology*, *27*(1), 77-83. https://doi.org/10.1177/0269881112460112

Stern, R. M., Stern, R. M., Ray, W. J., & Quigley, K. S. (2001). *Psychophysiological recording*. Oxford University Press.

Snel, J., Lorist, M. M., & Tieges, Z. (2004). *Coffee, caffeine, and cognitive performance.* In A. Nehlig (Ed.), *Nutrition, brain, and behavior. Coffee, tea, chocolate, and the brain* (p. 53–71). CRC Press. https://doi.org/10.1016/j.patrec.2019.04.014

Uddin, M. B., Hossain, M. Z., Ahmad, M., Ahmed, N., & Rashid, M. A. (2014). Effects of Caffeinated Beverage Consumption on Electrocardiographic Parameters among Healthy Adults. *Modern Applied Science*, *8*(2). https://doi.org/10.5539/mas.v8n2p69

Vetterli, M., & Herley, C. (1992). Wavelets and filter banks: Theory and design. *IEEE transactions on signal processing*, *40*(9). https://doi.org/10.1109/78.157221

Appendices

Appendix A

Sociodemographic Questionnaire

PROJETO DELTA

Código do participante: ______________________________

Human Neurobehavioral Laboratory

UNIVERSIDADE CATÓLICA PORTUGUESA PORTO

QUESTIONÁRIO SÓCIO DEMOGRÁFICO

Sexo: __________ Idade: __________ Estado Civil: ____________

Habilitações literárias: ____

Profissão: ____

Tem algum problema de visão não corrigido? __________________________________

Tem algum problema cardiovascular? _______________________________________

Hoje é um dia típico ou ocorreu algum evento inesperado? ______________________

Quanto à quantidade e qualidade do sono, teve uma noite típica? ____

Há algo em especial que hoje a esteja a preocupar? ___________________________

Sente algum nível de fadiga no dia de hoje? Sim ___ Não ___

Se sim, classifique de 1 (muito baixa) a 5 (muito alta): ______________________

Tomou alguma bebida que contenha cafeína (e.g. bebidas energéticas, chá, coca-cola) nas últimas 24 horas antes da vinda ao laboratório? Sim ___ Não ___

Se sim, há quantos minutos atrás? ___________________________________

Que outros produtos com cafeína costuma consumir (e.g. bebidas energéticas, chá, coca-cola)? ___________________

Ingeriu álcool antes da vinda ao laboratório? Sim ___ Não ___

Se sim, há quantos minutos atrás? ______________________________________

Se fumar, há quanto tempo fumou o último cigarro? ____________________________

Porque é que não consome café? Coloque uma cruz nas opções que se identifica:

Não gosta do sabor ___	É dispendioso ___
Não gosta do efeito ___	Possibilidade de adição ___
Pressão para não tomar ___	Grupo social não consome ___
Nunca experimentou ___	Outros motivos_______________________

Appendix B

Declaration of Informed Consent

DECLARAÇÃO DE CONSETIMENTO INFORMADO

O presente estudo tem como principal objetivo avaliar o comportamento psicofisiológico após a toma de produtos com cafeína. Esta investigação será conduzida por investigadores associados ao *Human Neurobehavioral Laboratory* (HNL) da Faculdade de Educação e Psicologia (FEP) e à Escola Superior de Biotecnologia (ESB) da Universidade Católica Portuguesa (UCP).

A recolha de dados deste estudo consistirá numa tarefa laboratorial no HNL, com uma duração aproximada de 60 minutos, na qual se solicita aos participantes a ingestão de produtos com cafeína e, subsequentemente, que realize um conjunto de tarefas cognitivas. Ao longo da tarefa serão igualmente recolhidas medidas de caráter fisiológico (e.g. atividade cardíaca, respiratória e eletrodérmica). Adicionalmente, será pedido aos participantes alguns dados sociodemográficos, relevantes para a caracterização da amostra, bem como o preenchimento de um questionário para a avaliação de humor (antes e após a tarefa).

A informação recolhida e tratada pela FEP-UCP no âmbito deste estudo será estritamente confidencial, sendo assegurado o anonimato de todos os participantes do estudo. Informamos que, dado o caráter de anonimato deste estudo, não será possível aos participantes exercer o direito de acesso e retificação dos dados ou requerer a sua eliminação. Os dados recolhidos serão usados apenas para fins de identificação e instrumentos dos participantes serão eliminados após o final do estudo.

A participação no estudo é totalmente voluntária, podendo o participante desistir a qualquer momento, sem que isso envolva qualquer prejuízo para o mesmo. Não está prevista qualquer despesa ou forma de remuneração aos participantes, e não foram identificados quaisquer riscos que possam advir da participação neste estudo.

Assinatura do Participante: Assinatura do Investigador: