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Behavioural Interventions in Support of Healthy Brain Aging

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I would like to dedicate this thesis to the most important people in the World - my Dad, my Mom, André and Avó...

Acknowledgements

Time is a funny thing. It is a duality between the eternal and the ephemeral.

Embarking on this dissertation appeared to be a never-ending journey, one I felt I was unprepared to undertake since it was only recently I started my undergraduate degree. Or was that already five years ago?!

I started my first year pursuing an engineering degree in micro and nanotechnology but by the end of second semester I was curious about technological developments combined with "real" applications in the field of health care. I transferred to biomedical engineering. I thought the move would also spare me from a few scary courses, but no, they all caught up to me. The cramming, sleepless nights and agonizing anticipation of grade results felt interminable.

Such a strange sense now that all this has passed!

I am truly fortunate. I have come across some amazing people – friends, colleagues, professors. People who have guided and helped me to understand and grow, both intellectually and as a human being.

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I would also like to thank all of my friends for always being by my side, for making me laugh, for listening to me, for giving me advice and for all the great times.

Finally, to my family to whom I owe everything and love with all my heart - my mom, my dad, my brother Andre and avó, thank you. I am so blessed to have you in my life.

You always believed in me and constantly push me to go further. You are who I aspire to be one day.

Winds in the east,
Mist coming in,
Like something is brewing,
And about to begin!

-Mary Poppins

Abstract

- Motivation: Neuroplasticity is the brain's ability to change across it's lifespan. These changes may occur due to genetics or the environment that each person is brought up into. Understanding how behavioural changes can enhance cognition may help delay the manifestations of disorders associated with neurodegenerative or neuropsychiatric conditions.
- Hypothesis: For this study we hypothesized that individuals who spend their lives training to excel in a specific activity will present an enhanced cognition in old age compared to a sedentary lifestyle.
- Experimental Procedure: In order to better understand how specific lifestyle activities have an impact on cognition, a comparison between four groups of people over the age of 60 was made. Expert musicians, meditators and athletes were compared to a group of people that led a sedentary lifestyle. Questionnaires were presented to withdraw demographic information, IQ and scores regarding their health and well-being. Brain wave activity and behavioural components were assessed using an electroencephalogram and tasks such as the Go/No-Go, the Short-Term Memory test, the Colour Search task and Resting State was recorded and analyzed.
- Results: The overall results show that the meditation group excelled at attention tasks, whereas musicians and athletes tended towards higher inhibitory component. Entropy measurements were carried out and showed that higher values across all times scales were linked to expert groups, possibly translating in a higher amount of available brain resources, when compared to people who follow sedentary patterns.

Keywords: brain plasticity; cognition; electroencephalography; lifestyle; attention; inhibitory control; entropy

Resumo

- Motivação: Plasticidade cerebral é a capacidade de o cérebro se alterar ao longo da vida. Estas alterações podem ocorrer devido a caraterísticas genéticas ou devido ao envolvente em que a pessoa se encontra (e com que cresceu). Compreender de que modo alterações comportamentais estimulam a cognição pode retardar as manifestações de patologias associadas a condições neurodegenerativas ou neuropsiquiátricas.
- Hipótese: Propomos como hipótese que as pessoas que dedicam grande parte das suas vidas focadas numa atividade específica, apresentarão uma cognição fortalecida em idades mais avançadas, quando comparados com aqueles que levam uma vida sedentária.
- Processo Experimental: Foi realizada uma comparação entre quatro grupos, com participantes de idades superiores a 60 anos. Indivíduos especializados em música, meditação e desporto foram comparadas com pessoas que possuem um estilo de vida sedentário. Para além das informações demográficas, QI e resultados referentes à saúde e bem-estar, atividade cerebral e componentes comportamentais foram avaliadas usando um eletroencefalograma, e tarefas como o Go/No-Go, testes de memória a curto prazo e de identificação de cor e o estado de repouso do cérebro.
- Resultados: Os resultados mostram que o grupo de meditação se destacou nos testes de atenção, enquanto que o grupo de músicos e de atletas apresentaram um maior componente de inibição. Valores de entropia também foram avaliados revelando que os mais elevados ao longo de todas as escalas temporais estão associados com os grupos especializados, o que possivelmente se traduz numa maior quantidade de recursos disponíveis comparativamente a pessoas que seguem padrões sedentários.

Palavras-chave: plasticidade cerebral; cognição; eletroencefalografia; atividades diárias; atenção; controlo de inibição; entropia

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Abbreviations

AD Alzheimer's Disease.

ADHD Attention Deficit Hyperactivity Disorder.

Ag/AgCl Silver/Silver Chloride.

BNT Boston Naming Test.

BR Brain Reserve.

CNS Central Nervous System.

Cz Midline Central Electrode Location.

DC Direct Current.

EC Entorhinal Cortex.

EEG Electroencephalogram.

EFs Executive Functions.

EMG Electroyogram.

ERP Event-Related Potential.

FCz Midline Fronto-Central Electrode Location.

Fz Midline Frontal Electrode Location.

GUI Graphic User Interface.

ICA Independent Component Analysis.

IQ Intelligence Quotient.

MCI Mild Cognitive Impairment.

MSE Multi-Scale Entropy.

N2 Negative Deflection Peaking at About 200 msec After Presentation of Stimulus.

P3 Positive Deflection Peaking at About 300 msec After Presentation of Stimulus.

PCA Principal Component Analysis.

RSPM Raven's Standard Progressive Matrix.

SF-36 36-Item Short Form Health Survey.

SNS Sympathetic Nervous System.

VRII Visual Reproductive Delayed Recall.

CHAPTER 1

INTRODUCTION

1.1 Context and Motivation

Given that the population is getting older and the associated neuropsychiatric disorders increase with age, it is important to better understand how to maintain brain and cognitive health in order to prevent cognitive deterioration. For this reason, it is relevant to "identify and remediate brain and cognitive dysfunction before clinical symptoms manifest and disability develops" (Freitas, Farzan, & Pascual-Leone, 2013).

It is comprehensible that the brain is altered across the lifespan, however, what remains unclear is how exactly it changes. Over the past few years, evidence has increasingly shown that the aging process alters cognition and behaviour throughout each individual's life (Freitas et al., 2013). Dividing cognitive functions into three main groups, i.e. basic, high-level and complex, allows to better understand how the brain's changes (affected by age) will influence daily lives. The basic cognitive functions mostly affected are attention and memory. Language processing and decision-making are high-level cognitive functions which may also suffer changes. Complex cognitive tasks will depend on executive functions (EFs) which are thought to be the main contributors to age-related declines in a range of cognitive tasks (Riddle, 2007). Table 1.1 presents a summary of how executive functions may impact certain aspects of life, such as its influence on physical or mental health, quality of life and academic or professional accomplishments. In particular, the cognitive functions that rely on the medial temporal lobe and prefrontal cortex, such as learning, memory and executive functions, show significant age-related decline (Burke & Barnes, 2006). EFs are defined by Miyake as being "general-purpose control mechanisms that modulate the operation of various cognitive sub-processes and thereby regulate the dynamics of human cognition" (Miyake et al., 2000). Because they are involved in several daily activities, the smallest change in EFs could have a significant

impact on a person's life (Moreno & Farzan, 2015).

Aside from observing the brain's structure and function change over time, we see the brain's plasticity affected (Stern, 2012). Brain plasticity can be defined "as the ability of the brain to modify itself or be altered by the external environment" (Moreno & Bidelman, 2014). Freitas et al., (2013) indicate that a "functionally normal" brain is a changing brain, a brain whose capacity and mechanisms of change are shifting appropriately from one time-point in life to another", however, understanding how and why those changes occur may be crucial to develop reliable and adaptable methods to individually assess the mechanisms of brain plasticity.

Aspects of life	The ways in which EFs are relevant to that aspect of life	References
Mental health	EFs are impaired in many mental disorders, including:	
	- Addictions	Baler & Volkow 2006
	- Attention deficit hyperactivity (ADHD)	Diamond 2005, Lui & Tannock 2007
	- Conduct disorder	Fairchild et al. 2009
	- Depression	Taylor-Tavares et al. 2007
	- Obsessive compulsive disorder (OCD)	Penadés et al. 2007
	- Schizophrenia	Barch 2005
Physical health	Poorer EFs are associated with obesity, overeating, substance abuse, and poor treatment adherence	Crescioni et al. 2011, Miller et al. 2011, Riggs et al. 2010
Quality of life	People with better EFs enjoy a better quality of life	Brown & Landgraf 2010, Davis et al. 2010
School readiness	EFs are more important for school readiness than are IQ or entry-level reading or math	Blair & Razza 2007, Morrison et al. 2010
School success	EFs predict both math and reading competence throughout the school years	Borella et al. 2010, Duncan et al. 2007, Gathercole et al. 2004
Job success	Poor EFs lead to poor productivity and difficulty finding and keeping a job	Bailey 2007
Marital harmony	A partner with poor EFs can be more difficult to get along with, less dependable, and/or more likely to act on impulse	Eakin et al. 2004
Public safety	Poor EFs lead to social problems (including crime, reckless behavior, violence, and emotional outbursts)	Broidy et al. 2003, Denson et al. 2011

Table 1.1: The effect of executive functions (EFs) in different aspects of life (Diamond, 2012)

1.2 State of the Art

In 1955, Brody was the first to suggest that age-related reductions in brain weight were due, in part, to a decline in neuron numbers in all cortical layers (Brody, 1955). The data obtained from these early studies, however, had some technical and methodological issues, such as tissue processing and sampling design, that later called into question their accuracy (Morrison & Hof, 1997). In 1993, in order to explain the unclear and contradicting data that had been so far put forward on age-related neuron loss, it was proposed a new way to identify and eliminate most of the unreliable factors of the previous studies, using new stereological principles (West, 1993).

Contrary to what Brody believed, the loss in most brain areas does not have a meaningful role in age-related cognitive decline. Instead, small, specific regional changes in the dendritic branching and spine density are more characteristic of the consequences that age will have on the neural morphology (Burke & Barnes, 2006). In Figure 1.1 it is possible to visualize the physical repercussions of aging, as it compares the dendric branching in the entorhinal cortex and hippocampus of a young subject with an elder subject.

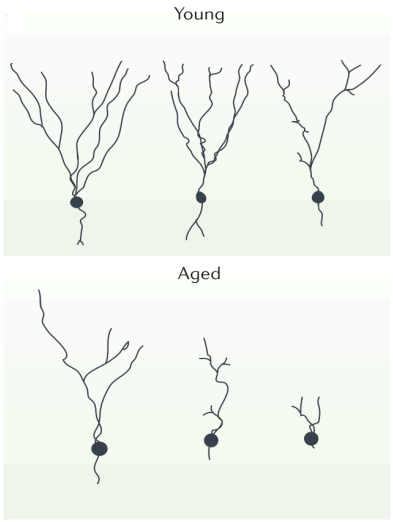


Figure 1.1: Dendric branching deteoration in human entorhinal cortex and hippocampus (Burke & Barnes, 2006)

This has been confirmed over the years by developing research. Throughout the lifespan, we can see meaningful brain size differences in healthy adults. As Raz stated, "although brain shrinkage is widespread, its magnitude varies across regions. The regions with the most pronounced atrophy are the cerebellum, prefrontal white matter, fusiform gyrus, visual cortex and inferior temporal cortex" (Raz et al., 2005). Age-related atrophy differs between brain regions, with the frontal lobe being the region that shows the steepest rate of atrophy, with an average decline between 0.9% and 1.5% per year (Dennis & Cabeza, 2008). The decline rate for parietal lobes have the second steepest rate with an annual rate between 0.3% and 0.9%. The occipital lobe shows non-significant atrophy when compared to the previous lobes (Pfefferbaum, Sullivan, Rosenbloom, Mathalon, & Lim, 1998). In analysing Figure 1.2 it is possible to better understand the decline rate associated to each lobe as mentioned above, and as seen, the frontal and parietal lobes have the highest decline rates which are followed by the temporal lobe, the occipital lobe has the least evident decline rate, as stated previously. There is also evidence that within the frontal and parietal cortex, sub-regions may exist that show an even steeper rate of decline than the values previously indicated (Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003).

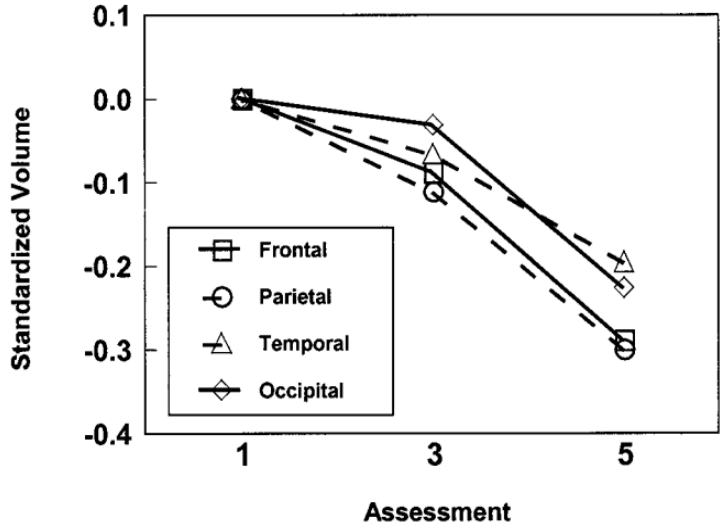
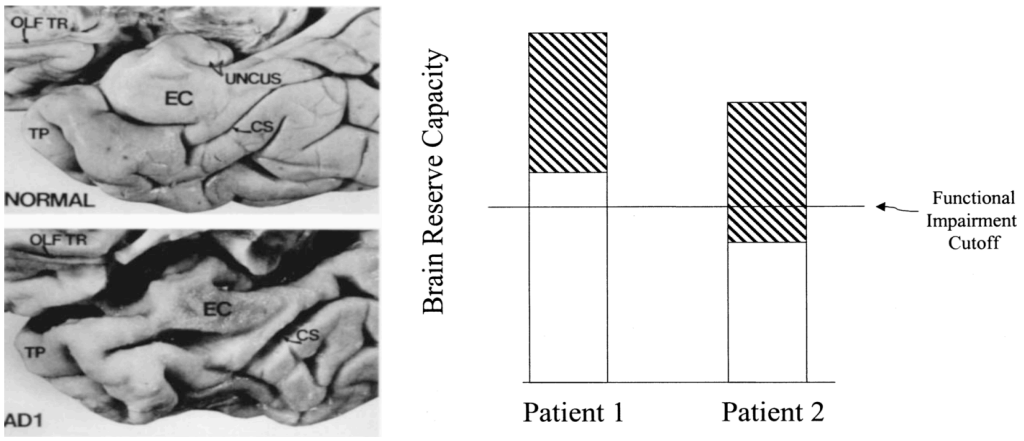


Figure 1.2: Mean longitudinal change for each brain region (Resnik, Pham, Kraut, Zonderman & Davatzikos, 2003)

The temporal lobes also suffer some shrinkage, however, different sub-regions of the temporal lobes shrink at different rates. The sub-regions that form the temporal lobes include the entorhinal cortex, the hippocampus and the parahippocampal gyrus. A study from 2005 showed that in healthy adults, the hippocampus showed a substantial atrophy with age (per year after the age of 70), whilst the entorhinal cortex (EC) did not (Raz et al., 2005).These finding are useful to better understand some neurodegenerative diseases, since the entorhinal cortex is one of the regions first affected by Alzheimer's disease (AD) as seen in Figure 1.3 (a) (Van Hoesen, Hyman, & Damasio, 1991).



(a) (b)

Figure 1.3: (a)-Comparison between the EC of a healthy subject (top) and a subject with AD (bottom); (b)-Two patients with different BRs have the same brain lesion but different clinical manifestations ((a) - Van Hoesen, Hyman, & Damasio,1991; (b) - Stern, 2002)

In 1988 Robert Katzman and his team performed a post-mortem examination on 137 seniors whose mental status, memory, and functional status had been previously assessed. They found that even though some people had the same extent of AD pathology as others i.e., visually the atrophy was the same, their manifestation of the disease was completely different.

"These non-demented subjects with Alzheimer changes were functionally and cognitively as intact as those in the control group (. . .) suggesting that there has been less atrophy than is normally found in the very elderly or that this group of patients started with more neurons and a larger brain and thus had a greater reserve" (Katzman, Terry, Deteresa, & Brown, 1988)

This was the first time in literature that the word reserve was used in this context. In other words, the brain's capacity to function effectively even though having suffered some amount of damage (Stern, 2002). Figure 1.3 (b) represents the concept of brain reserve (BR). Two different patients have different amounts of brain reserve capacity, i.e., even though they have the same brain injury (represented in gray), it will manifest itself differently on both patients, since one will be over the BR threshold and the other one will not.

Researchers later noticed that the brain's size or number of neurons were not the only contributing factors to an individual's reserve. In 1999, Stern confirmed what Katzman had previously perceived and introduced a new term: cognitive reserve (Stern, Albert, Tang, & Tsai, 1999). While brain reserve is the brain's resistance to physical damage (i.e. even though there is damage to the brain, there is still enough brain so that the neuropathological damage will not have an impact on the subject) cognitive reserve is the mind's resilience to brain damage, meaning that a certain task will be processed using less brain resources, which also means that there is less room for error (Bennett, Arnold, Valenzuela, Brayne, & Schneider, 2014). Stern defines cognitive reserve as "the ability to optimize or maximize performance through differential recruitment of brain networks, which perhaps reflect the use of alternate cognitive strategies" (Stern, 2002). It is postulated that seniors will have a lower risk of dementia if they have a higher cognitive ability or other factors related to cognitive ability which are all connected to cognitive reserve (Whalley, Deary, Appleton, & Starr, 2004).

It is hypothesized that enhanced cognitive functions may translate to better cognitive reserve. Stern et al., (1999), believed that even though it would take a longer time for an individual with a higher reserve and threshold to achieve the level of cognitive impairment caused by the same degree of disability as someone else, after that threshold was surpassed, the individual whose reserve was higher also had a much faster decline rate. In terms of the cognitive reserve threshold, this relies on the amount of additional synapses or increased number of redundant neuronal networks (Stern, 2002), supporting the above mentioned hypothesis. But what will contribute to enhance a person's cognitive reserve? It is thought that a higher IQ, education and an active lifestyle may contribute to enhance

a person's cognitive functions, and as such, besides a physically larger brain and a larger amount of neurons, these protect from the negative effects of aging and disease on brain function (Satz et al., 1993). In order to better understand how executive functions relate to cognitive reserve, see Figure 1.4 below.

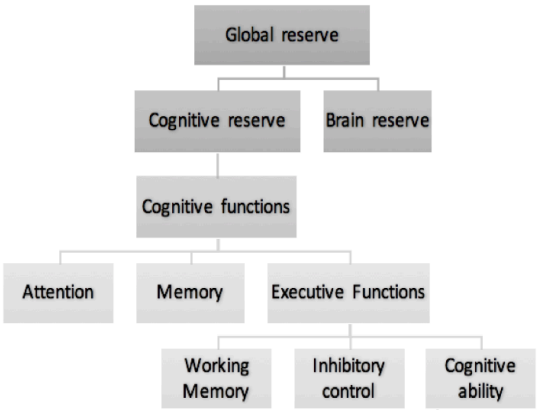


Figure 1.4: Diagram explaining the relation between cognitive and neural reserve

Working memory involves saving information in the mind, and although it is now perceptually there, one can still mentally use it (Diamond, 2012). Evidence from a study presented by Ando, Ono, & Wright (2001) showed that the genetic influences of 236 twins exceeded the environmental influences and that the effects were considerable for both working memory and cognitive ability. Swan & Carmelli (2002) quantified the genetic influence stating that 79% of the EFs can be explained by genetics. Reinvang et al., (2010) showed that there is a substantial heritable component for cognitive functions, and that even though the heritability varies from one cognitive domain to another, it is one of the main contributors to certain cognitive phenotypes. (Reinvang et al., 2010).

Scarmeas et al. (2003) concluded that "inter-individual differences in lifestyle may affect cognitive reserve by partially mediating the relationship between brain damage and the clinical manifestation of AD" since at any given degree of the disease, there are less manifestations of the illness in patients who are more engaged in activities, even when education and IQ are taken under consideration. In addition, the influence exercise and activities have on the cerebral blood flow are greater than those caused by education and IQ. No changes are as significant as one might expect to see in the voxels located both in the temporal, and the temporal-occipital-parietal association cortices typically noted in AD. Richards, Hardy, & Wadsworth (2003) suggest that there is a connection between physical activity and protection of memory. Even skills learnt in adult life may increase cognitive reserve, conferring protection against cognitive decline (Stern, Alexander, Prohovnik, & Mayeux, 1992). The paths through which different kinds of activity influence cognition may, however, be diverse (Richards et al., 2003).

In 2009, vocabulary knowledge and years of education were found to be related to levels of cognitive functioning. This suggests that cognitive reserve reflects the insistence of earlier distinctions in cognitive functioning rather than different rates of age-related cognitive reduction. These benefits seem to be persevered throughout the lifespan and therefore serve as a shield against functional impairment, having, for that reason, significant implications for everyday functioning in later life (Tucker-Drob, Johnson, & Jones, 2009). Other studies report strong evidence that higher-level education result in a significant reduction in the occurrence of dementia (e.g. Meng & D'Arcy, 2012).

Despite the clear difference between brain reserve and cognitive reserve previously described, and the various ways through which the brain is influenced by them, both make independent and synergistic contributions to an individual's resistance to brain pathology (Stern, 2012). It is important, however, to bear in mind that neither cognitive reserve, nor brain reserve prevent AD or dementia from appearing, it is, however, protective of the clinical manifestations of the disease. Other interesting findings observe that particular brain waves Event-Related Potentials (ERPs) such as N2 and P3 also change across the lifespan. For instance, Zurrón, Lindín, Galdo-Alvarez, & Díaz (2014) compared the brain waves of a group of young people and compared them to the brain waves of seniors while performing a Stroop test as shown in Figure 1.5

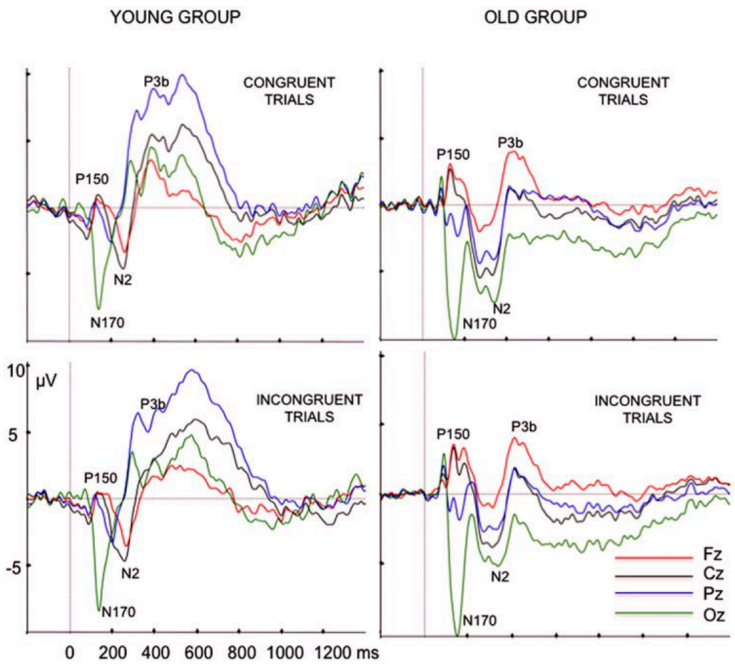


Figure 1.5: Average of ERP waveforms at Fz, Cz, Pz and Oz, obtained by a Stroop test for young and senior participants (Zurrón et al., 2014)

By assessing the N2 and P3 components, is was concluded that the latencies of both these ERPs were longer in the elder than in the younger subjects. Both these waves are observed whenever one has to focus on a task in order to make a decision, and they

are considered to be most present when presented with a stimulus in working memory (Folstein & Van Petten, 2008). Since they hypothesized that the cognitive process of the evaluation and categorization of the colour and word were slower in older participants, these results came to support their theory (Zurrón et al., 2014). Additionally, information obtained from Figure 1.5 show that the P3 amplitude at Pz was larger in the younger group. The reduction in the P3 wave amplitude in the elderly in oddball tasks is a consequence of the aging process. Walhovd, Rosquist, & Fjell (2008) believe that this results from a reduction in the neural resources allocated to the process of categorization of the target stimuli with age. As for the N2 amplitude, this was smaller in older subjects for incongruent stimuli (Zurrón et al., 2014). The N2 deflection appears when a repetitive, non-target stimulus occurs, whilst a P3 wave will appear in the presence of an unexpected or surprising stimulus (Luck, 2014). See Appendix I for details on electrode location and information as to how the electroencephalogram (EEG) works.

More recently, researchers are focused on understanding how some executive functions and other cognitive skills can be improved (Moreno & Farzan, 2015). Comprehending what one can learn or do in order to delay the appearance of a neurological disorder, would have a significant impact. Despite the lack of more in-depth research, activities such as music, meditation and exercise are thought to bring certain advantages in neuroplasticity and inhibitory control, where neuroplasticity is defined as the brain's aptitude to adapt to environmental factors that cannot be anticipated by genetic programming (Münte, Altenmüller, & Jäncke, 2002). Diamond, (2012) defines inhibitory control as "the ability to control one's attention, behaviour, thoughts or emotions to override a strong internal predisposition or external lure, and instead do what's more appropriate or needed". These three types of activities have shown to have an important impact on cognitive development.

Specifically, studies have indicated that there is a link between musicianship and higher behavioural performance in different activities, and that these have led to behavioural advantages and enhanced perceptual abilities (Moreno & Farzan, 2015). Studies show that music training influences the brain quickly, effectively, and does so across the lifespan. Moreover, music expertise, unlike any other skill, improves the brain's network, promoting a variety of auditory and domain-general cognitive mechanisms (Moreno & Bidelman, 2014). Schellenberg (2004) compared 6 year olds by randomly dividing them into music and control groups. The results showed that the music lessons caused an increase in IQ when compared to non-musical activities that have an inferior influence in the children's IQ, as can be seen in Figure 1.6, which translates into an increase of the children's cognitive skills.

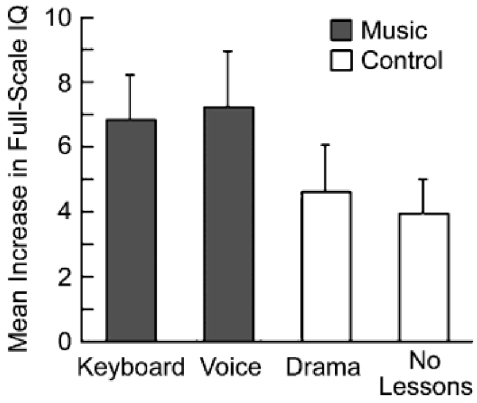


Figure 1.6: Mean increase in full-scale IQ for each group (Schellenberg, 2004)

Later in 2011, Schellenberg looked to better comprehend the link between music lessons and intelligence, and understand if this was mediated by executive functions. This study compared children ages 9-12, with at least two years of music training with children of the same age group who had no musical experience. The results of the study showed that the IQ scores and performance on EF tasks were correlated and that musician children had higher IQ scores than the non-musician group. However, the connection between musical training and EFs was small, and there was no evidence that the link between music training and intelligence was mediated by EFs (Schellenberg, 2011).

Other studies have sought to determine if behavioural activities can improve brain health in older adults. One such practice involves the use of meditation. Meditation is a very broad term and its technique can vary with respect to the type of mental activity stimulated, the amount of training, whether or not a qualified instructor is needed, and the level of religion or spirituality (Goyal et al., 2014). Since there is a wide variety of meditation practices, it is difficult to understand how exactly meditation influences cognitive and neurophysiological outcomes (Xiong & Doraiswamy, 2009). There have also been developments on the correlation between meditation and "attentional-blink" deficit. Slagter et al., (2007) identify this deficit as relating to the non-detection of a second target, when two targets, surrounded by a rapid stream of events, are presented in close temporal proximity. They concluded that after three months of intensive Vipassana meditation, practitioners could more often detect both targets, providing evidence that meditative training can improve performance on a new task that required trained attentional abilities. This suggests that meditation can have a positive influence on brain plasticity and mental functions. Transcendental meditation has also been studied, and researchers such as Canter & Ernst, (2003) have shown that from ten randomizes controlled trials, four had a positive effect on cognitive functions. Xiong & Doraiswamy, (2009) believe such findings may suggest that meditation may enhance brain longevity, and as a consequence reduce strokes and vascular factor risks as well harmful consequences of stress-induced

hypercortisolemia on hippocampal atrophy. Furthermore, the authors consider that meditation may enhance the brain-derived neurotrophic factor which when in reduced levels has been linked to depression and dementia.

Convergent evidence shows that physical activity improves neuroplasticity, certain brain structures and as a consequence, cognitive functions (Hötting & Röder, 2013). Kramer et al., (1999) compared aerobic exercise with stretching training and observed that the first requires a higher degree of executive control. Colcombe & Kramer, (2003) later confirmed that aerobic exercise had a bigger impact on executive functions and tasks that required cognitive control as shown in Figure 1.7. They add that "the present results, along with the extant animal literature, suggest that fitness training can also enhance cognitive vitality of older adults". After analysing the neuroimages of people over the age of 53, Colcombe et al., (2004) were able to establish that functional brain activation indeed changed in the frontal brain regions after a few months of aerobic exercise. They concluded that increased cardiovascular fitness can decrease the decline rate of brain plasticity with age and may serve to decrease biological and cognitive senescence in humans.

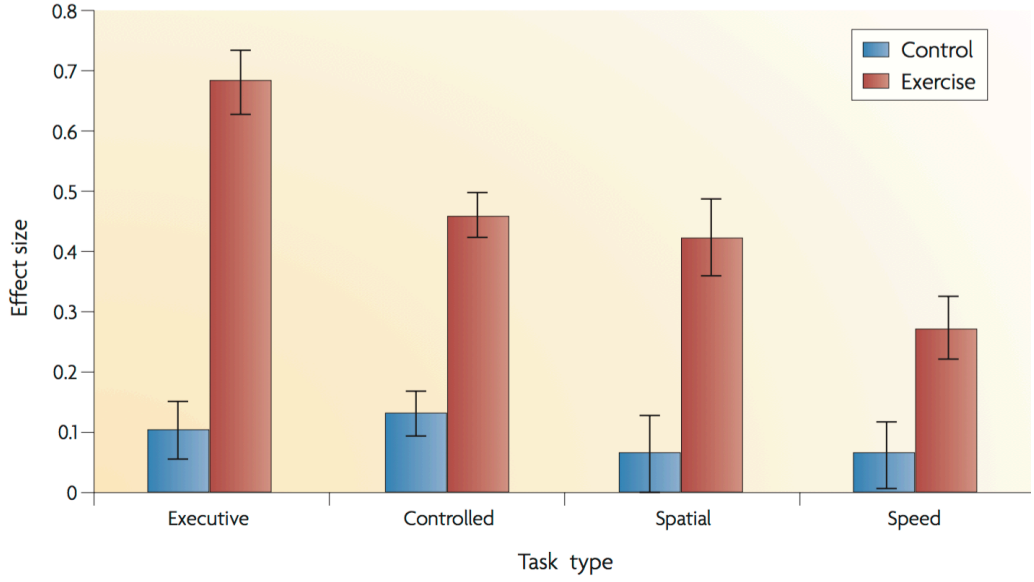


Figure 1.7: Difference in effect size between sedentary and active in regards to different cognitive processes (Colcombe, Kramer, 2003)

Other studies have also reported that physical activity has meaningful effects on other cognitive functions, such as auditory and visual attention, motor control, spatial cognition and cognitive speed (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). Ruscheweyh et al. (2011) presented a study that showed an increase in verbal memory after comparing a sedentary group of adults with a group of the same age that continuously exercised. The same study concluded that physical activity is related to increases in

memory functions, accommodated by local grey matter volume and neurotrophic factors.

Physical activity has been shown to have a positive effect on patients with dementia by preventing or delaying memory decline (Intlekofer & Cotman, 2013), and those with AD. Although physical activity "can significantly improve hippocampal function to a degree even with advancing age and disease", this is a topic in need of further research. Since the beneficial effects of physical exercise have shown to have a positive outcome on executive functions and frontal brain regions, it is important that research on this field continues to develop (Hötting & Röder, 2013).

The aim of this work is to better understand the influences that the research previously described have on age-related cognitive decline, specifically if and how they lead to a greater inhibitory control, working memory, attention and entropy in older adults. In the following sections, we will carry out a case study involving four groups of senior citizens (> 60 y.o.), musicians, athletes, meditators and controls, with the purpose of better understanding the influence that each type of activity has on the brain's plasticity and cognition. In the long-term, this and similar studies will help understand how to decrease the number of cognitive impairments and neurodegenerative diseases which include dementia and AD.

1.3 Objectives and Hypothesis

As mentioned, the aim of this project is to investigate if specific lifetime-acquired expertise can protect against age-related cognitive decline. Specifically, we will carry out a pilot study to assess if skills in music, physical activity and meditation leads to superior inhibitory control, working memory, attention and entropy in the elderly. This will be assessed using a standard Go/No-Go task, a short-term memory test, a colour search task and by assessing resting state data (brain activity at a state of relaxation), respectively. Brain electrical responses will be measured using and EEG, and changes will be measured at the entropy level for different time-scales and in event-related components, including the N2 and P3 components.

Participants will be over the age of 60 and all groups will be have similar degrees of education and IQ. Expertise levels amongst musicians, athletes and meditators will be equivalent, but to do so, the eligibility criteria will have to differ slightly. In addition to the cognitive assessments previously mentioned, an IQ test and a health and well-being questionnaire will also be included. We will start by comparing all groups with the control group, and subsequently analyze the results in between the experts.

Hereinafter is the proposed main hypothesis. In addition to this, sub-hypothesis were added to confirm the validity of the main one. All variables presented in the sub-hypothesis have been linked to executive functions and cognitive performance.

Hypothesis: Lifestyle activities lead to enhanced cognition in old age compared to a sedentary lifestyle.

- Sub-hypothesis: Expert groups will score better on all tests and tasks, including the health and well-being questionnaire;
- Sub-hypothesis: Meditators will perform better in attention tasks;
- Sub-hypothesis: Expert groups will have similar N2 but higher P3 when compared to controls;
- Sub-hypothesis: Expert groups will have overall greater entropy levels.

CHAPTER 2

BRAIN HEALTH AND LIFESTYLE

2.1 Brain Aging Process

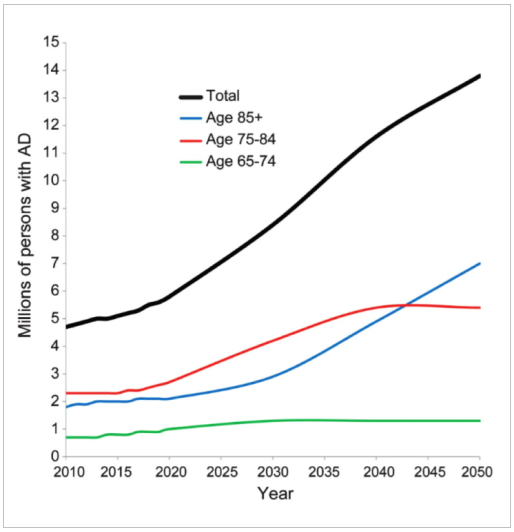


Figure 2.1: Number of people with AD in 2050 according to census (Hebert, Weuve, Scherr, & Evans, 2013)

Most of the existing studies have focused on the pathologies associated to aging, such as mild cognitive impairments, dementia, Alzheimer's or Parkinson's disease, etc. There are few studies that focus on the healthy brain aging, i.e., brain changes that occur in the absence of neurodegenerative or neuropsychological diseases, nevertheless, existent research suggests that the aging process is paired with several structural, chemical and functional changes in the brain, including cognitive alterations. Fig 2.1 was created based on the results from the United States 2010 census, and it shows that it is predicted that by the year of 2050, the number of people with AD will triple. A reasons for this might be that due to the baby boom that occurred between the 40s and the 60s there are now more people over the the age of 65 than under the age of 15 in Canada (Christie et al., 2017).

Different areas of the brain may be more or less predisposed to age-related reductions. Broadly, the brain matter can be either classified as white matter or grey matter, where the latter consists of cell bodies in the cortex and subcortical region and the former involves

the myelinated axons connecting the neurons of the cerebral cortex to each other and the periphery. (Kramer & Madden, 2008)

As mentioned in the first chapter and focusing on gray matter alterations, studies have shown that there are changes in whole brain volume as a function of aging (Raz et al., 2005). These changes are not linear, however, they become steeper in older ages. Age-related atrophy differs between brain regions, with the frontal lobe being the region that shows the steepest rate of atrophy, with an average decline between 0.9% and 1.5% per year (Dennis & Cabeza, 2008). The decline rate for parietal lobes have the second steepest rate with an annual rate between 0.3% and 0.9% (Pfefferbaum, Sullivan, Rosenbloom, Mathalon, & Lim, 1998).

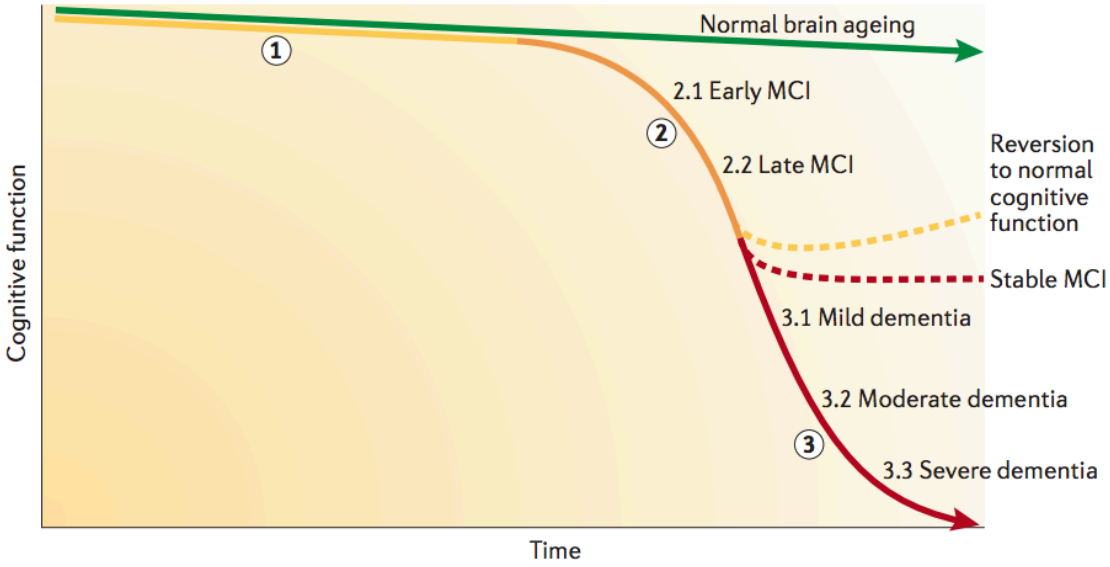


Figure 2.2: Normal, with MCI and with dementia decline rate in cognitive function (Hampel, H. & Lista, S., 2016)

The decline rate by which different brain regions shrink differs slightly between young adults and older adults, however, these changes are not outrageously big. When you add to this normal brain aging, mild-cognitive impairments (MCI), the decline rate by which the brain is altered increases drastically, when neurodegenerative and neuropsychiatric disorders come into place, the decline rate increases even more as can be seen in Fig. 2.2. This figure aims to represent the changes of cognitive function over time, starting at the point in time where cognition is at it's peak (which happens between the ages of 25 to 29).

This study aims to understand how behavioural changes can aid in this cognitive decline, which in practical terms translates into "if a person develops a neurodegenerative disorder, will his/her brain be able to find alternative neurological paths or create new paths more easily than those with a sedentary lifestyle".

Every person is different, and as explained in the previous chapter, two people with similar lifestyles can respond differently to the same neurodegenerative/neuropsychiatric disorder. Reasons for this are the person's genetic, or the environment he/she has been exposed to (in which the behavioural activities are included).

2.2 Behavioural Interventions

2.2.1 Sedentary Lifestyle

Research has shown that sedentary behaviour is linked to lower cognitive function. The table below (Table 2.1) is from a review article regarding the impact of sedentarism in cognition, and the presented studies are just some of the mentioned in Falck, Davis, & Liu-ambrose, (2017). The overall results across all studies is that sedentary behaviour is associated with a decrease in executive function, and with an increase of risk in developing dementia. An interesting conclusion is that the findings suggest that reducing sedentary time to less than two hours per day and engaging in just 150 minutes per week of physical activity is enough to help promote healthy cognitive aging.

Publication and study design	Participants, country, setting and length of follow-up	Sedentary behaviour (exposure assessment)	Cognitive function (outcome assessment)	Results
Cohort designs				
Hamer and Stamatakis[23] Cohort design	6359 men and women from the English Longitudinal Study of Ageing England 2-year follow-up	Self-reported TV viewing considered sedentary behaviour (SB)	Immediate word recall, delayed word recall and verbal fluency.[31] All three used to create a global cognitive function score (primary outcome)	Linear inverse relationship between TV time and cognitive function. Decreased cognition from baseline (EMM=0.39, 95% CI [0.33 to 0.45]) to follow-up (EMM=0.25, 95% CI (0.19 to 0.31)), but no association between baseline SB and changes in cognitive function
Kesse-Guyot *et al*[24] Cohort design	2430 participants from the Supplémentation en Vitamines et Minéraux Antioxydants Study France 13-year follow-up	Self-administered French version of the Modifiable Activity Questionnaire (MAQ).[32] Participants reported average time spent at home watching TV (min/day)	Digit span forward and backward (primary outcome),[33] Delis-Kaplan Trail Making Test,[34] RI-48 cued recall test,[35] semantic fluency and phonemic fluency[36]	SB associated with decreased global cognitive function (β= −1.28; 95% CI (−2.46 to −0.11)) and decreased verbal memory (β= −1.38; 95% CI (−2.58 to −0.18)) over time
Kesse-Guyot *et al*[25] Cohort design	2579 participants who agreed to participate in the follow-up period of the Supplémentation en Vitamines et Minéraux Antioxydants Study France 8-year follow-up	Self-administered French Modifiable Activity Questionnaire (MAQ).[32] Participants asked about average daily time spent with SB (min/day)	Phonemic and semantic fluency (primary outcome),[36] RI-48 test,[35] digit span forward and backward,[33] Delis-Kaplan Trail Making Test[34]	Negative association observed between TV viewing and executive function cross-sectionally (β=−0.98; 95% CI (−1.93 to −0.04)), no association between executive function and SB over time
Case-control designs				
Kivipelto *et al*[26] Nested case-control design	1449 participants from the Cardiovascular Risk Factors, Aging and Dementia Study (65–79 years) Finland Mean follow-up time of 21 years	Self-reported leisure-time physical activity (PA) dichotomised into categories: active and sedentary (persons who participated in leisure-time PA less than two times per week)	Cognitive status determined via scores on the Mini-Mental State Examination (MMSE),[37] and all-cause dementia diagnosis (primary outcome) confirmed according to the Diagnostic and Statistical Manual of Mental Disorders[38]	The odds of developing all-cause dementia were 2.07 times greater for participants who were sedentary (95% CI 1.12 to 3.86) as compared to physically active when controlling for age, sex, follow-up time, education, body mass index (BMI), cholesterol, blood pressure, heart attack, stroke and diabetes
Lindstrom *et al*[27] Case-control design	Participants born between 1915 and 1944. 135 cases of Alzheimer's disease 331 controls recruited from clinical settings and from the community. USA	Participants self-reported daily hours of television viewing	Diagnosed case of Alzheimer's disease (primary outcome)	Cases watched significantly more television than controls (F (1, 464) =35.37). The odds of developing Alzheimer's disease increased 1.32 times for every hour of daily television viewing (95% CI 1.08 to 1.62)

Table 2.1: Studies focused on how sedentarism affects cognition (Falck, Davis, & Liu-ambrose, 2017)

There have also been studies that aim to understand the affect of sedentarism in the brain's structure. Specifically, a study conducted by the Wayne University School of Medicine compared brain structural differences between a group of active mice and a

group of sedentary mice. The active group was kept in a cage with ropes and spinning wheels which the mice used frequently, whereas the sedentary group had nothing in the cage that would promote them to be active. After 3 months, the mice's neurons were injected with a dye. What was concluded from this study is that even though the actives group's neurons remained practically the same, the sedentary group had overly branched neurons which were affecting the sympathetic nervous system (SNS) (the part of the nervous system that controls the fight or flight response) making them more sensitive to stimuli. An overly responsive SNS can result in confusing messages to the brain that can lead to serious health problems such as heart attacks or aneurisms, Mischel, Llewellyn-Smith, Mueller (2014)

2.2.2 Physical Activity

While exercising, besides all the health benefits which include decreased risk of stroke, high blood pressure and diabetes, our brain releases endorphins. These hormones control pain and pleasure responses in the Central Nervous System (CNS) and are linked to improving focus and memory. Increased aerobic exercise can also enhance the creation of new hippocampal neurons and make them last longer.

In fact, studies have shown that there is a significant effect of cardiorespiratory fitness in the brain size (Firth et al., 2018). Specifically, people who exercise have shown to increase the hippocampal volume both in young adults but also in older adults. Animal studies have supported the theory that aerobic exercise doesn't help grow the hippocampus, but it prevents the usual decrease in neurogenesis (the process by which new neurons are formed in the brain) associated with aging and therefore resulting in greater retention of neural matter.

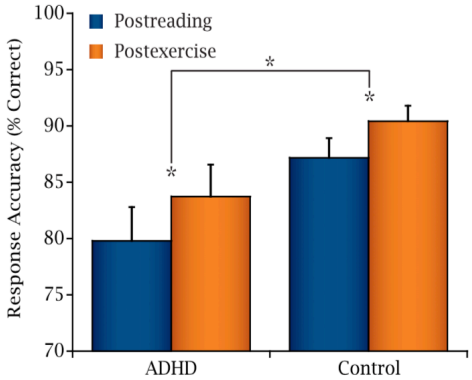


Figure 2.3: Difference in effect size between sedentary and active in regards to different cognitive processes (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013)

The figure above belongs to a study that aimed to understand the impact of aerobic exercise on pre-adolescent children with attention deficit hyperactivity disorder (ADHD). In fact, Fig. 2.3. reveals that, after a flanker test, despite the fact that children with ADHD

performed worse than controls, after doing aerobic exercise the amount by which their accuracy improved was higher than for the matching controls. (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013)

Alongside the vast benefits for metabolic risk and physical and mental health, aerobic exercise has shown to be suitable for promoting healthy aging, in order to maintain both physical and neurological functioning (Silveira, Roy, & Almeida, 2018).

2.2.3 Musicianship

While reading or solving math problems each activate their own specific brain area, listening to music activates multiple brain areas. It includes processing sound, melody, rhythm at very fast rates. When playing an instrument practically every area of your brain is activated. A lot more information is being processed, coming from the visual, auditory and motor cortices (Christie et al., 2017).

Motor skills, which are used when playing an instrument, are controlled by both hemispheres, which allows signals to get across the brain faster and through more diverse paths and it also reinforces the sharing of information of both hemispheres, plus playing music has also been linked to an increase in activity and volume in the brain's corpus callosum (the bridge between both hemispheres).

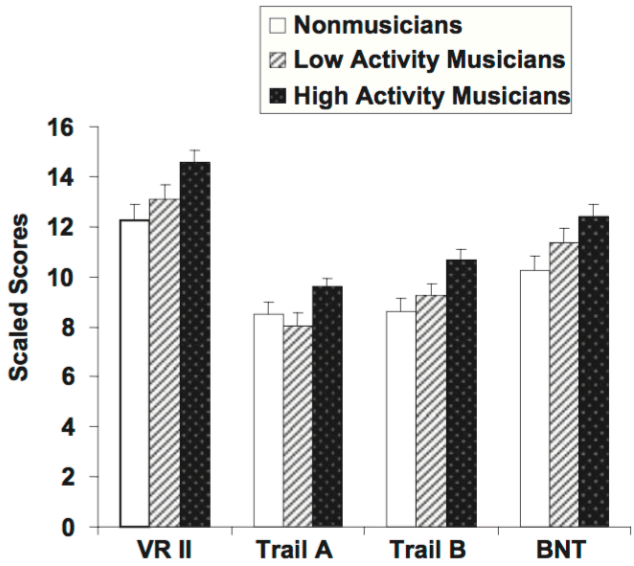


Figure 2.4: Relation between non-musicians, low activity musicians and high activity musicians and performance for different cognitive processes. VRII - Visual Reproduction Delayed Recall; Trails A and B test cognitive flexibility by asking the subject to switch rapidly between numbers and letters; BNT - Boston Naming Test (Hanna-Pladdy, MacKay, 2011)

The results of the study from the Fig. 2.4 are from subjects over the age of 65 and

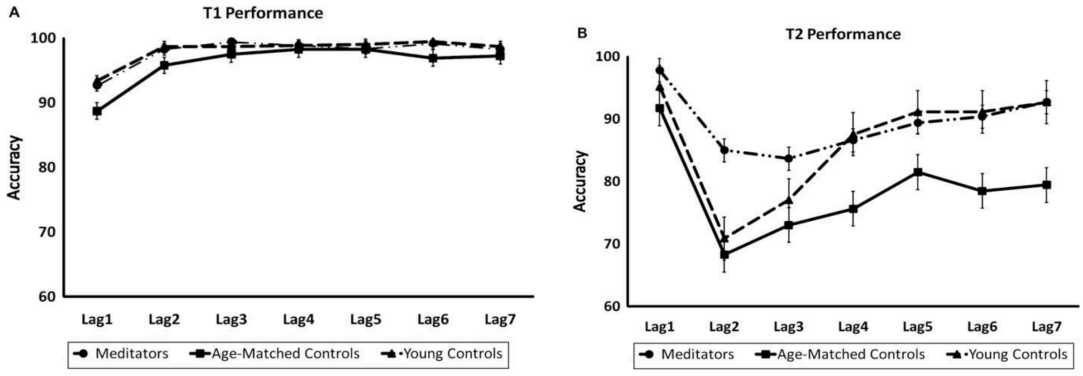
reveal that there are significant differences between high activity musicians and non-musicians on measures of naming, nonverbal memory recall, visuo-motor speed, visuo-motor sequencing, and cognitive flexibility. It also shows that there is somewhat of a linear relation between years of musical experience and cognitive function (Hanna-Pladdy, MacKay, 2011).

As shown, musicians tend to have higher levels of executive function, excelling at planning, strategizing and attention to detail. They also exhibit enhanced memory function, creativity, soring and retrieving memories faster and more efficiently than non-musicians, both in young adults and older adults.

2.2.4 Meditation

Studies show that brain regions associated with attention, interoception and sensory processing had a greater volume in meditation participants than matched controls, suggesting that this activity can counteract age-related cortical thinning (Lazar, et al, 2005).

Research has also shown that meditation can increase the density and volume of the hippocampus, an important brain area fundamental for memory. Moreover, while the brain area responsible for sustaining attention tends to shrink throughout the lifespan, meditation seems to contradict this decay.



(a) (b)

Figure 2.5: (a) - Accuracy scores for meditators, age-matched controls, and young controls for T1 target ; (b) - Accuracy scores for meditators, age-matched controls, and young controls for T2 target (Leeuwen, Muller, Melloni, 2009)

There are studies, such as the one from which Fig. 2.5 belongs to, that show that meditators can score higher than young adults on tests of attention and working memory, which is the ability to temporarily store and manage new information. This study in particular the subjects (meditators, age-matched controls and young controls) were asked to perform an attention task where a rapid serial visual presentation of 10–21 random letters were shown on a screen. Each letter would stay on screen for 100 ms. Two digits

were sequentially presented amongst the letters (T1 and T2), and the participants task was to identify both T1 and T2.

The results show that even though all three groups had very similar scores for identifying T1 (Fig. 2.5.(a)), the accuracy score for identifying T2 was highest for meditators, even when compared to young adults (Fig. 2.5. (b)).

CHAPTER 3

Tasks and Analyzed Components

When building the pipeline for the study, it was important for us to use well-known and robust tasks such as the Go/No-Go and resting state and add less common tasks that would give us novel information that would help answer our hypothesis such as the Colour Search and the Short-Term Memory task.

3.1 Psychological Assessment

3.1.1 Ravens Standard Progressive Matrix

The Ravens Standard Progressive Matrix (RSPM) is an IQ test where the subject is asked to choose from the options, the one that completes the patterns presented, both vertically and horizontally (Fig. 3.1). The subject is asked to do this as fast but as accurately as he/she can within 1 min.

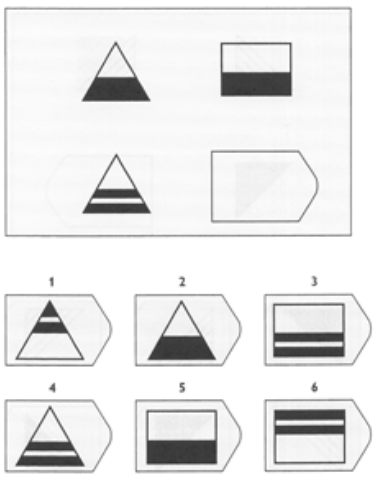
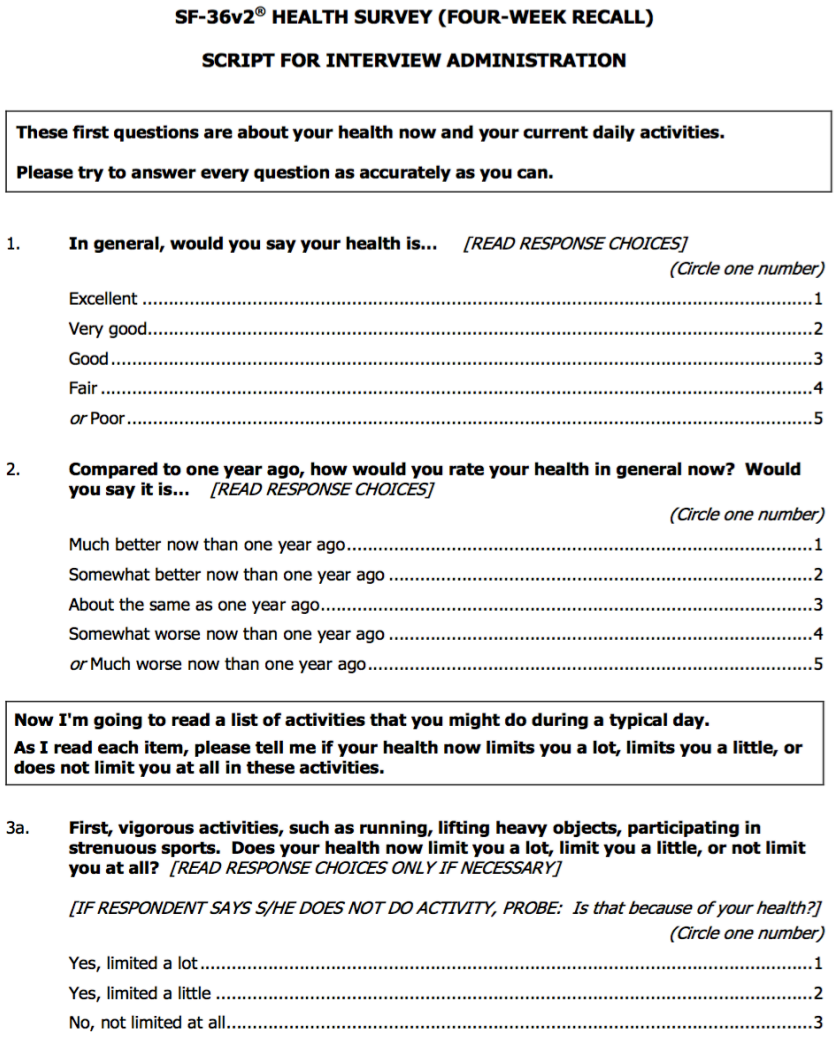


Figure 3.1: Example of an exercise from RSPM

This IQ test has a few advantages over a full scale IQ battery such as the Wechsler Intelligence Scale in studies as the one presented in this thesis. These advantages include the fact that the RSPM is faster to administer (The Wechsler takes between 60 and 90 min), it is language agnostic (meaning that the participant doesn't have to be fluent in the English language to perform the test) and it is easily adaptable for age specificity.

3.1.2 Health and Well-Being Assessment

The Health and Well-Being Assessment, also known as the 36-Item Short Form Health Survey (SF-36) is an 11 question survey that asks for the participant's views on his/her health (Fig. 3.2). This information was asked to help understand how the subject feels and how well he/she is able to do usual activities.



SF-36v2® HEALTH SURVEY (FOUR-WEEK RECALL)

SCRIPT FOR INTERVIEW ADMINISTRATION

These first questions are about your health now and your current daily activities.

Please try to answer every question as accurately as you can.

1. **In general, would you say your health is...** *[READ RESPONSE CHOICES]*

(Circle one number)

Excellent 1
Very good 2
Good 3
Fair 4
or Poor 5

2. **Compared to one year ago, how would you rate your health in general now? Would you say it is...** *[READ RESPONSE CHOICES]*

(Circle one number)

Much better now than one year ago 1
Somewhat better now than one year ago 2
About the same as one year ago 3
Somewhat worse now than one year ago 4
or Much worse now than one year ago 5

Now I'm going to read a list of activities that you might do during a typical day.
As I read each item, please tell me if your health now limits you a lot, limits you a little, or does not limit you at all in these activities.

3a. **First, vigorous activities, such as running, lifting heavy objects, participating in strenuous sports. Does your health now limit you a lot, limit you a little, or not limit you at all?** *[READ RESPONSE CHOICES ONLY IF NECESSARY]*

[IF RESPONDENT SAYS S/HE DOES NOT DO ACTIVITY, PROBE: Is that because of your health?]

(Circle one number)

Yes, limited a lot 1
Yes, limited a little 2
No, not limited at all 3

Figure 3.2: Example of the questions asked in the SF-36

The subject is asked to choose the option that comes closest to the way they feel is true to them. The final results can be divided into global health, physical health and mental health. This questionnaire took about 15 minutes to administer and the participants could ask for clarification of refuse to answer if they didn't feel comfortable doing so. This health and well-being questionnaire contains 36 items within 8 specific topics. It includes questions in regards to physical functioning, social functioning, limitations due to physical problems, limitations due to emotional problems, mental health, energy/vitality, pain and general health perceptions.

3.2 Resting State: Entropy

Resting state data is collected by asking the participant to sit as still as possible for 5 minutes, while staring at a fixation cross (Fig. 3.3). It was asked that the participant would not move or blink too often. This data allows us to do an entropy assessment.

Figure 3.3: Presentation of fixation-cross for resting state data collection

Entropy values give important information regarding the degree of underlying randomness of a random variable. These random variables with small entropy levels have a high level of predictability. On the other hand, large entropy values correspond to low levels of predictability and therefore high levels of randomness. Due to the interactions of the many neural networks that operate over a wide range of spatial and temporal scales, the brain is considered a complex system.

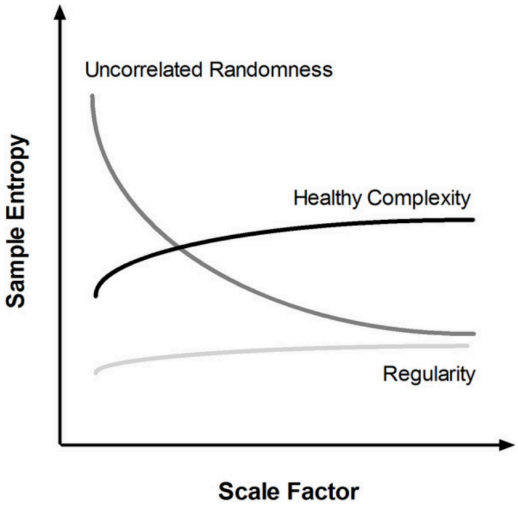


Figure 3.4: Comparison of entropy values across different scale factors for random, complex and regular systems

These interactions and the complexity that defines the system is a reflection of the brain's adaptability and can be used as a quantitative marker for the system's health. This measurement tool is not exclusively a brain-based measurement, however, the information collected is of interest since studies have shown different brain entropy levels between young and old adults (Wang et al., 2014). With old age and on a larger scale in mentally impaired people, the system's health starts getting compromised, thus reducing this adaptability, leading to ordered or random behavioural patterns (See Fig. 3.4). Reasons behind why this complexity declines across the lifespan may be related to a decrease in the number of excitatory neurons and the excitatory conductance with age (Yao et al., 2013).

Studies have shown that variations and variability observed in biological signals have a crucial role in shaping the brain's capacity for information processing. (Costa, Goldberg. & Peng, 2005; Sporns, Tononi, & Edelman, 2000). The less recurring temporal patterns are, the more complex and unpredictable the signal is. In the brain, the complexity of signals at fine and coarse timescales (smaller and larger time increments respectively) refer to increases and decreases in correlated activity among local and distributed brain regions, promoting the integration and segregation of information at different spatio-temporal scales (Sporns et al., 2000; McIntosh et al., 2014; Farzan et al., 2017).

Specifically, the brain-based measurement technique used in this study is the Multi-Scale Entropy (MSE) to quantify the change in complexity across multiple time-scales (Farzan et al.,2017). This novel technique is gaining emphasis amongst the research community because, when compared to the commonly used Power Spectral Analysis, it has the advantage of examining long-range temporal dynamics and being more localized to specific brain regions.

Coarse-Graining

Given a specific time series $\{x_1, x_2, \ldots, x_N\}$, several coarse-grained time series are created by averaging each data point with non-overlapping windows of increasing length τ. As can be seen in Fig. 3.5. the coarse-graining process, includes an average of 2, 3, 4, ..., N, data points, depending on which scale factor is being used. A scale factor of 1 represents the original time-series.

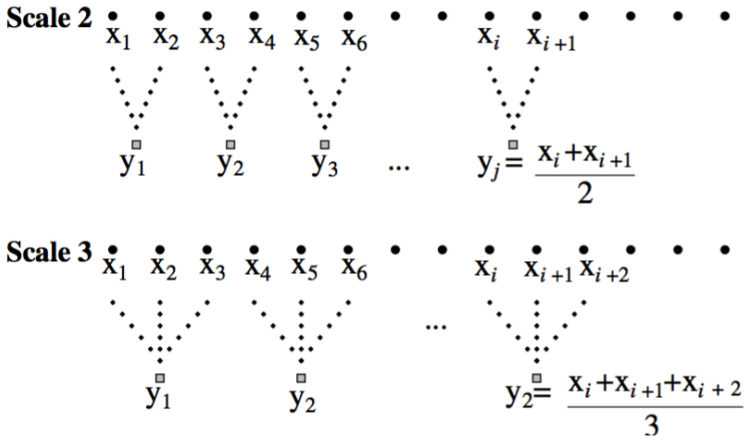


Figure 3.5: Coarse-graining process (Costa et al., 2005)

Each element of the coarse-grained time series $y_j^{(\tau)}$, was calculated according to the equation:

$$y_j^{(\tau)} = \frac{1}{\tau} \sum_{i=(j-1)\tau+1}^{j\tau} x_i \tag{3.1}$$

where τ represents the scale factor and $1 \leq j \leq N/\tau$. The length of each coarse-grained time series is N/τ. For the scale factor of $\tau = 1$, the coarse-grained time series is the original time series.

Sample Entropy

Sample entropy is calculated for each of the multiple coarse-grained time series, and then plotted as a function of the scale factor. This stage is referred to as a "regularity statistic" because it looks for patterns in a time series $\{y_1^{(\tau)}, y_2^{(\tau)}, \ldots, y_N^{(\tau)}\}$ and aims to quantify its degree of predictability (Fig. 3.6).

As can be seen in Fig. 3.6. the first step in calculating the sample entropy is to compare a single data point at a time. Looking at u[1], which is the first data point, we can observe the range factor (r), which is represented by the dotted line immediately above and below u[1] (this is a similarity range in which we will look for other data points). Note that each colour represents the points that fall into the same similarity criterion. Therefore assessing the plot, we can find four data points that are similar to u[1] (all five data points represented in green). Looking at u[2], we can also find four similar data points that are included in the range limit (in red). The next step is to compare two data points at each time. So instead of looking solely at u[1] or u[2], we look at u[1] & u[2] together. Looking at the plot, we find two sets of data points similar to u[1] & u[2], which are u[13] & u[14] and u[43] & u[44] (all the green-red sequences). Similarly we repeat the process for data points u[2] & u[3] and we find 1 set of similar data points which are u[44] & u[45], and so on (all the red-blue). The same process is repeated for 3, 4, 5, ..., N, sequential data points.

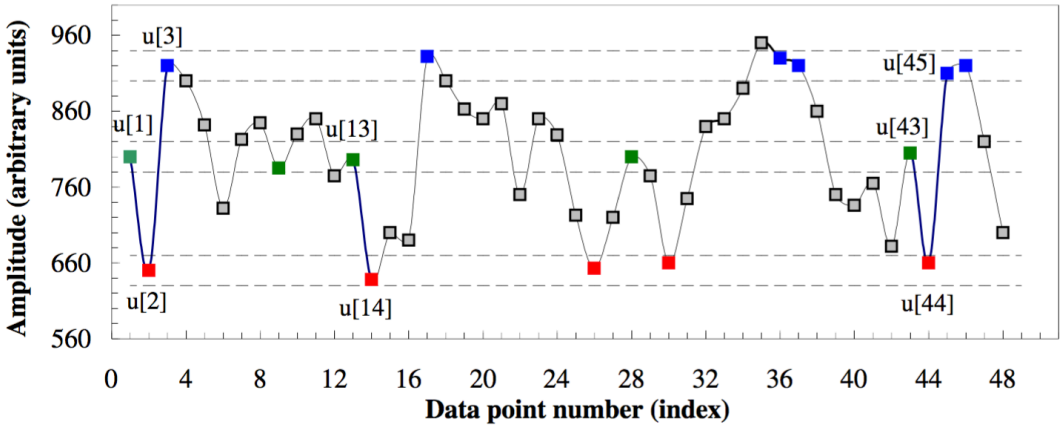


Figure 3.6: Sample entropy process (Costa, Goldberger, Peng, Israel, & Medical, 2005)

Sample entropy is calculated according to the equation:

$$SamEn(r, m, M) = -\ln\left(\frac{C(m+1)}{C(m)}\right) \tag{3.2}$$

where $C(m)$ is the total number of pairs of m consecutive similar data points and $C(m+1)$ is the total number of pairs of $m+1$ consecutive similar data points in the multiple coarse-grained time series. The time series predictability is calculated by quantifying its amplitude variability patterns.

Based on previous studies using this MSE technique, two consecutive data points were used for data matching (i.e. $m = 2$) and data points were considered to match if their absolute amplitude difference was <15% (i.e. $r = 0.15$) of the standard deviation of the time series. MSE was calculated for 30 second continuous epochs (Farzan et al., 2017).

3.3 Go/No-Go: N2 and P3

The Go/No-Go task is a well-known task due to it's simplicity and good neurofeedback. The purpose of this task is to assess the individuals efficiency of response inhibition. It specifically measures the participant's capacity for sustained attention and response control. Despite the several possible adaptations, it consists mainly of the presentation of two different stimuli where the participants are required to either respond (i.e., pressing a designated key) or withhold a response (not pressing designated key) depending on whether a go stimulus or a no-go stimulus is presented (Fig.3.7.).

Per trial, the go stimuli is presented 80% of the time, making it harder to predict the no-go stimuli. This task was colour balanced, meaning that for some participants the go-stimuli was the no-go stimuli for other participants. This ensures that the colour of the stimuli is not the driving cause for the impulse suppression. For half of the participants the go trials would be the stimuli presented in Fig. 3.7 (a), and the no-go trials would be the stimuli presented in Fig. 3.7 (b), and the opposite for the other half of the participants.

(a) (b)

Figure 3.7: Go/No-Go task. (a) - Go trial for 50% of participants; (b) - Go trial for 50% of participants

Because stimuli is being presented to the subject, event-related potentials (ERPs) appear. Specifically for the Go/No-Go task, two very well studied ERPs are analyzed, the N2 (the negative waveform at 200 ms) and the P3 (the positive waveform at 300 ms). The N2 deflection is caused by a repetitive, non-target stimulus (Naatanen & Picton, 1986), such

as the go trial stimulus in the Go/No-Go task performed by our subjects, that appeared 80% of the time. This ERP is strongly related to response inhibition, which is one effect that this study aims to better understand. The P3 ERP waveform is elicited by unexpected stimuli, and therefore is greater in the no-go trials that occur 20% of the time.

ERPs, or Event-Related Potentials are brain responses that result from the specific sensory, cognitive or motor events. Voltages, that increase when neurotransmitters bind to the receptors on the membrane of the postsynaptic cell, cause ion channels to open. This leads to a change in gradient in voltage across the membrane and are referred to as *Postsynaptic Potential*. When these neurotransmitters are released and emit voltage spikes, they are called *Action Potentials* (Luck, 2014).

If an excitatory neurotransmitter is released at the apical dendrite of a cortical pyramidal cell, an electric current (in form of positively charged ions) will flow from the extracellular space into the cell, creating a net negativity on the outside of the cell in the region of the apical dendrites. Current will also flow out of the cell body and basal dendrites, creating a net positivity in this area. This continuous flow of current creates a small dipole. The dipole from a single neuron is too small to be detected by scalp electrodes, however, the dipoles from many neurons will sum together, making it possible to measure the resulting voltage at the scalp (also known as ERPs).

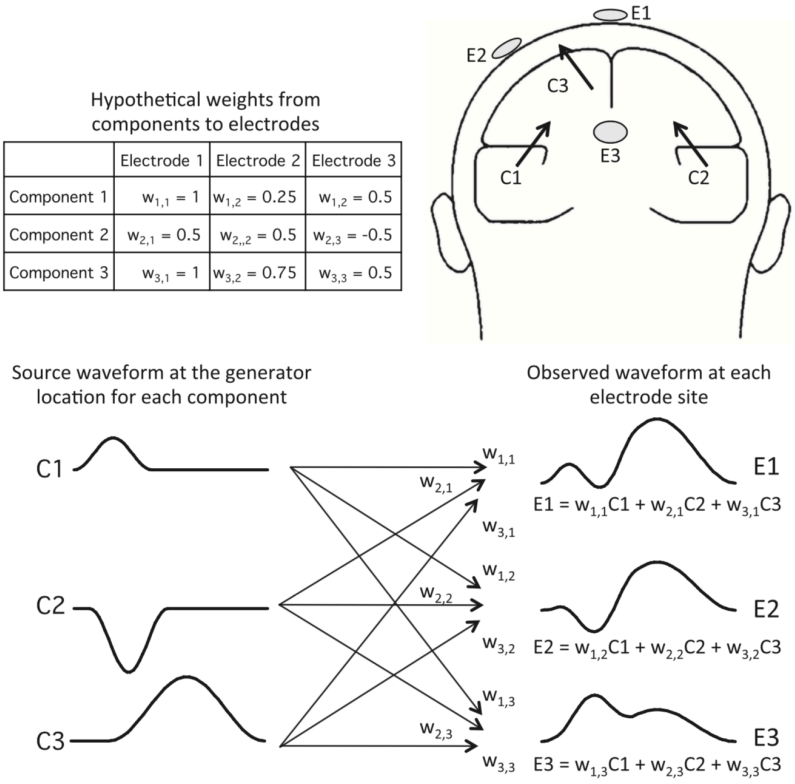


Figure 3.8: Schematic of how an ERP is detected in the scalp (Luck, 2014)

As can be seen in Fig. 3.8, the scalp electrodes represented by E1, E2 and E3 will

be able to pick up a certain percentage of voltage from any source generator present in the brain (represented by C1, C2 and C3). The percentage of the signal that will be detected by the scalp electrode will depend on the location and orientation of the source generator, and will also depend on how conductive the tissues the signal will have to cross until it reaches the electrode, are. Based on how that signal is directed, the voltage received by the electrode will either be positive or negative, altering the overall captured signal the same way. The table present in the same Figure, shows hypothetical weights (w[x,y]) from each component to each electrode. The bottom part of the Figure shows the source waveform at each generator location for each component, so at each electrode E[N], we will have a sum of all components with their specific weights, having therefore E1 = w[1,1]C1+ w[2,1]C2+ w[3,1]C3 ; E2 = w[1,2]C1+ w[2,2]C2+ w[3,2]C3 and E3 = w[1,3]C1+ w[2,3]C2+ w[3,3]C3 (Luck, 2014).

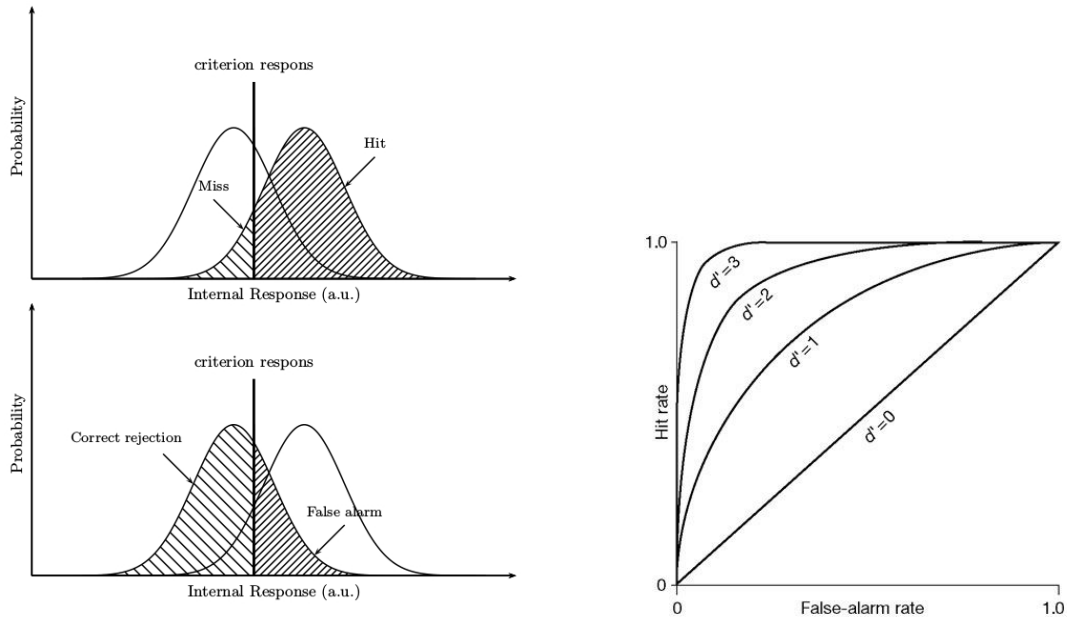
In theory, knowing all these variables, it should be possible to extract each component from each specific site. However, knowing the weight for each component and how many components are influencing the electrode's signal is not possible, and so by analyzing the signal at the electrodes, we are in fact analyzing a mixture of components and resulting in assumptions that depend on the technique being used to separate these components.

Examples of procedures used to separate signal components are dipole localization methods, PCA (principal component analysis), ICA (independent component analysis), Fourier analysis and time-frequency analysis. Each come with different assumptions that have to be made. For instance, the Fourier assumes that the basis functions are sine waves, in contrast, dipole localization methods assume that the scalp distribution reflects the conductivity of the brain, skull, and scalp.

For this study, ICA was used. The goal of ICA is to find an unmixing matrix that will allow a visualization of the waveform from the scalp electrodes and calculate the time courses of the underlying components. To do so, ICA uses the statistical properties of the observed EEG data to create this unmixing matrix. ICA uses a learning algorithm that leads to the components that are maximally independent and therefore can be rejected.

- **d' Prime Evaluation**

The d' prime evaluation comes form signal detection theory which looks to describe decisions made under uncertainty. Signal detection theory distinguishes between different types of errors/successes and describes the trade-offs between them.



(a) (b)

Figure 3.9: (a)- Plots of two possible signals, where the x axis shows the signal's strength and the y axis shows the probability of occurrence of the signal; (b)- receiving-operator characteristics curve in regards to d' (http://www.cns.nyu.edu/ david/handouts/sdt/sdt.html (March 5th, 2018))

It was initially created for radar operators, to help them understand whether the signal that appeared on screen was either a plane or a flock of birds. Looking at Fig. 3.9 (a) and interpreting the right positive deflection as the probability of it being an airplane and the left positive deflection as the probability of it being a bird, it is easy to understand that the overlapping area might make it hard for the radar operator to know what is indeed entering the proximities.

Depending on the type of signal and the type of response, there are four possible outcomes shown on Table 3.1.

Signal/Response	**Yes**	**No**
Yes	Hits	Misses
No	False Alarms	Correct Rejections

Table 3.1: Possible outcomes of signal detection theory

The criterion response, also seen in Fig. 3.9. (a) refers to the action the radar operator will have in case of doubt, meaning that he might have a more conservative criteria and mark more birds as planes (increasing the number of false alarms) or might have a more

liberal criteria and mark more planes as birds (increasing the number of misses). This assessment was made for the Go/No-Go task in order to asses each groups d', which refers to the distance between the means of distributions, scaled by standard deviation. Looking at Fig. 3.9 (b) it is easy to understand that the groups that score higher d' values are more likely to have higher hit rates than false-alarm rates, meaning that the groups with higher d' have are better at finding an adequate criteria response.

The d' is calculated by subtracting the z-transforms of the false alarm rates to the z-transforms of the hit rates as indicated in Equation 3.3. Equation 3.4 is the formula used in excel to calculate the d' values.

$$d' = z(0.8 * H) - z(0.2 * FA) \tag{3.3}$$

$$d' = NORMSINV(0.8 * H) - NORMSINV(0.2 * FA) \tag{3.4}$$

3.4 Colour Search: Behavioural Assessment

The Colour Search task is a behavioural experiment. In this experiment, the participants were shown either 4, 6, 8 or 10 circles, all different colors (Fig. 3.10). The goal of this task was to find either the green circle or the red circle, without moving their eyes from the fixation cross. Once they'd do so, they would have to assess weather the bar inside the circle was either vertically oriented or horizontally oriented. They press a "yes"button or a "no"button depending on what they thought. The purpose of the task was to understand how easily participants were able to ignore all the unnecessary information (the remaining coloured circles), and focus on the green and red circles.

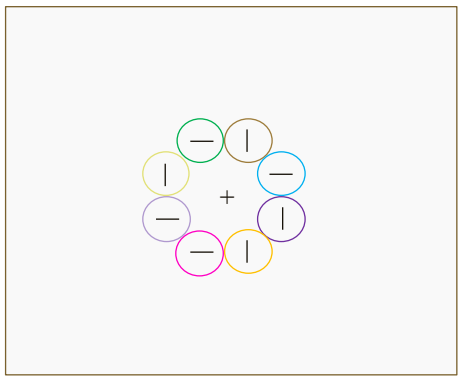


Figure 3.10: Colour search task presentation

Participant were asked to do this task as fast, but as accurately as they could, and response times and accuracy were extracted for the behavioural analysis. This specific task was chosen because of the strong attentional component. Attention selects which part of the sensory inputs are prioritized. Bringing attention to the most important surrounding stimuli, both voluntarily (e.g. looking for car keys) or involuntarily (e.g.

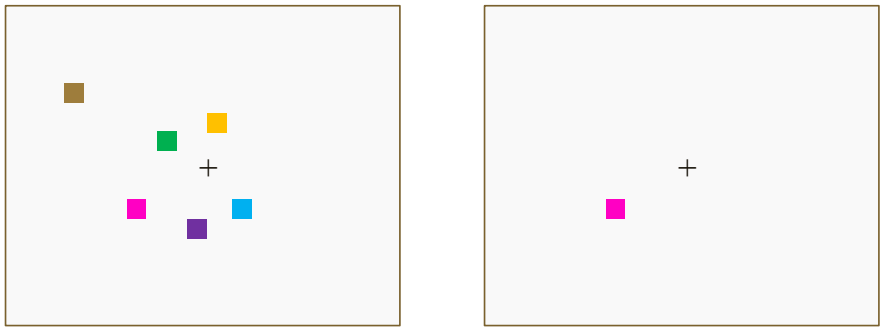
looking towards a sudden noise) promotes survival and well-being (Anderson, Laurent, & Yantis, 2011a).

The ways through which value and salience might be combined to assess attentional priority can vary. One is that learned value directly alters what is visually important, increasing the significance of reward-associated stimulus, thereby increasing the attentional priority. However, the time required to disengage attention after the stimuli has been captured is longer after that stimuli has been attributed with value (Anderson, Laurent, & Yantis, 2011b)

Studies show that a physically salient, task-irrelevant distractor previously linked to a greater reward slows the visual search more than an equally salient distractor previously associated with a smaller reward (Anderson, Laurent, & Yantis, 2011b). Previous studies also showed that the individual differences in visual working memory capacity may reflect a variation in a general ability to resist distraction. Furthermore, studies that included some sort of reward after a correct answer have shown that value-driven attentional capture is thought to play an important part in several clinical syndromes in which attention and reward are severely implicated. These syndromes include drug addiction, obesity, ADHD, and obsessive compulsive disorder (Anderson, Laurent, & Yantis, 2011a).

3.5 Short-Term Memory Test: Behavioural Assessment

During the Short-Term Memory Test, the participant would see a flash of either 2, 4, 6 or 8 coloured squares randomly placed on the screen for 1/8th of a second (Fig 3.11. (a)). Immediately next, they would see one square on the screen. The subject would then have to decide weather that square with that colour was positioned there before (Fig 3.11 (b)).They press a "yes"button or a "no"button depending on what they thought. From this task, accuracy was extracted for a behavioural analysis, and comparisons were made as for differences between observing 4, 6 or 8 items at once. These results would allow for an understanding of how many objects can be stored in each persons short-term memory. The number of items that people can score tend to range between 1.5 and 5 objects, where young adults tend to be able to score between 3 to 4 items.



(a) (b)

Figure 3.11: Short-term memory task presentation. (a) - First stimuli presentation; (b)- Second stimuli presentation

The capacity of visual short-term memory is very limited, maintaining only three to four objects simultaneously for young adults. This limitation needs efficient mechanisms to select only the most relevant objects from the environment to be stored in memory and to stop irrelevant items from consuming capacity (E. K. Vogel, Mccollough, & Machizawa, 2005).

Studies show that there are individual -specific characteristics in the ability to control what is stored in memory at any given moment. These individual differences in memory capacity might not only reflect the variability in free storage capacity, but might also indicate the efficiency with which the available space is allocated. A person's specific memory capacity does not always reflect on the number of objects that can be stores in memory, but also the efficiency by which the individual is excluding irrelevant information. Animal research has shown that the prefrontal cortex has an extremely important role in understanding which information is relevant to be kept in memory (E. K. Vogel, Mccollough, & Machizawa, 2005).

Visual working memory is thought to have a central role within cognition because it stores important information from the environment so that they may be acted on or manipulated. In fact, an individual's ability to execute many high-level cognitive functions has been shown to be directly influenced by memory capacity (E. Vogel & Machizawa, 2004)

Chapter 4

Experimental Procedure

4.1 Materials and Methods

4.1.1 The EEG System

The EEG system used was the BioSemi Active Two with a sampling rate of 512Hz. The BioSemi is an EEG system acquisition device that allows a visualization of the brain's electrical signal while recording it. This features allows for a rapid understanding of whether there is or not a bad connection and to fix it if necessary. A 64 electrode cap was used, and in addition to the CMS and DRL electrode (Common Mode Sense and Driven Right Leg, respectively) and 4 external electrodes (one electrode on each temple to track muscle/eye movement and one electrode on each mastoid to be used as reference). This portable EEG system allowed that the collection process occurred at a location of the participant's preference. In order for each experience to be the most similar between participants and to minimize the chance of errors, a script was produced (See in Appendix II), with a comprehensive explanation as what to do and what to say.

The entire system is divided into two suitcases that were transported to the participants preferred choice of location. One suitcase carried two laptops (one used to present the visual stimuli and another to visualize the raw data), respective chargers and mouse. The second suitcase contained the BioSemi system. The battery box and its charger, the AD-box, the active electrodes (both external and pin-type electrodes) and head caps (2 different sizes), the USB receiver and all the cables, conductive gel, syringes, adhesive disks, alcohol wipes and towels. The overall setup can be seen in Fig. 4.1.

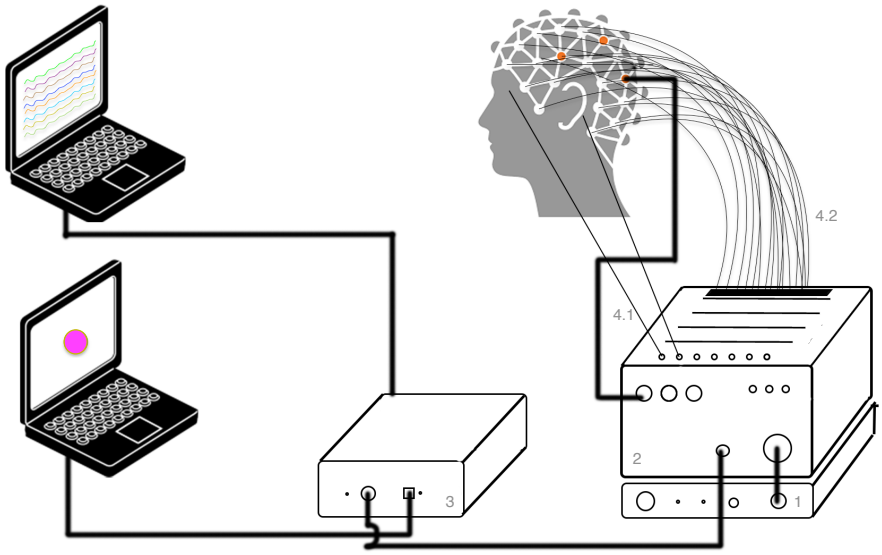


Figure 4.1: Schematic description of the overall montage, including the EEG setup, the participant and the laptops (for stimuli and raw data visualization)

1. The **battery-box** is the power supply of the AD-box and active electrodes. The battery-box contains a sealed lead-acid battery and a shutdown circuit to prevent the battery from deep discharge.

2. The **AD-box** channel consists of a low noise direct current (DC) coupled amplifier, with a first order anti-aliasing filter. The digital outputs of all the AD converters are digitally multiplexed and sent to the PC via a single optical fiber without any compression or other form of data reduction.

3. The **USB receiver** converts the optical data coming from the AD-box to an USB2 output. In addition, the USB2 receiver has a trigger port with 16 independent trigger inputs and 16 independent trigger outputs. This setup keeps the complete stimulation setup galvanically isolated from the subject.

4. The **active electrodes** reduce the problems associated with high electrode impedance's and cable shielding. This is possible due to an integration of the first amplifier stage with a silver/silver chloride (Ag/AgCl) electrode.

4.1 The **flat shape electrodes** allows for electromyogram (EMG) body surface measurements. There is a small gel cavity that is designed to reduce motion artifacts. The electrode has a sintered Ag/AgCl electrode pallet, providing very low noise, low offset voltages and very stable DC performance.

4.2 The **pin-type active electrodes** have a sintered Ag/AgCl tip, providing very low noise, low offset voltages and very stable DC performance. [1]

4.1.2 EEGLAB/ERPLAB

EEGLAB is an interactive Matlab toolbox for processing continuous and event-related electrophysiological data. EEGLAB provides an interactive graphic user interface (GUI) allowing users to interactively process EEG data. This toolbox was used to clean the raw EEG data outputted by the BioSemi. Integrated in the EEGLAB toolbox is the ERPLAB toolbox. Besides facilitating the event-related potential analysis, it also includes filters and other tools that are valuable in any EEG data analysis.

Because the BioSemi saves the recorded data as a .bdf file, to upload onto EEGLAB, no changes had to be made. Through EEGLAB, the first step towards a good data analysis is re-referencing and filtering. Initially, the mastoids were used as a reference, however, comparing the mastoids with an average across all electrodes, the latter option showed better results. Both EEGLAB and ERPLAB have filtering tools embedded, yet, the filtering provided by ERPLAB proved to be much faster (and just as efficient) than the filtering from EEGLAB. These two steps were mandatory throughout all of the recordings, and as for the Resting State data this is how far the data preprocessing went.

For the Go/No-Go task however, a few more steps were incorporated. Besides re-referencing, applying a band-pass filter of 1Hz - 30 Hz and removing ICA components twice to ensure ocular artifacts were minimized, an event-related potential analysis was done. Under ERPLAB, binfiles were created (Please see Appendix III for bin file code), epochs were extracted and artifact rejection was implemented on this epoched data. Next, an overall average of the ERPs was computed and plotted for the time frame of the ERPs of interest, specifically the N2 and the P3 (from -200ms to 700ms after the stimuli was presented).

4.1.3 Presentation

Presentation® is a stimulus delivery and experiment control program for neuroscience. Through this program it was possible to code all of the above mentioned tasks, and save the event codes so that the data analysis could be easier, and understood when a stimuli was presented and when a response was given.

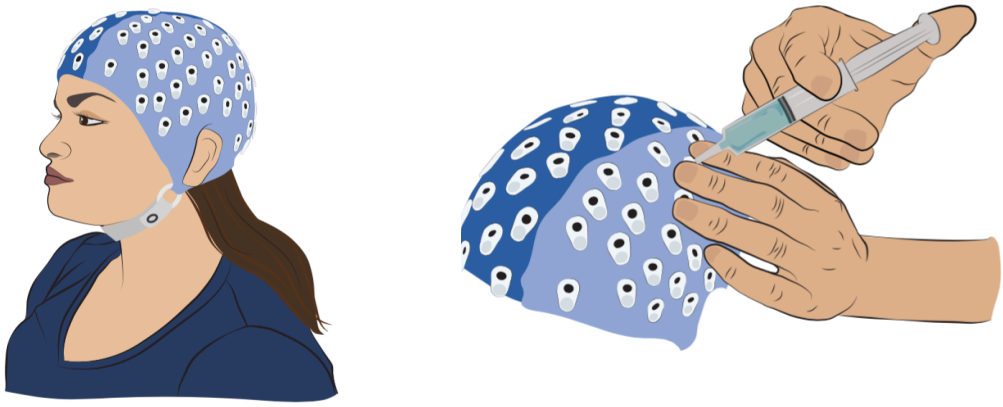
The coding language is specific for *Presentation*, each task was divided into 3 files, the .sce file, the .pcl file and the .exp file. The first file is associated to the design of each figure or background. The second file is related to how the figures act throughout the tasks - the amount of time each figure stays on screen, the randomization, etc. The .exp

[1] Source: *https://www.biosemi.com/* (February 25th, 2018)

file is a file created by *Presentation* that allows the user to call the task, that has the .sce and the .pcl files embeded.

4.2 The Collection Process

Once at the location, the experimental procedure would be explained to the participant, as it is presented in the scrip (Appendix II). First, the participant would have to sign a consent form explaining all tasks in detail, that they were free to withdraw at any moment, that it was an anonymous study and that no personal information was going to be shared or made possible to trace back. After that, a few questions were asked for the health and well-being assessment following an IQ test. Once the EEG system was setup, the subject would be equipped.



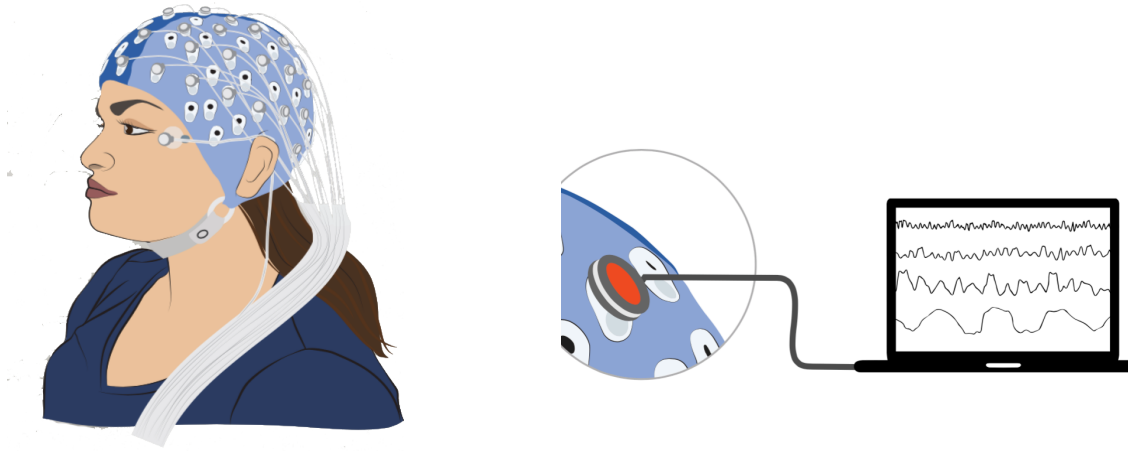
(a) (b)

Figure 4.2: (a) - Sketch of participant with cap and chin strap on; (b) - Sketch of the insertion of conductive gel into the cap's holes

Measurements of the head's circumference were taken (from the nasion to the inion) in order to know which cap size the participant would require. Next, the skin would be abrased so that the external electrodes would have better contact with the skin.

Four external electrodes were placed (one on each temple and one on each mastoid) and then the cap was placed on the head, secured with a chin strap (Fig.4.2(a)). Conductive gel was inserted into each cavity (Fig.4.2(b)) followed by the insertion of the pin-type electrodes (Fig.4.3(a)). Once everything was complete, the EEG system was used for a real-time visualization of the brain's electrical signal to help correct possible bad connection flaws before beginning with data recording. (Fig.4.3 (b)). [2]

[2]Figures 4.2 and 4.3 were created by Biomedical Designer Angela Wen, SFU



(a) (b)

Figure 4.3: (a) - Sketch of participant with external electrodes and pin-type electrodes inserted; (b) - Sketch of raw signal being sent from the electrodes to the laptop for quality assessment

Participants

Overall, 18 people were tested (four of whom were males). Four individuals were initially used to validate the entire pipeline and later added to the control group. Because some of the tasks changed between the test subjects and the actual participants, the number of subjects per task varies; for this reason, this number will be presented before explaining the results for each task. The table below shows the demographic data.

—	**Subjects**	**Age Range**	**Post-Sec Education**
Controls	10 (8F)	[63 ; 84]	6
Musicians	4 (2F)	[68 ; 76]	2
Meditators	2 (2F)	[69 ; 79]	2
Athletes	2 (2F)	[68 ; 79]	1

Table 4.1: Demographic data of subjects that participated in this study

Besides the information from Table 4.1., we only considered subjects that were monolingual. Chirality and level of expertise with each of the activities that this study addressed was additionally collected.

The definition of level of expertise differed slightly between groups, because it was difficult to apply a general form of measurement. For the Musicians group, one was considered to be an expert if they played a string or keyboard instrument at a professional level. For the Athletes group, one was considered to be an expert if they played at a competitive level or practiced strenuous sports regularly for over 8 years. For the Meditators group, one was considered to be an expert if they have meditated regularly for over 8 years.

CHAPTER 5

RESULTS

5.1 Data Analysis

5.1.1 Psychological Assessment

Before equipping the participants with the EEG system, we asked them to complete two questionnaires. Table 5.1 presents the mean scores of each group in regards to those questionnaires, the RPM and the SF-36. The RPM scores refer to the number of correct answers over the number of answered questions. The control group scored an average of 6.17 correct answers, and answered an average of 7.33 questions in 1 minute. Similarly, the musicians group scored an average of 6 correct questions over a total of 7 answered questions in 1 minute. The meditators group scored an average of 7.5 correct answers, and answered an average of 9.5 questions in 1 minute and finally the athletes group ansered correctly to 6 of the presented questions, over an average of 9 answered questions in 1 minute.

	Controls	**Musicians**	**Meditators**	**Athletes**
RPM	6.17/7.33	6/7	7.5/9.5	6/9
SF-36				
Total	120.6	143.5	140.0	139.0
Total (%)	74.91	89.13	86.96	86.34
Mental Health (%)	71.11	88.33	84.44	87.22

Table 5.1: Psychological assessment scores

In regards to the SF-36 questionnaire, because it is composed of questions regarding both physical and mental health, it was possible to withdraw the mental health percentage. Focusing on the overall scores, we can see that there is a difference of over 10% in how

controls and experts perceive their physical and mental health. Both meditators and athletes have very close overall percentages, however the musicians have the highest score. The same happens when looking solely at the mental health aspect with the musicians feeling the best in regards to their mental health, however, the athletes and the meditators showed a slight difference in these scores. Nevertheless, the control group shows to be the less satisfied group in regards to their mental health, presenting a difference of 17% when compared to the highest scoring group.

5.1.2 Multi-Scale Entropy

For the MSE (Multi-Scale Entropy) analysis, the Resting State data from the Cz electrode was used. From the raw data, the only preprocessing carried out included re-referencing to an average across all electrodes and applying a band-pass filter of 0.1Hz - 30Hz. Next, the data was divided and epoched into 30 seconds of continuous data. A Matlab code was prepared for the MSE analysis according to Costa et al., (2005) C code available online. Each time-scale that is added works as a filter, since the coarse-graining process averages the number of data points according to the time-scale that is in place.

In the data analysis, the following was considered:

1. Amplitude difference of **15%** of the standard deviation of time series;
2. **Two** consecutive data points were used for data matching in the coarse-graining section;
3. MSE was calculated for a maximum of **70 time-scales**.

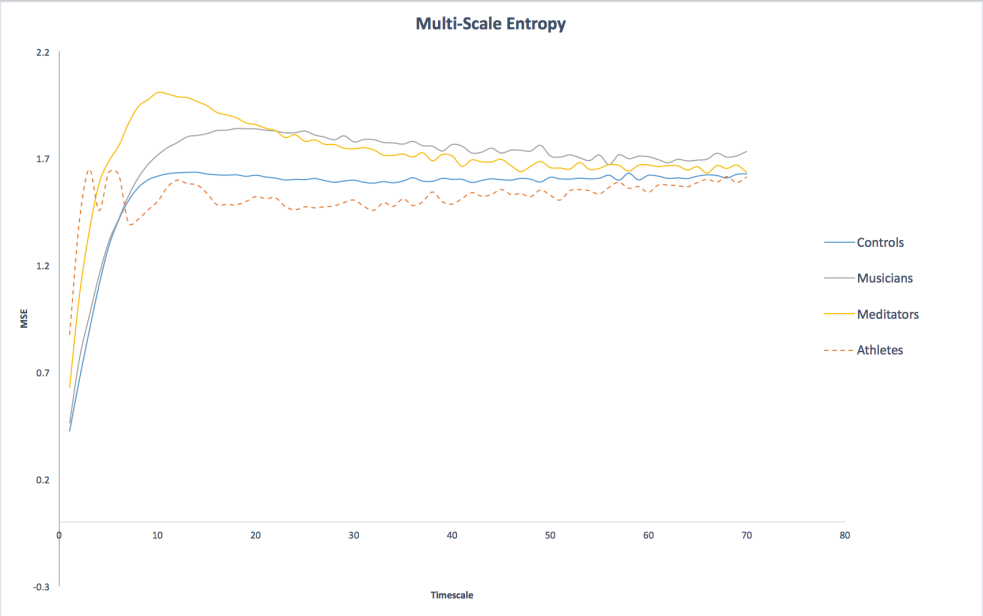


Figure 5.1: MSE results for all groups across different time-scales

As can be seen in Fig 5.1, the Athlete's plot is dashed, due to a drop-out of a participant; as such, the plot refers to a single subject, hence the data was excluded from the analysis. For the remaining three groups, we can observe that both the musicians and meditators have higher peaks (particularly at a timescale of 10) when compared to the control group. Also, we see that at bigger timescales, as the plot stabilizes, the expert groups tend to stay at a higher MSE value. At a timescale of approximately 22, the musicians start having slightly higher entropy values than the meditators.

As for the control group, even though they seem very similar to the musicians group at finer timescales, they do not reach the peak of the musicians group and seem to stabilize slightly earlier than the two other groups, remaining constantly below their MSE plots.

5.1.3 ERP Components

- **Control Group**

  The figures below show the ERP results regarding the Go/No-Go task. Previous studies show that the N2 and P3 component are bigger in electrodes Cz, Fz and FCz shown below. In addition the scalp maps display additional information on power distribution. The ERP waveforms for the entire scalp are presented in Appendix IV.

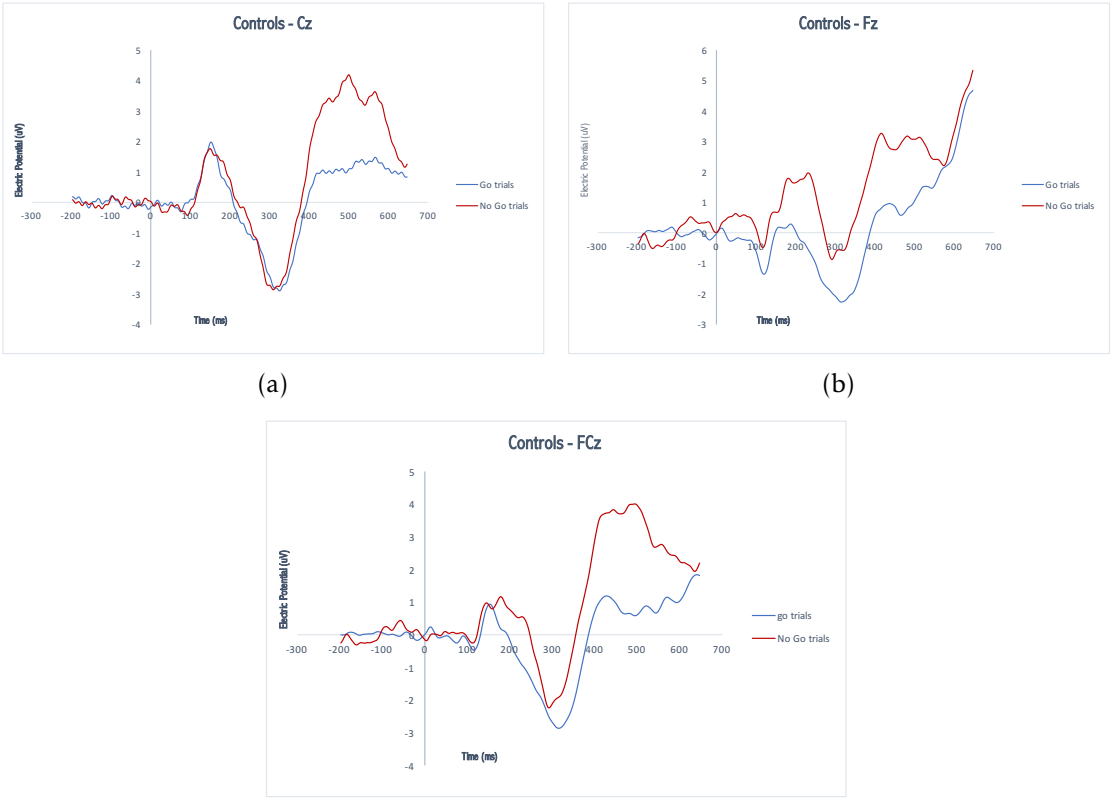


Figure 5.2: ERP components from Control group at the (a) -Cz electrode, (b) - Fz electrode and (c) - FCz electrode

For the sake of simplicity, the interpretation of data will focus on the FCz electrode, because although the P3 waveform is stronger in the posterior electrodes, the N2 component is more robust in the medial frontal electrode and not as visible further back in the scalp.

On the FCz electrode, the N2 negative deflection peak is at approximately 300 ms for both the Go Trials and the No-Go Trials, with an electric potential of -2.855uV and -2.245uV, respectively. The P3 positive deflection peak is at approximately 450 ms for both the Go Trials and the No-Go Trials, with an electric potential of 4.678uV and 6.244uV, respectively.

Figure 5.2 shows the ERP scalp map pertaining the previously described ERP waveforms.

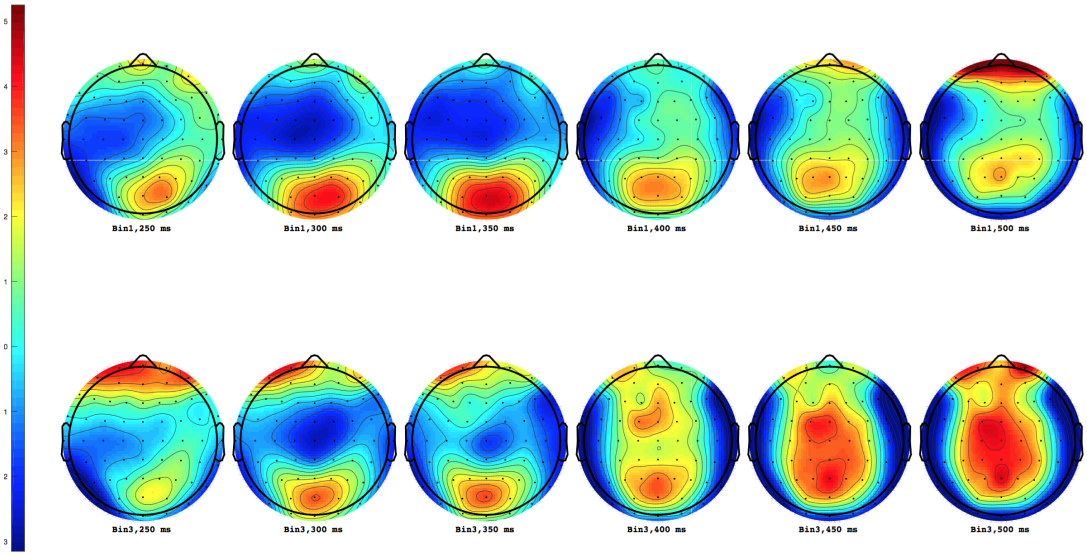


Figure 5.3: Scalp map power distribution for the Control group, for bin 1 (correct go trials) and bin 3 (correct no-go trials)

Note that bin 1 refers to the correct go trials and bin 3 refers to the correct no go trials, these "bins"come from a bin file that was created for the ERP analysis (see in the Appendix III). This file is necessary so that EEGLAB /ERPLAB identifies correct or incorrect response after stimuli exposure. By comparing the ERP waveforms to the scalp maps, it is possible to see the strong N2 for the Go trials and its early onset, whereas for the No-Go Trials we can see the same early onset, but with much less intensity and less sustained. Moreover, for the No-Go Trials we can see a very strong P3, more intensely than for the Go Trials and very disperse.

As can be seen in Fig. 5.3, the negative power seems to be most present between 300 and 350 ms for both bin 1 and bin 3, however, this power is more negative for

bin 1 than for bin 3 which correlates with the N2 waveform seen in Fig. 5.2. At approximately 450 ms the positive power seems to be the strongest for both bin 1 and bin 3, however there is a higher power density from bin 3 at this specific point in time, which also correlates correctly to the P3 waveform shown before where the P3 peak for the No-Go trials was shown to be greater than for the go-trials.

- **Musicians Group**

  Below you can see the ERP waveforms belonging to the Musicians group. The full scalp ERP waveform is represented in Appendix IV. It is again possible to observe the N2 and P3 components on all 3 electrodes presented below and just like in the control group, and as expected the P3 component is greater for the No-Go trials than for the Go trials.

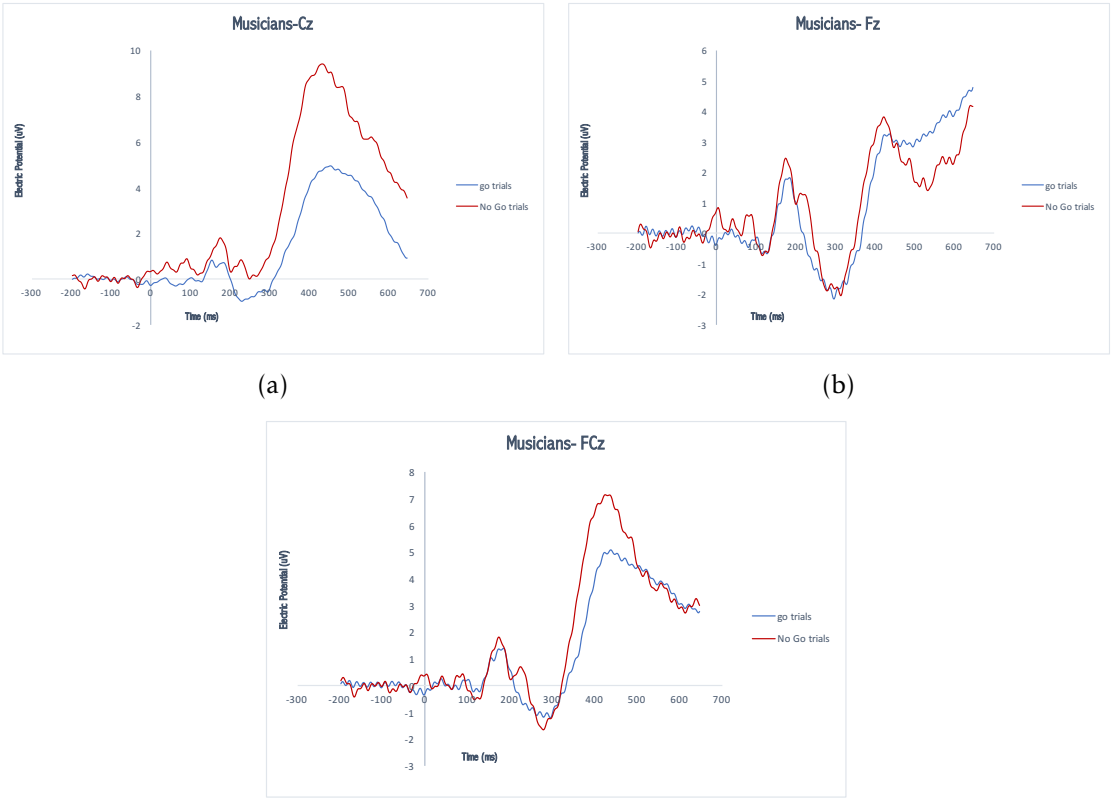


Figure 5.4: ERP components from the Musicians group at the (a) -Cz electrode, (b) - Fz electrode and (c) - FCz electrode

Assessing Fig. 5.4, on the FCz electrode, the N2 negative deflection peak is at approximately 280 ms for both the Go Trials and the No-Go Trials, with an electric potential of -1.202uV and -1.650uV, respectively. The P3 positive deflection peak is at approximately 450 ms for both the Go Trials and the No-Go Trials, with an electric potential of 5.096uV and 7.149uV, respectively.

The scalp maps for the Musicians group is presented below between 250 and 500 ms at every 50 ms (Fig. 5.5). Similarly to the Control group, it is possible to see a change throughout time 250 ms after the stimuli was presented and how the information was processed by the brain. We observe a similar N2 activity for both the Go Trials and the No-Go Trials, both presenting strong intensity and early onset, but the P3 activity is significantly more intense in the No-Go Trails and focal.

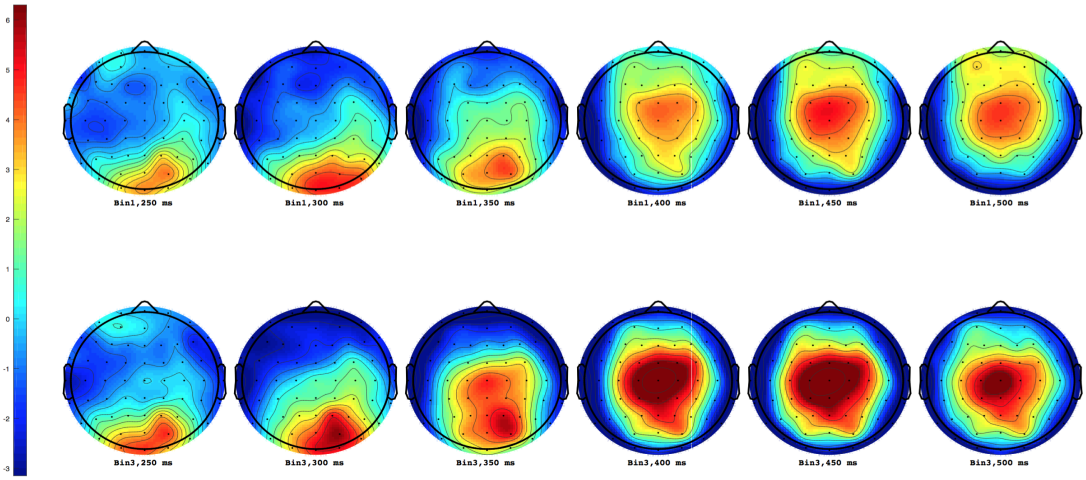


Figure 5.5: Scalp map power distribution for the Musicians group, for bin 1 (correct go trials) and bin 3 (correct no-go trials)

Again, the ERP waveform plot is comparable to the scalp maps. We can observe the power density change from the N2 to the P3 at the respective times, and also weigh the changes in intensity between the go trials and the No-Go trials. Because there is less disparity in amplitudes in Fig. 5.4, the power intensity in the scalp map is not as different as observed for the Control's group.

- **Meditators Group**

  Fig. 5.6 shows the ERP waveforms belonging to the Meditators group. The full scalp ERP waveform representation is shown in Appendix IV. This figure shows the N2 and P3 ERP components from the mid-line electrodes. When examining the FCz electrode it is clear that this group has the biggest amplitude difference between the N2 and the P3 for the No-Go trials.

  The N2 negative deflection peak is at approximately 310 ms for both the Go Trials and the No-Go Trials, with an electric potential of 1.117uV and -3.365uV respectively. The P3 positive deflection peak is at approximately 450 ms for both the Go Trials and the No-Go Trials, with an electric potential of 5.551uV and 9.780uV, respectively.

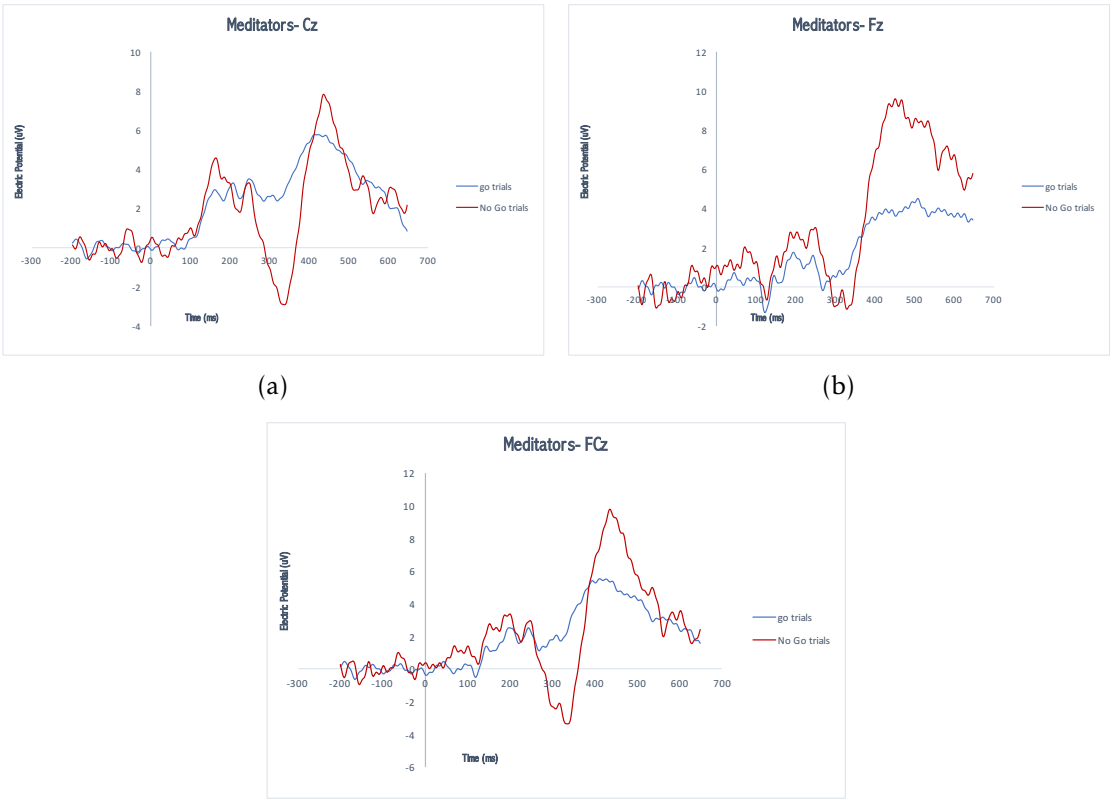


Figure 5.6: ERP components from Meditators group at the (a) -Cz electrode, (b) - Fz electrode and (c) - FCz electrode

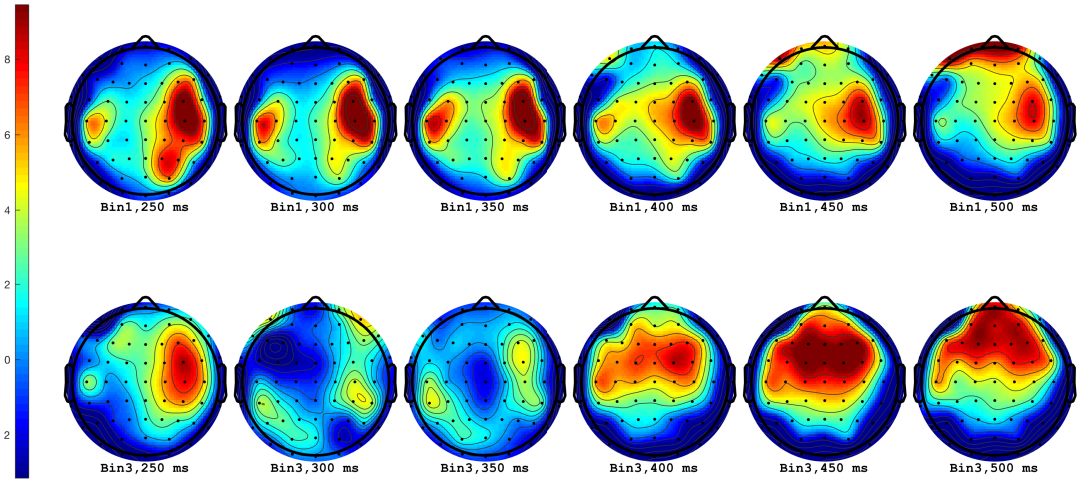
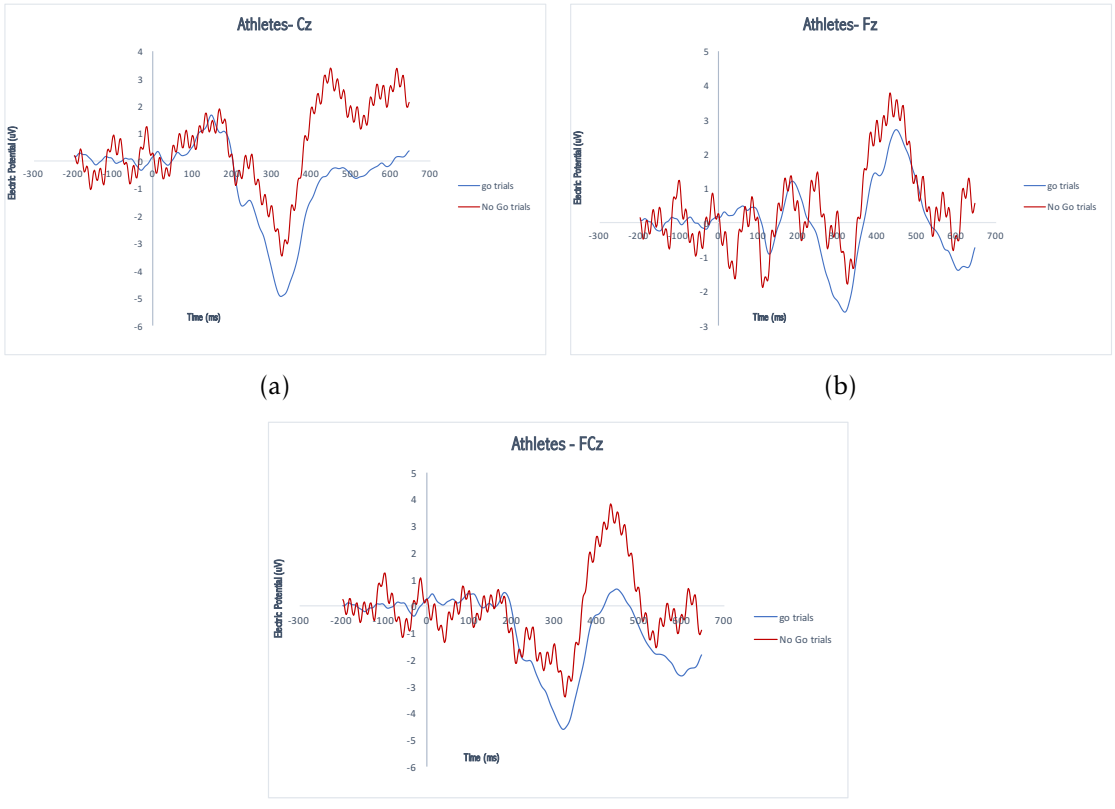


Figure 5.7: Scalp map power distribution for the Meditators group, for bin 1 (correct go trials) and bin 3 (correct no-go trials)

This is also the only group that has a constantly positive *Go trial* plot, which only means that the difference between the N2 and the P3 is much smaller in these trials than with the rest of the groups. Because the meditators didn't show a very big N2 negative deflection for the go trials, the scalp maps don't show a big negative power intensity at around 300 ms for the Go Trials (Fig. 5.7), however, it can be seen for the No-Go Trials, as shown in the ERP waveforms. A big P3 peak, specially for the No-Go trials can be seen between 400 and 500 ms, which correlates to the ERP waveforms seen above. For the *Go Trials* it is also seen in the scalp map activity a strong lateralized activity happening throughout the entire time.

- **Athletes Group**

  Finally, it is possible to observe the Athletes results for the ERP waveforms on Fig. 5.8. The full scalp ERP waveform representation is in the Appendix IV. Unfortunately, due to the small number in participants for this group, these are the results that show more noise, particularly in the No-Go trials.



(a) (b)

(c)

Figure 5.8: ERP components from Athletes group at the (a) -Cz electrode, (b) - Fz electrode and (c) - FCz electrode

It is also shown on the ERP waveforms that this group has the most negative N2 waveform, and interestingly, it the plot for the Go trials is always more negative than the plot for the No-Go trials.

The N2 negative deflection peak is at approximately 300 ms for both the Go Trials and the No-Go Trials, with an electric potential of -4.626uV and -3.403uV, respectively. The P3 positive deflection peak is at approximately 450 ms for both the Go Trials and the No-Go Trials, with an electric potential of 0.662uV and 3.820uV, respectively.

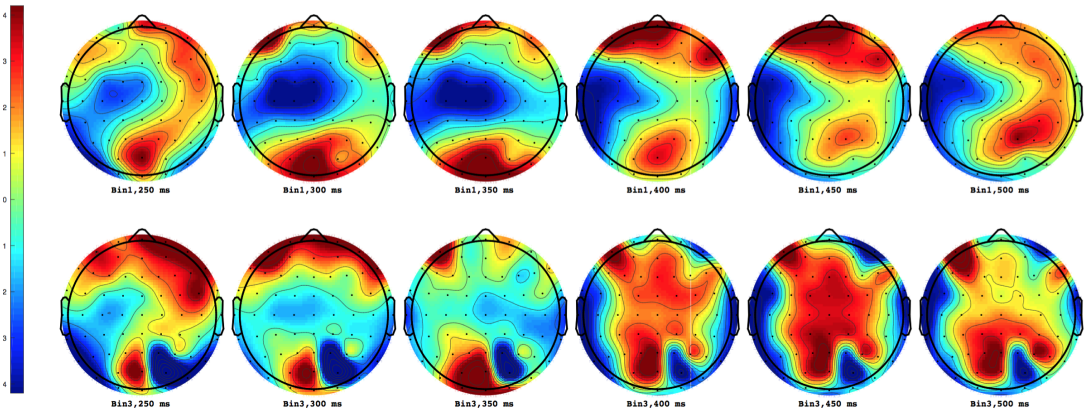


Figure 5.9: Scalp map power distribution for the Athletes group, for bin 1 (correct go trials) and bin 3 (correct no-go trials)

The big negative deflection shown for the go-trials is represented in Fig.5.9. where the scalp map power intensity distribution is shown at about 300 ms, and the big positive deflection shown for the No-Go trials is represented in the scalp map power distribution at around 450 ms which matches the results from the ERP waveforms N2 and P3 presented above. The N2 component is stronger for the Go Trials and have a early onset but the P3 component is very strong for the No-Go Trials and very disperse

Accuracy values were calculated using the equation presented below. The overall accuracy scores for each group in regards both to the Go trials and the No-Go trials is presented in Table 5.2.

$$Accuracy = \frac{Numberof\,CorrectHits}{(TotalNumberof\,Hits) * (Probabilityof\,Occurrence)} \tag{5.1}$$

	Correct *Go Trials*	**Correct *No-Go Trials***
Controls	97.7%	80.5%
Musicians	98.3%	94.0%
Meditators	99.6%	81.3%
Athletes	97.1%	92.2%

Table 5.2: Accuracy scores over all groups in regards to the Go/No-Go task

From ERPLAB it was possible to extract the exact number of correct and incorrect trials. The number of correct trials was then divided by the total number of trials multiplies by the probability of occurrence.

The probability of occurrence was 80% for the Go Trials and 20% for the No-Go Trials. Overall, all scores are very high, which means that the task was not very hard for none of the groups, making their ERP waveforms and power intensity scalp maps more comparable.

d' Prime Evaluation

As mentioned in the precious chapter, d' is based on signal detection theory, referring to a difference between the correct hit rate and the false alarm rate.

Signal/Response	**Yes**	**No**
Yes	Hits	Misses
No	False Alarms	Correct Rejections

Table 5.3: Possible outcomes of signal detection theory

Based on Table 5.3, data from each group was calculated and can be seen below.

- **Controls**

Signal/Response	**Yes**	**No**	***d'***
Yes	249.2	5.6	2.73
No	12.6	51.3	

Table 5.4: d' table and score for the control group

- **Musicians**

Signal/Response	**Yes**	**No**	***d'***
Yes	243.8	4.25	3.15
No	3.75	58.25	

Table 5.5: d' table and score for the musicians group

- **Meditators**

Signal/Response	Yes	No	*d'*
Yes	255	1	2.78
No	12	52	

Table 5.6: d' table and score for the meditators group

- **Athletes**

Signal/Response	Yes	No	*d'*
Yes	248.5	7.5	3.04
No	5	59	

Table 5.7: d' table and score for the athletes group

5.1.4 Colour Search

Response times were analyzed for this task, and understanding the differences in speed of processing between each group, was the main purpose of this task. The figure below (Fig. 5.10) shows the median time it took for each group to respond to a certain number of items, ranging from 4 to 10. The athletes group is dotted, because even though we had two athletes, one of the athletes dropped out of the study, half way through the data collection process, and so the data was insufficient to include. Therefore the athlete line in this task is only regarding one person.

	Control Group	Musicians	Meditators	Athletes
4 Items	1084	1151	1035	1288
6 Items	1151	1152	1046	1311
8 Items	1405	1409	1129	1260
10 Items	1467	1527	1265	1416
Time Difference	64	63	38	21

Table 5.8: Median response time, in ms, per number of items presented, and time difference per added item to the visual field

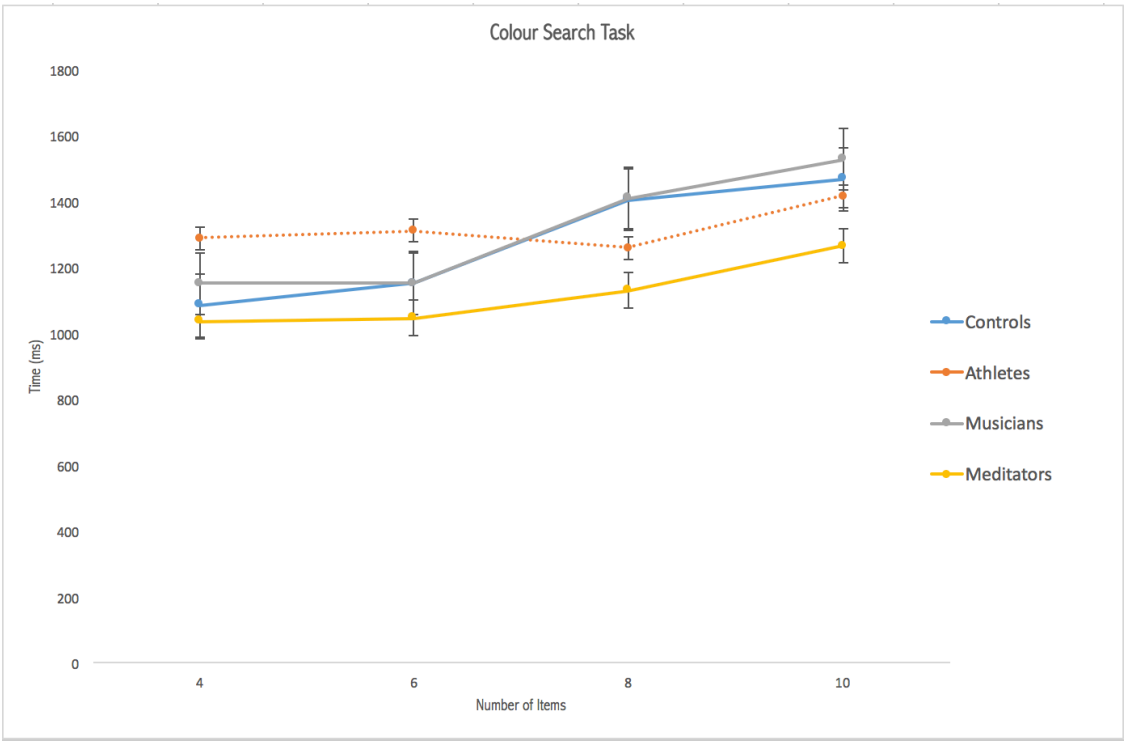


Figure 5.10: Plot of response times, in ms, per number of items presented. The dotted line for the Athletes group represents a single subject

Besides looking at differences between response times, with this data it was also possible to calculate how much time each group needed to understand an increase in the number of items. In Table 5.8 it is presented the median time in ms it takes for each group to answer correctly to the respective number of items and how much time each group needs to acknowledge and process an increase in the number of items. There is no considerable difference between the control group and the musicians, however, the meditators take half the time to process the new information given by the task when compares to the two previous groups.

5.1.5 Short-Term Memory

For this task, accuracy was assessed and inserted in the table below (Table 5.9). The values correspond to the number of items that can be stored in an individual's short-term memory. The results are presented for only the 4 and 6 item display and for the 4, 6 and 8 item display. Even though the participant would also answer to a 2 item display, this was not included because it was very easy to answer ans therefore would not show differences between groups.

—	4 and 6	4, 6 and 8
Controls	1.5	1.4
Musicians	1.6	1.3
Meditators	3.2	3.0
Athletes	1.3	1.1

Table 5.9: Short-term Memory test scores for each group, including only the 4 and 6 item display, or the 4, 6 and 8 item display

As seen on the table above, the result between both columns do not differ a lot, however, it would be expected that the response times would slightly increase when the 8 item display was included, which was not the case. Between groups the scores are also very similar with the exception of the meditators. Despite the low number of participants, this group scored almost twice as better than the remaining groups, showing a capability of storing 3 items in their short-term memory, while the rest can only store almost 1.5.

Chapter 6

Discussion and Conclusions

The number of older adults is increasing at a fast rate in most developed countries. In 2016, Canada had for the first time in its history a greater proportion of people over the age of 65 (16.9%) than under the age of 15 (16.6%) (Government of Canada, Statistics Canada, 2016). In the United States, the number of older adults is expected to grow from approximately 45 million to 70 million by the year 2030 (Ortman et al., 2014). Fig. 6.1 and 6.2 show the proportion of population aged over 60 years, by country in 2015, and projections for 2050, respectively. According to Fig. 6.1, there is only one country whose people over the age of 60 exceed 30% of the total population - Japan. However, assessing Fig. 6.2, many countries, including European countries, North America and China will have similar proportions by the year of 2050 (The 2015 Ageing Report, 2015).

Associated with older age are neuropsychiatric and degenerative disorders, and for that reason it is important to investigate and learn how to maintain brain and cognitive health in order to prevent cognitive deterioration. Studies have shown that dementia affects approximately 24 million people globally, but given the increasing number of older adults it is forecasted that this number will grow to approximately 81 million people by the year 2040 (World Health Organization, 2006).

Understanding that due to the brain's plasticity, changes in behaviour lead to changes in cognition, it is important to study how and in what way do lifetime experiences convey an enhanced cognition. Specifically, it is necessary to investigate if lifetime expertise lead to a greater inhibitory control, working memory, attention and entropy in older adults. For this reason, the aim of this study was to understand the cognitive advantages that experts in music, meditation and sports carried out, when compared to people that led a sedentary lifestyle.

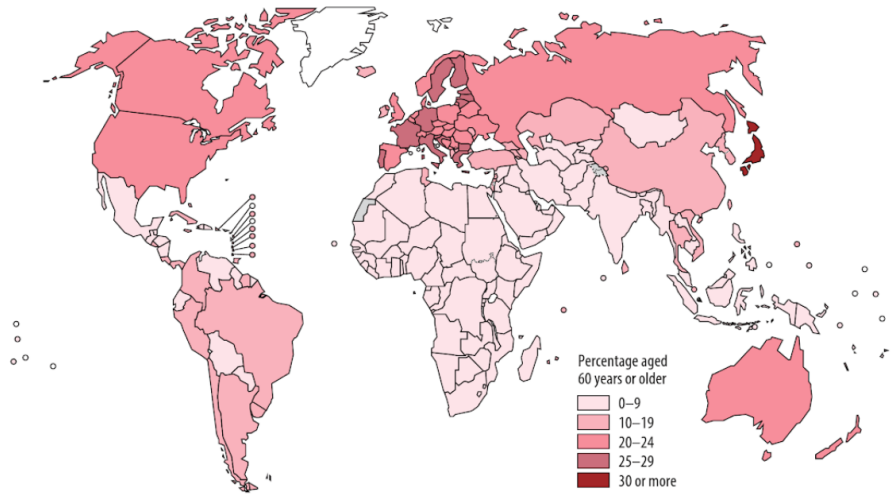


Figure 6.1: Proportion of population aged 60 years or older, by country, in 2015 (The 2015 Ageing Report, 2015)

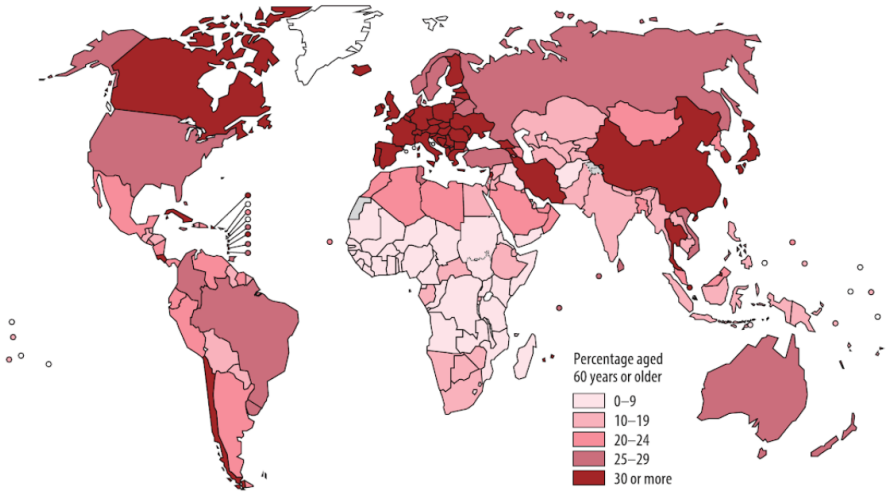


Figure 6.2: Proportion of population aged 60 years or older, by country, 2050 projections (The 2015 Ageing Report, 2015)

An overall assessment of the results allowed for a validation of the proposed hypothesis, where it was suggested that lifestyle activities lead to enhanced cognition in old age, compared to a sedentary lifestyle. This validation was made due to the understanding of the sub-hypothesis. Firstly, it was confirmed that expert groups obtained higher scores for the health and well-being questionnaire when compared to the age and IQ matched controls. Secondly, as previous studies suggested, meditators showed a higher performance in all attention based tasks, attaining scores that were almost twice as good as the remaining groups. Thirdly, even though in absolute values, the athletes had the

lowest P3 values, the difference of the distance between the N2 and P3 components of both trials, show that it is smallest for the sedentary control group. Finally, and despite the fact the the athlete's scores were not included in this evaluation, both musicians and meditators showed overall superior MSE results when compared to the control group. All these conclusions support the main theory whether in regards to inhibitory control, working memory, attention or entropy, since all of which are crucial elements of cognition. Albeit the number of participants that were included in this study are not sufficient to prove with certainty the reasons behind these results, it is interesting that with even two or four subjects, the outputs vary so greatly between groups and align with the proposed hypothesis.

The MSE results that were acquired through this study go in line with one of the proposed sub-hypothesis, where is was stated that is was expected that experts would have higher MSE values across all time-scales. In fact, looking at Fig. 5.1., this is true for both smaller and bigger time-scales. It is also interesting to point out that at around a time-scale of 20, the musicians start having bigger MSE scores than the meditators. Because entropy is a recent concept, how the results translate into practical information is still not fully understood, however, it is known that entropy values are linked to cognitive processing and that MSE values from finer timescales are associated with higher frequencies and the results from coarser timescales are associated to lower frequencies of relative power. The figure presented below compared the MSE values between young (mean age of 23) and older adults (mean age of 68). The plot that is presented at the further left is the MSE score for resting state data, where the next two plots refer to an auditory task, where on the central plot, the participant was simply asked to listen to the stimuli, and on the further right plot the participant was asked to count how many tones he/she heard (Sleimen-malkoun et al., 2015).

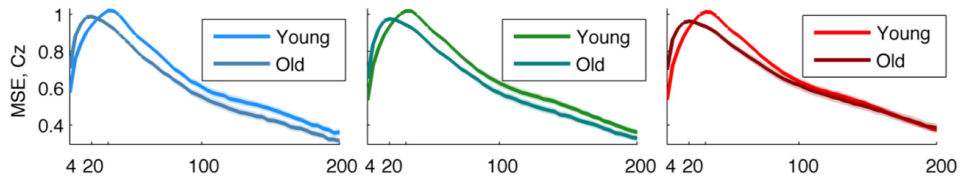


Figure 6.3: MSE scores for resting state, auditory task and auditory task with counting, respectively (Sleimen-malkoun et al., 2015)

In all plots, young adults have overall higher MSE values than older adults, particularly at bigger time-scales. It is interesting to see that the results from the present study seem to show a trend towards a similarity between the expert groups and the younger adults. A possible translation as to what higher MSE values represent include higher cognitive processing at all time-scales. These MSE scores show how much a signal changes across different frequencies, and these different frequencies have different cognitive importances. Higher MSE scores represent a greater complexity, possibly translating in

greater resource availability. Studies have shown that correlations between time series represent the creation of new brain networks and associations (Nunez, 1989) and it is hypothesized that finer time-scales reflect localized dynamics, whereas coarser time-scales are related to longer range interactions (Mcintosh et al., 2013). As shown in Fig. 6.3, we can observe that associated with age is a transition from long-range connections to a more focalized processing (Mcintosh et al., 2013).

Observing the obtained results, it seem like both expert groups maintain a greater capacity for both short and long range neural communications when compared to the sedentary group. In particular, the meditation group appears to have the biggest difference between brain complexity when it comes to varied range processing (both smaller and greater time-scales), varying from an MSE value of 2 (at the peak) to 1.6, whereas the musicians group appears to have a more stable and constant complexity level for all neurological interactions, barely shifting from an MSE value of 1.8 to 1.7 (in particular, after a time-scale of 10).

The meaning of these changes and how they relate to structure, function, and dynamics still have to be explored (Sleimen-malkoun et al., 2015), and even though theories and simulation studies can be made, more human studies, specifically with older adults have to be done. The findings of this study are encouraging, despite the small number of participants, and a better understanding of this neurophysiological tool will only be possible with further research.

This study provided a large amount of results in regards to the Go/No-Go task, including the ERP waveforms, the scalp maps, the accuracy percentages and d' prime scores. Across all group, there is an early onset and high intensity power for the N2 component in the Go Trials, except with the meditation group. With the meditation group, this intensity and early onset is seen in the No-Go Trials. In regards to the P3 component, which is a bigger indicator of inhibitory control, it is possible to see a focal and intense P3 waveform in the musicians group, which might translate in a more efficient P3 complex, that needs less resources to function correctly. This matches the information presented both in the accuracy table and the d' prime tables (Tables 5.2 and 5.5, respectively) where the musicians excelled. Another group that excelled in both these sectors was the athletes group, and looking at the P3 component in the scalp maps, even though it is disperse, it is intense, showing that perhaps more resources are available to perform the task correctly. The P3 component does not only represent inhibition, when centralized, it also represents the response towards conflicting information, however the way it is presented in the meditators (in the go trials), where it is more lateralized, tends to be understood as a purely inhibitory response. This seems to show greater inhibitory control for the meditation group, however, by assessing the no-go trails and observing the high-intensity and highly disperse P3 component, it appears that it is hard for meditators to suppress the urge to press the button when a no-go stimuli is presented, and a big conflict takes

over. This goes in line with the accuracy results of correct no-go trials (Table 5.2) and the d' prime scores from Table 5.6, where this group did not score as well as the musicians and athletes group.

	N2		P3	
	Go	**No-Go**	**Go**	**No-Go**
Controls	-2.85uV	-2.25uV	1.68uV	6.24uV
Musicians	-1.20uV	-1.65uV	5.09uV	7.15uV
Meditators	1.18uV	-3.37uV	5.55uV	9.78uV
Athletes	-4.63uV	-3.40uV	0.66uV	3.82uV

Table 6.1: Peak amplitudes for N2 and P3 components

Overall, when compared to the control group, it is possible to see that all expert groups have cognitive features that might show higher inhibition control, whereas the control group shows less intensity in power, and bigger distribution, which might mean less available brain resources when it comes to responses that require inhibitory control. Because of the lack of participants, further studies have to be made in order to better understand what this information means.

Looking at the values from the Table 6.1 we can also understand the differences between peak amplitudes. Comparing differences between the Go Trials and the No-Go Trials also helps in an understanding of the effects of responding to a situation of conflict. For the Control group, the difference for peak distances between the Go Trails and the No-Go Trials is 0.96uV, for the Musicians group, that difference is slightly more marked, being 2.31 uV. The Meditators have the biggest difference of 8.78uV and the Athletes have the smallest difference amongst the expert groups of 1.93uV. This information is useful because it supports the hypothesis that both musicians and athletes have bigger inhibitory response than controls. The high value for the Meditation group might represent an overuse of resources, showing that it is hard for that group to ignore and suppress responses.

In regards to the behavioural tasks, the meditators group outperformed the remaining groups. Despite the small number of participants, there is a trend that verifies the link between meditation and attention. Furthermore, the fact that both the smaller response times for the colour search task and the increased number of stored items for the short-term memory test, encourage that further studies should be made with a larger group of participants in order to extract robust conclusions. Previous studies have shown that meditators have great abilities at attention tasks, and in fact these behavioural tasks helped confirm that, and gave new information in regards as to where other expert groups stand when compared to both meditators and sedentary people.

By comparing the results from this study to previous ones, we can understand that they fit together. Starting with musical experience, previous papers found that there

are several benefits from this activity, including greater intelligence (Schellenberg and Moreno, 2010) and inhibitory control (Moreno et al., 2014), coming hand in hand with the scores above presented from the Go/No-Go task and MSE. Furthermore, studies including trained older musicians concluded that these individuals have superior neural activity for specific executive functions when compared to the matched controls (Parbery-Clark et al., 2012), leading to substantial reductions in the likelihood of dementia and cognitive impairments in older age (Balbag et al., 2014). Studies in regards to meditative experience are not abundant, however, given that this activity involves sustaining attention and controlling changes in cognitive state, many authors believe that regular practice leads to enhanced cognitive reserve and an overall improvement of mental health across the lifespan (Christie et al., 2017). MacLean et al. (2010), showed that expert meditators outperformed matching controls in tests of sustained attention and Hasenkamp & Barslou (2012) hypothesized that meditation is involved in the regulation of attentional networks, allowing them to focus attention on relevant objects while disengaging from any distractors. These results also match what was presented in this study, where meditators outperformed matching controls in the behavioural tasks (and all other expert groups), where attention was the main factor. With respect to the athletes group, preliminary studies have shown that an assessment of oxygen intake as a direct measurement of cardiovascular fitness in older adults has an inverse relationship between physical activity and cognitive decline (Barnes et al., 2003). Other studies have shown that aerobic exercise has led to improvements in global cognitive ability, in particular, working memory (Zheng et al., 2016), which comes in line with what was presented in this study with the high scores in inhibitory control components. Moreover Rovio et al. (2005) showed that participants with dementia who engaged in physical activity at midlife exhibited a reduction in the neurodegenerative disease.

In conclusion, all three of the exposed activities present benefits when compared to participants that lead a sedentary lifestyle. The study suggests that exercise and musicianship may lead to an enhancement in cognitive abilities, in particular working memory, whereas meditation appears to confer several benefits in attentional processing, which comes in line with what previous studies had suggested. This study gives valuable insight as to how these activities differ amongst each other and in what way and aspect is one more advantageous than the other, even though further testing must be carried out for a more robust assessment of these behavioural interventions.

6.1 Challenges

There were, overall some challenges throughout the study development process. Starting at the development of the study pipeline, it was a quite challenging to create parameters that would fit all participating groups. Understanding what it meant to be "an expert"for each group was not easy and it varied from activity to activity. Special considerations were taken into account, such as excluding athletes that could have had head injuries (sports such as hockey, rugby, soccer, would be automatically excluded). As for the musicians, only the ones that played either a keyboard of string instrument were included, and as for the meditators, only purely motionless types of meditation were included (activities such as yoga was not included in this study). Also, deciding on what tasks to present was also quite challenging, due to the fact that we did not want to have bias results. Therefore, we tried to choose tasks that were simple enough to activate specific cognitive abilities without focusing on only one cognitive process (e.g. if we had only chosen attentional tasks, the results would have shown that meditators outperformed all groups with no information as to why music and sports enhance cognitive reserve)

Finding interested participants was also a challenge. Initially, putting up flyers at community centres was thought to be the easiest way to find candidates, however few people contacted me to show interest in participating. Looking up music schools, meditation centres, recreation centres and personally going there to talk to people or calling the schools/centres showed to be the best way to attract people. Even though this solution was better than the original one, once specific aspects were elaborated on, and I explained that the overall process would take about 2 hours to complete, the conductive gel would have to be inserted into the holes in the cap so participants would have to take a shower after, and that personal questions about their health would be asked, many of the older adults drop out or lose interest in the study.

Another challenge was that, even though the EEG system is characterized as a portable system, it weights between 10 and 15 Kgs (including both laptops). Carrying it to the participant's house, and back to the lab and washing everything after each collection were both time-consuming and exhausting. The cleaning process included washing the EEG cap with soap and hot water and alcohol, and using a (dental) water sprayer to clean each hole in the cap guaranteeing no gel would be left. Each electrode and the syringes also had to be cleaned with water and alcohol, again to guarantee that no gel was left. After setting up the system and putting the EEG cap on the participants, it was also hard to keep them following the rules, such as not blinking too much, not talking, not moving their head or not moving their eyes away from the fixation cross. All of these small details are important for a perfect data collection, but it was almost impossible to achieve with all the participants, particularly in this age range. Between groups, I noticed that it was easier for the meditators to sit through the two hour experiment, and that it was really hard for the athletes to do so, which is a reflection of their habits and practices.

6.2 Future Directions

The results presented in this study, despite the small number of participants, show interesting trends as to the possible effects of behaviour on cognitive processing. Further studies have to be made with a bigger number of participants to validate that these results. If they do, the next step would be to understand how much of these activities need to be done (how much time of experience) for people to start seeing an improvement in cognition. Also, studies on specific types of meditation/music/sports can be made, so that an understanding as to which one has the biggest impact in the brain.

Also, as for future studies, comparisons between the BioSemi and commercial EEG systems have to be made, in order to understand if it is possible to retrieve the same information from a system that is easier to transport, setup and clean. Additional questions would be interesting to analyze in future studies such as understanding what part of the experiment presented greater challenges for each person and/or other, more group specific tasks may be introduced.

Bibliography

[1] Anderson, B. A., Laurent, P. A., & Yantis, S. (2011a). Learned Value Magnifies Salience-Based Attentional Capture. PLoS ONE, 6(11).

[2] Anderson, B. A., Laurent, P. A., & Yantis, S. (2011b). Value-driven attentional capture. PNAS, 108(25).

[3] Ando, J., Ono, Y., & Wright, M. J. (2001). Genetic structure of spatial and verbal working memory. Behavior Genetics, 31(6), 615–624.

[4] Angevaren, M., Aufdemkampe, G., Verhaar, H. J. J., Aleman, A., & Vanhees, L. (2008). Physical activity and enhanced fitness to improve cognitive function in older people without known cognitive impairment. The Cochrane Database of Systematic Reviews, (3), CD005381.

[5] Bennett, D. A., Arnold, S. E., Valenzuela, M. J., Brayne, C., & Schneider, J. A. (2014). Cognitive and social lifestyle: Links with neuropathology and cognition in late life. Acta Neuropathologica, 127(1), 137–150.

[6] Brody, H. (1955). Organization of the cerebral cortex. III. A study of aging in the human cerebral cortex. The Journal of Comparative Neurology, 102(2), 511–556.

[7] Burke, S. N., & Barnes, C. A. (2006). Neural plasticity in the ageing brain. Nature Reviews, 7(1), 30–40.

[8] Canter, P. H., & Ernst, E. (2003). The cumulative effects of Transcendental Meditation on cognitive function–a systematic review of randomised controlled trials. Wiener Klinische Wochenschrift, 115(21–22), 758–766.

[9] Colcombe, S. J., Kramer, A. F., Erickson, K. I., Scalf, P., McAuley, E., Cohen, N. J., Elavsky, S. (2004). Cardiovascular fitness, cortical plasticity, and aging. Proceedings of the National Academy of Sciences, 101(9), 3316–3321.

[10] Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults. Psychological Science, 14(2), 125–130.

[11] Costa, M., Goldberger, A. L., & Peng, C. (2005). Multiscale entropy analysis of biological signals. Physical Review, 1–18.

[12] Dennis, N. A., & Cabeza, R. (2008). Neuroimaging of healthy cognitive aging. The Handbook of Aging and Cognition, (November), 1–54.

[13] Diamond, A. (2012). Executive functions. Annual Review of Psychology, 64(September 2012), 135–68.

[14] Falck, R. S., Davis, J. C., & Liu-ambrose, T. (2017). What is the association between sedentary behaviour and cognitive function? A systematic review, 800–811.

[15] Farzan, F., Atluri, S., Mei, Y., Moreno, S., Levinson, A. J., Blumberger, D. M., & Daskalakis, Z. J. (2017). Brain temporal complexity in explaining the therapeutic and cognitive effects of seizure therapy. Brain, 1011–1025.

[16] Firth, J., Stubbs, B., Vancampfort, D., Schuch, F., Lagopoulos, J., Rosenbaum, S., & Ward, P. B. (2018). NeuroImage Effect of aerobic exercise on hippocampal volume in humans: A systematic review and meta-analysis. NeuroImage, 166, 230–238.

[17] Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. Psychophysiology, 45(1), 152–170.

[18] Freitas, C., Farzan, F., & Pascual-Leone, A. (2013). Assessing brain plasticity across the lifespan with transcranial magnetic stimulation: Why, how, and what is the ultimate goal?. Frontiers in Neuroscience, (7 APR).

[19] Goyal, M., Singh, S., Sibinga, E., Gould, N., Rowland-Seymour, A., Sharma, R., Al, E. (2014). Meditation programs for psychological stress and well-being: a systematic review and meta-analysis. JAMA Intern Med, 174(3), 357–68.

[20] Christie, G. J., Hamilton, T., Manor, B. D., Farb, N. A. S., Farzan, F., Sixsmith, A. (2017). Do Lifestyle Activities Protect Against Cognitive Decline in Aging? A Review, 9(November), 1–12.

[21] Hampel, H., & Lista, S. (2016). Dementia: The rising global tide of cognitive impairment. Nature Reviews, 12(3), 131–132.

[22] Hanna-pladdy, B., & Mackay, A. (2011). The Relation Between Instrumental Musical Activity and Cognitive Aging. Neuropsychology, 25(3), 378–386.

[23] Hebert, L., Weuve, J., Scherr, P., & Evans, D. (2013). Alzheimer disease in the United States (2010-2050) estimated using the 2010 census. Neurology, 80(19), 1778–1783.

[24] Hötting, K., & Röder, B. (2013). Beneficial effects of physical exercise on neuroplasticity and cognition. Neuroscience and Biobehavioral Reviews, 37(9), 2243–2257.

[25] Intlekofer, K. A., & Cotman, C. W. (2013). Exercise counteracts declining hippocampal function in aging and Alzheimer's disease. Neurobiology of Disease, 57, 47–55.

[26] Katzman, R., Terry, R., Deteresa, R., & Brown, T. (1988). Clinical, Pathological, and Neurochemical Changes in Dementia: A Subgroup with Preserved Mental Status and Numerous Neocortical Plaques. Ann Neurol 138–144.

[27] Kramer, a F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., Colcombe, a. (1999). Ageing, fitness and neurocognitive function. Nature, 400(6743), 418–419.

[28] Kramer, A.F., & Madden, D.J. (in press). Attention. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (3rd ed.). Mahwah, NJ: Erlbaum, 2008

[29] Lazar, S. W., Kerr, C. E., Wasserman, R. H., Jeremy, R., Greve, D. N., Treadway, M. T., Fischl, B. (2006). Meditation experience is associated with increased cortical thickness. Neuroreport, 1–19.

[30] Leeuwen, S. Van, Müller, N. G., & Melloni, L. (2009). Age effects on attentional blink performance in meditation. Consciousness and Cognition, 18(3), 593–599.

[31] Luck, Steven J. *An Introduction To The Event-Related Potential Technique.* 2nd ed. Print., 2014

[32] Mcintosh, A. R., Vakorin, V., Kovacevic, N., Wang, H., Diaconescu, A., & Protzner, A. B. (2013). Spatiotemporal Dependency of Age-Related Changes in Brain Signal Variability. Cerebral Cortex, 1–12.

[33] Mcintosh, A. R., Vakorin, V., Kovacevic, N., Wang, H., Diaconescu, A., & Protzner, A. B. (2013). Spatiotemporal Dependency of Age-Related Changes in Brain Signal Variability, 1–12.

[34] Meng, X., & D'Arcy, C. (2012). Education and dementia in the context of the cognitive reserve hypothesis: A systematic review with meta-analyses and qualitative analyses. PLoS ONE, 7(6).

[35] Mischel, N., Llewellyn-Smith, I., & Mueller, P. (2014). Physical (in)activity-dependent structural plasticity in bulbospinal catecholaminergic neurons of rat rostral ventrolateral medulla. Journal of Comparative Neurology, 522(3), Spc1.

[36] Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, a H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. Cognitive Psychology, 41(1), 49–100.

[37] Moreno, S., & Bidelman, G. M. (2014). Examining neural plasticity and cognitive benefit through the unique lens of musical training. Hearing Research, 308, 84–97.

[38] Moreno, S., & Farzan, F. (2015). Music training and inhibitory control: A multidimensional model. Annals of the New York Academy of Sciences, 1337(1), 147–152.

[39] Morrison, J. H., & Hof, P. R. (1997). Life and death of neurons in the aging brain. Science (New York, N.Y.), 278(5337), 412–419.

[40] Münte, T. F., Altenmüller, E., & Jäncke, L. (2002). The musician's brain as a model of neuroplasticity. Nature Reviews, 3–8.

[41] Näätänen, R., & Picton, T. W. (1986). N2 and Automatic versus Controlled processes. Cerebral Psychophysiology, 169-186.

[42] Nunez, P. L. (1989). Generation of Human EEG by a Combination of Long and Short Range Neocortical Interactions, 1(3), 199–215.

[43] Pfefferbaum, a, Sullivan, E. V, Rosenbloom, M. J., Mathalon, D. H., & Lim, K. O. (1998). A controlled study of cortical gray matter and ventricular changes in alcoholic men over a 5-year interval. Archives of General Psychiatry, 55(10), 905–12.

[44] Pontifex, M. B., Saliba, B. J., Raine, L. B., Picchietti, D. L., & Hillman, C. H. (2013). Exercise Improves Behavioral, Neurocognitive, and Scholastic Performance in Children with Attention-Deficit/Hyperactivity Disorder. The Journal of Pediatrics, 162(3), 543–551.

[45] Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. Cerebral Cortex, 15(11), 1676–1689.

[46] Reinvang, I., Deary, I. J., Fjell, A. M., Steen, V. M., Espeseth, T., & Parasuraman, R. (2010). Neurogenetic effects on cognition in aging brains: A window of opportunity for intervention?. Frontiers in Aging Neuroscience, 2(NOV), 1–15.

[47] Resnick, S. M., Pham, D. L., Kraut, M. A., Zonderman, A. B., & Davatzikos, C. (2003). Longitudinal Magnetic Resonance Imaging Studies of Older Adults: A Shrinking Brain. Journal of Neuroscience, 23(8), 3295–3301.

[48] Richards, M., Hardy, R., & Wadsworth, M. E. J. (2003). Does active leisure protect cognition? Evidence from a national birth cohort. Social Science and Medicine.

[49] Riddle, David R. *Brain Aging: Models, Methods, and Mechanisms.* Boca Raton: CRC, 2007

[50] Ruscheweyh, R., Willemer, C., Krüger, K., Duning, T., Warnecke, T., Sommer, J., Flöel, A. (2011). Physical activity and memory functions: An interventional study. Neurobiology of Aging, 32(7), 1304–1319.

[51] Satz, P., Morgenstern, H., Miller, E. N., Selnes, O. A., McArthur, J. C., Cohen, B. A., ... D'Elia, L. F. (1993). Low education as a possible risk factor for cognitive abnormalities in HIV-1: findings from the multicenter AIDS Cohort Study (MACS). Journal of Acquired Immune Deficiency Syndromes.

[52] Scarmeas, N., Zarahn, E., Anderson, K. E., Habeck, C. G., Hilton, J., Flynn, J., Stern, Y. (2003). Association of Life Activities With Cerebral Blood Flow in Alzheimer Disease. Archives of Neurology, 60(3), 359.

[53] Schellenberg, E. G. (2004). Music lessons enhance IQ. Psychological Science, 15(8), 511–514.

[54] Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. British Journal of Psychology, 102(3), 283–302.

[55] Silveira, C. R. A., Roy, E. A., & Almeida, Q. J. (2018). Neuroscience Letters Acute e ff ects of aerobic exercise on cognitive function in individuals with Parkinson ' s disease. Neuroscience Letters, 671(February), 60–65.

[56] Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. PLoS Biology, 5(6), 1228–1235.

[57] Sleimen-malkoun, R., Perdikis, D., Müller, V., Blanc, J., Huys, R., Temprado, J. (2015). Brain Dynamics of Aging: Multiscale Variability of EEG Signals at Rest and during an Auditory Oddball Task. eNeuro, 2(June).

[58] Sporns, O., Tononi, G., & Edelman, G. M. (2000). Connectivity and complexity: the relationship between neuroanatomy and brain dynamics. Neural Networks, 13, 909–922.

[59] Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. Journal of the International Neuropsychological Society: JINS, 8(3), 448–60.

[60] Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. The Lancet Neurology, 11(11), 1006–1012.

[61] Stern, Y., Albert, S., Tang, M.-X., & Tsai, W.-Y. (1999). Rate of memory decline in AD is related to education and occupation: Cognitive reserve?. Annals of Neurology, 45(4), 466–472.

[62] Stern, Y., Alexander, G. E., Prohovnik, I., & Mayeux, R. (1992). Inverse relationship between education and parietotemporal perfusion deficit in Alzheimer's disease. Annals of Neurology, 32(3), 371–375.

[63] Strait, D. L., Parbery-Clark, A., Hittner, E., & Kraus, N. (2012). Musical training during early childhood enhances the neural encoding of speech in noise. Brain and Language, 123(3), 191–201.

[64] Swan, G. E., & Carmelli, D. (2002). Evidence for genetic mediation of executive control: A study of aging male twins. Journals of Gerontology Series B-Psychological Sciences and Social Sciences, 57(2), P133–P143.

[65] Tononi, G., Sporns, O., & Edelman, G. M. (1994). A measure for brain complexity: Relating functional segregation and integration in the nervous system. Proc. Natl. Acad. Sci. USA, 91(May), 5033–5037.

[66] Tucker-Drob, E. M., Johnson, K. E., & Jones, R. N. (2009). The cognitive reserve hypothesis: a longitudinal examination of age-associated declines in reasoning and processing speed. Developmental Psychology, 45(2), 431–46.

[67] Van Hoesen, G. W., Hyman, B. T., & Damasio, a R. (1991). Entorhinal cortex pathology in Alzheimer's disease. Hippocampus, 1(1), 1–8.

[68] Vogel, E. K., Mccollough, A. W., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory. Nature, 438(November).

[69] Vogel, E., & Machizawa, M. (2004). Neural activity predicts individual differences in visual working memory capacity. Letters to Nature, 428(April).

[70] West, M. J. (1993). Design-based stereological methods for counting neurons. Progress in Brain Research, 135, 43–51.

[71] Whalley, L. J., Deary, I. J., Appleton, C. L., & Starr, J. M. (2004). Cognitive reserve and the neurobiology of cognitive aging. Ageing Research Reviews, 3(4), 369–382.

[72] Xiong, G. L., & Doraiswamy, P. M. (2009). Does meditation enhance cognition and brain plasticity? Annals of the New York Academy of Sciences, 1172, 63–69.

[73] Yao, Y., Lu, W. L., Xu, B., Li, C. B., Lin, C. P., Waxman, D., & Feng, J. F. (2013). The Increase of the Functional Entropy of the Human Brain with Age. Scientific Reports, 3:2853.

[74] Zurrón, M., Lindín, M., Galdo-Alvarez, S., & Díaz, F. (2014). Age-related effects on event-related brain potentials in a congruence/incongruence judgment color-word Stroop task. Frontiers in Aging Neuroscience, 6(JUN), 1–8.

Appendix I - The Electroencephalogram

The electroencephalogram is an electrophysiological monitoring system that allows recordings of the brain's electrical activity. Multiple electrodes are placed on the scalp with a conductive gel, normally non-invasively and their positioning normally follows the International 10-20 system. This system guarantees that the naming of the electrodes is the same for different studies and for that reason easier to understand. As seen in Fig. A, the electrodes have mainly four letters, F, T, P and O, which refer to the frontal, temporal, parietal and occipital lobe respectively. The letter A stand for "anterio-" and the letter C represents the electrodes in the horizontal midline. Even numbers are put on the right side of the head and odd numbers go on the left. The lower case z represents the number zero and only exists in association with electrodes on the vertical midline.

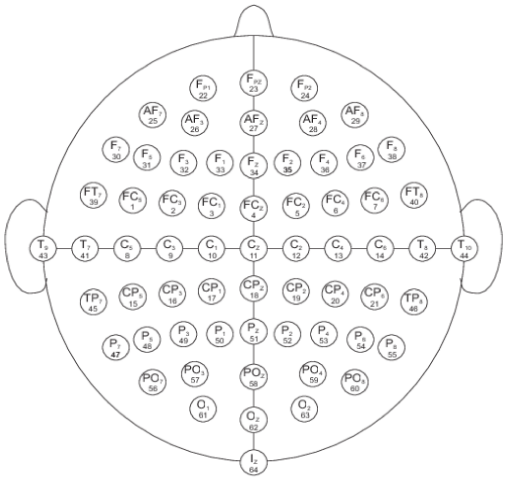


Figure A -Positioning of the electrodes according to the 10-20 system and respective labels

Source: www.physionet.org/pn4/eegmmidb/ (March 10th, 2018)

Each of the electrodes captures a signal between 5 and 500uV. They are connected a differential amplifier (DA) that measures the potential difference of two electrodes. That difference is then sent to a second amplifier whose gain depends on the used resistor. An active high pass filter and an active low pass filter of 1 Hz and 100 Hz respectively is then added to cut off that frequency range, to guarantee that the EEG signals lies within it. In order to remover the 60 Hz (or 50 Hz in some countries) power line interference, a notch filter has also been added. Consecutively, the writing unit will amplify the EEG signal further and output it. For digital systems, a data acquisition component is also added to convert the analog signal into digital values for storage, analysis and presentation on a computer.

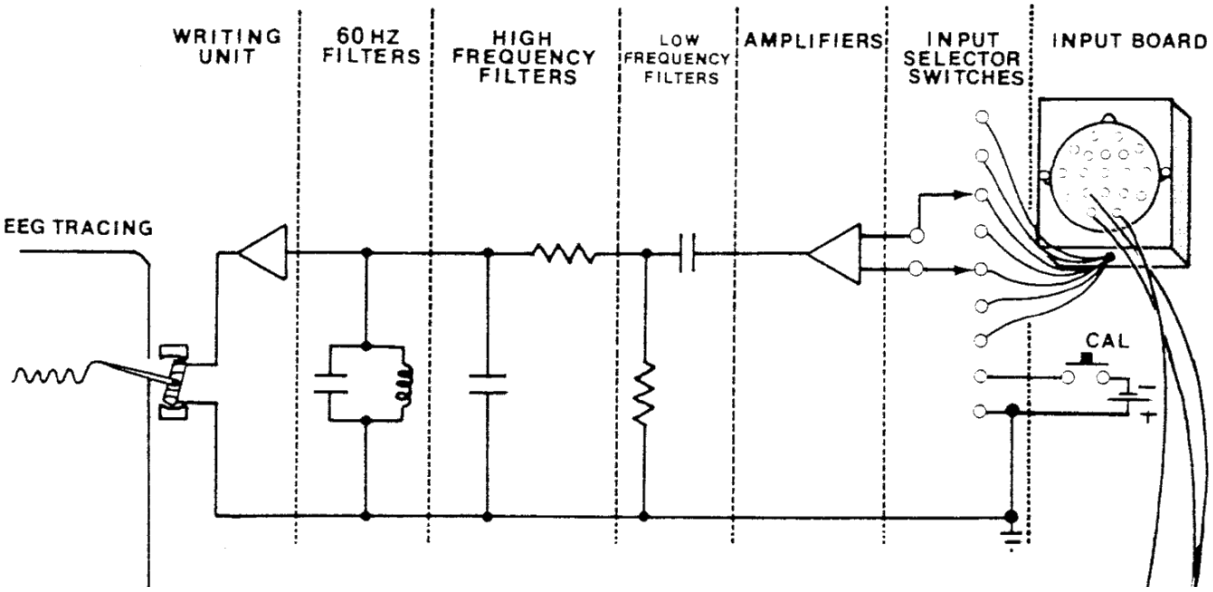


Figure B- Basic circuit schematic for an EEG system

Source: Fisch, Spehlmann - 1999

Appendix II - Study Script

3M's Study – *A detailed description*

- Pre-screening Questionnaire

  On the phone, ask their date and country of birth. After that ask the 10 following questions, to certify that they're eligible for the study. If the answer to any of the questions is **yes**, then say

  > "Thank you very much for your time, but unfortunately we will not be able to use you for this study, but would you be okay with us calling you in case you match the requirements for a future study?"

  Note: Subject naming (for anonymity purposes) is - Project Name + t, c, me, mu or a + # + date separated by "_" (example: 3M_t01_22.08.17)

- Consent

Once you're with the volunteer, hand them the consent form and say

"Since this is a research study, you will have to read and sign this consent form in order to perform all the required tasks. It says that this research has been approved by the ethics committee at Simon Fraser University. It explains the goal of the study, what type of personal health information we are going to ask and what type of tasks you're going to be asked to do. It also says that all the information obtained throughout this study will be kept confidential and if at any time you'd like to refuse or withdraw from this study, you can do it."

Ask them the remaining questions for the psychological assessment.

- Raven's Progressive Matrices

Show the volunteer the dossier with the Raven's Progressive Matrices task and say:

"This is an observation and clear thinking test. This task will be made on the laptop, but to be easier to understand I'll show you a few examples on the dossier. [As you open the dossier] As you can see, at the top part of Example 1 there is a pattern with a bit cut out. You must think what the piece needed to complete the pattern correctly both along and down must be like. Then find the right piece out of the eight options shown below. Once you know the answer, press the number on the keyboard corresponding to the piece that you think fits the pattern best. So, in this case, the correct answer would be… 4.

Ask if they understood

Like I said earlier, you'll be doing this test on the laptop. You'll just have to press on numbers 1 to 8 depending on which answer you think is the correct one. You can only use the numbers above the letters, not the numeric keypad on the right. You can now start whenever you're ready."

- SF-36 quality of life (Do this while capping)
  While **capping**, try to explain some of the steps to the subject. Keep them engaged and not bored. Its not good if they're bored before the tasks start.
  Say:

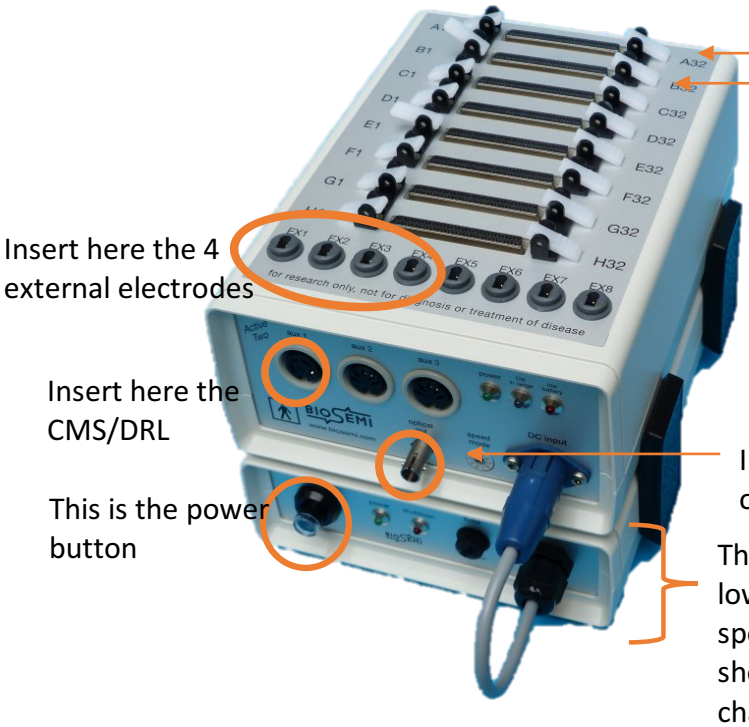
  "We want to pick up some of the electricity that your brain gives off. To do so, we are going to put this cap on your head. It will feel just like a swimming cap. We will start by putting two electrodes on your temples (point on your face) and two on your mastoids (point again on your face). We do this to measure electrical activity given by the muscular movements around your eyes. We will have to clean the area so that we get a better signal. **Do it**
  After that, we'll put the cap on you and we will put some gel into these holes (show the holes, because the electrodes need a medium to conduct the electrical signal from the scalp to the metal (show them how). I'll need your help. I'll need you to hold this front part against your forehead please. (Place the 3 frontal electrodes of the cap on the correct place and let them hold it down while you pull the back part of the cap down – be sure that the cap is well applied by verifying the mid line both longitudinally and transversally)"

  Show the volunteers the SF-36 questionnaire and say:

  "We would like to better understand how you feel, how well you are able to do your usual activities, and how you rate your own health. To help us better understand these things about you, we are going to ask you some questions about your general health. This is not a test, and there are no right or wrong answers. Choose the response that best represents the way you feel. Please answer every question. As we proceed, please feel free to ask me any questions you may have."

  <u>To cap, please remember to:</u>

  - **Measure the circumference of the head** (the measuring tape must go over the inion and the nasion). This will allow you to choose the right sized cap (if someone is on the limit, always choose the smallest of both options);
  - **Abrase** mastoids and temples with NuPrep (or an existing alternative);
  - **Glue circular stickers onto external electrodes** (1-4) with the centre of the sticker coinciding with the centre of the electrode and **add some gel to the area**;
  - Put **external electrodes 1 and 3 on the left mastoid and temple respectively**, and **2 and 4 on the right mastoid and temple respectively**. (Remember to try to put these on with the wires directed to the back of the head so that they can be tucked behind the subject's ear);
  -Put the **cap on the subject's head**. You can ask him/her to help by holding the Fp1, Fpz and Fp2 electrodes against her forehead.
  - Start **gelling all the labeled electrodes**.
  -Insert the **electrodes in the cap** (two sets of 32 electrodes (A and B)). Be careful so that none of the electrodes touch any metallic surfaces, and keep in mind that they are very fragile (that's why we call them "angel hair"). It might be easier to put the electrodes around your neck so that there's not a lot of weight on them.
  -Insert **DRL and CMS electrodes**.



- EEG Tasks (Randomize this)

  Notice that one of the laptops is for the **data acquisition** and the other one is for the **task presentations**.

  Summary (there's a more detailed description below if needed):

Laptop - EEG	Laptop - Presentation
- Open ActiView program - Change the Trigger **(A)** Format from *Analog* to *Decimal* - Change Decimation **(B)** from 1 to ¼. - Press Start (You should start seeing the signal being acquired) - Click on Electrode Offset **(C)** - Make sure that the red bars are the smallest possible. If they aren't, check if the electrode in question is correctly inserted. - Remember that since you won't be using EX5 - EX8 these will always have massive bars. - Once everything is okay press Start File and Pause Saving (it will only be saving when this turns green!!!) **(D)**	-You will have to randomize tasks, however there are a few important things that you have to remember. -Always open the .exp files for Go/NoGo, Visual Search, Colour Search and K-test tasks. For the resting state open the .sce file. -Once they're open, check the screen size -You'll have to verify the buttons that are going to be used in the task - And finally, you'll also have to check the port codes for the Go/NoGo and Visual Search tasks – You'll be able to confirm that these are going through on (E)

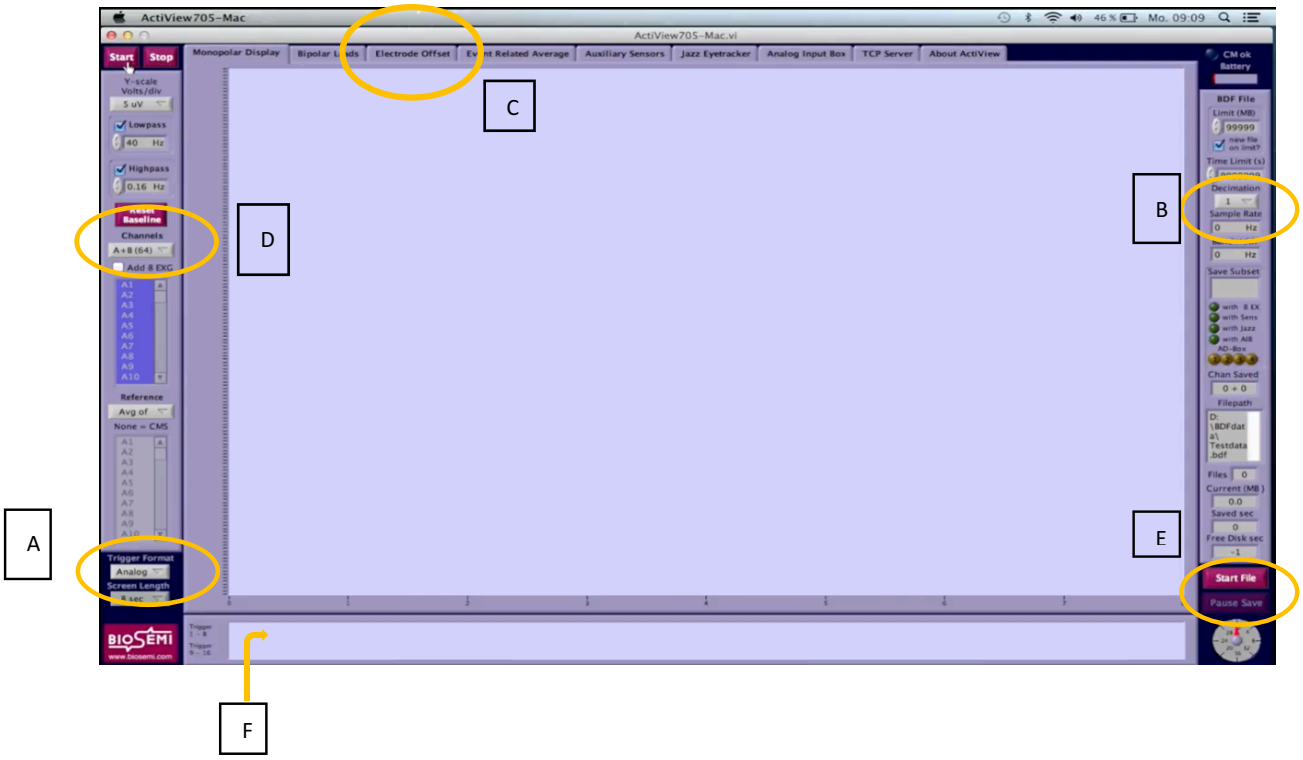
You can also show them the task completion sheet, and explain that that sheet is to help them understand how much they've progressed through the tasks, and that as they finish each task or block, a circle will be ticked.

On the EEG laptop,

Open the **ActiView** program. Change the Trigger **(A)** Format from *Analog* to *Decimal*, and the Decimation **(B)** from 1 to ¼.

Once this has been done and the cap is properly assembled you must click **Start**. You should start seeing the signal being acquired. To make sure that the signal is the cleanest possible, click on Electrode Offset **(C)** and make sure that the red bars are the smallest possible. If they aren't, check if the electrode in question is correctly inserted. If the signal still isn't good, "zoom in" by selecting either just the A channel or the B channel so you can verify which electrode is giving you problems **(D).**

Remember that since you won't be using EX5 – EX8 these will always have massive bars.

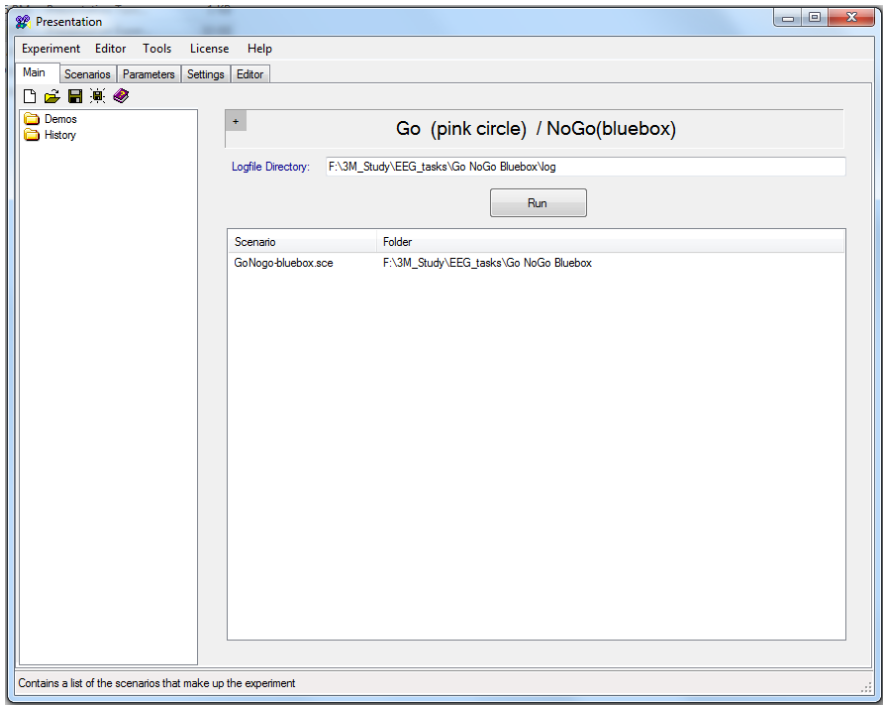


VERY IMPORTANT: To save the EEG acquisition you have to press on **Start File** and then on **Pause Save (E)**. A window will appear where you'll be able to choose a name for this file and write a small description of the task. You'll also have to tick a box where the option mentions the 8 External electrodes and the 64 Regular electrodes. It will only be saving the recordings when the button **Pause Save is green**! Once the task is

over press Pause Save again and Stop (at the top/left of the screen) so that you can start a new file for the next experiment.

On the Presentation laptop,

Whenever you open either one of the tasks this is what will appear. Ideally, you should be able to hit the Run button and everything would run smoothly… that never happens. You will however have to come back to this Main page and hit Run once you've made a few changes.



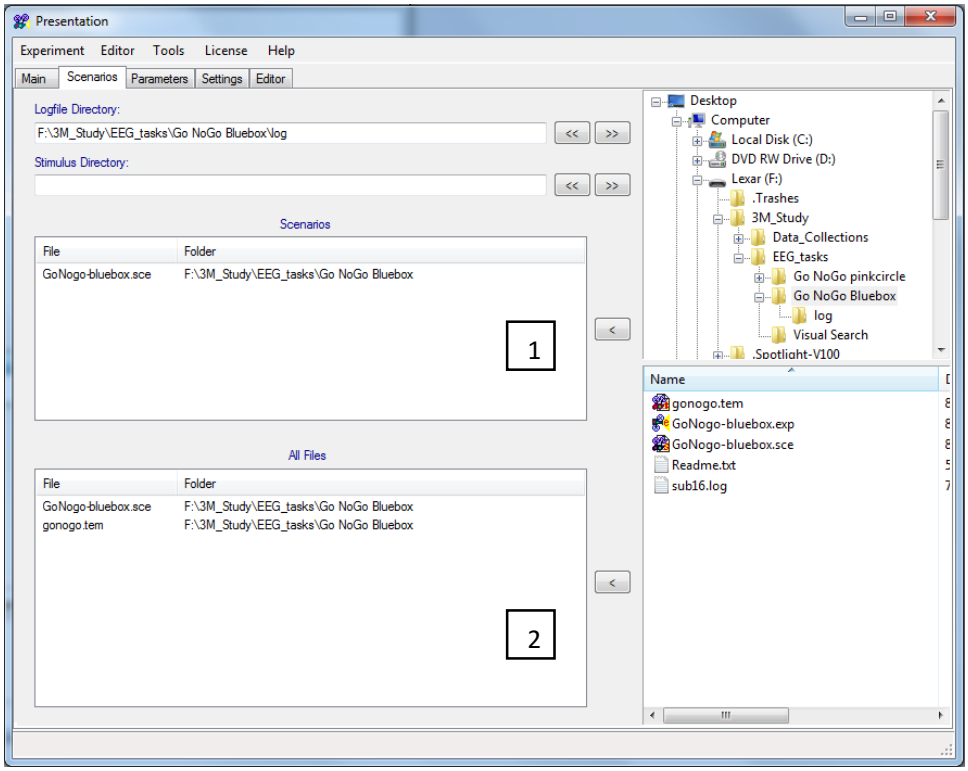
The first thing you can check is where the log files are being sent to (for all tasks except the resting state).

To do so, you'll have to go to the Scenarios tab as seen below. You will choose the log file directory, but you'll also have to say verify which files you're going to be working on (It might happen that when you close a task and open another, the program saved the previous one and it just gets confusing.)

On some of the experiments, the log file directory is implemented in the code. It will give you an error and it will show you where in the scrip the error occurred. Press CTL-F, write "path" and look for the previous time the word appeared, not the next. Then you can just replace the log file path.

Below Scenarios, you'll choose the .sce file you'll be working with. **(1)**

Below All Files, you'll choose the .sce file again plus all the other files needed to do the task (.tem, .pcl, etc) **(2)**



After that, you'll have to check the Settings tab. You'll have to do 3 **very important** things in this tab.

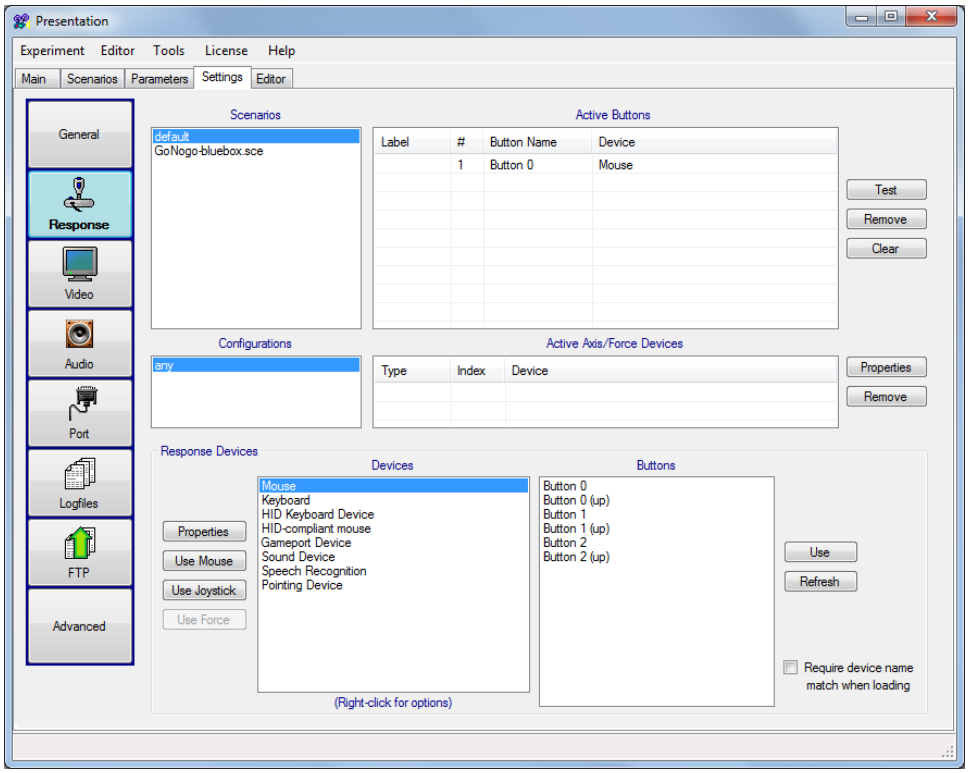
Go to Response.
You'll have to verify that the response buttons are the ones that you'll be using. You will need this for the Go/No-Go, Visual Search and Colour Search tasks. For all three of these you'll be using the mouse buttons.

For the Go/No-Go, you'll only need one mouse button (the left button – Button 0). You can test that the button is working by pressing the Test and clicking on the left button of the mouse, you should get an OK message whenever you click on it.

For the Visual and Colour Search, you'll need four mouse buttons: S – to start and the left, the middle and the right mouse button. To add buttons you just have to click on

Mouse (under Devices) > Button 0 > Use
Mouse (under Devices) > Button 1 > Use
Mouse (under Devices) > Button 2 > Use
Keyboard (under Devices) > S > Use

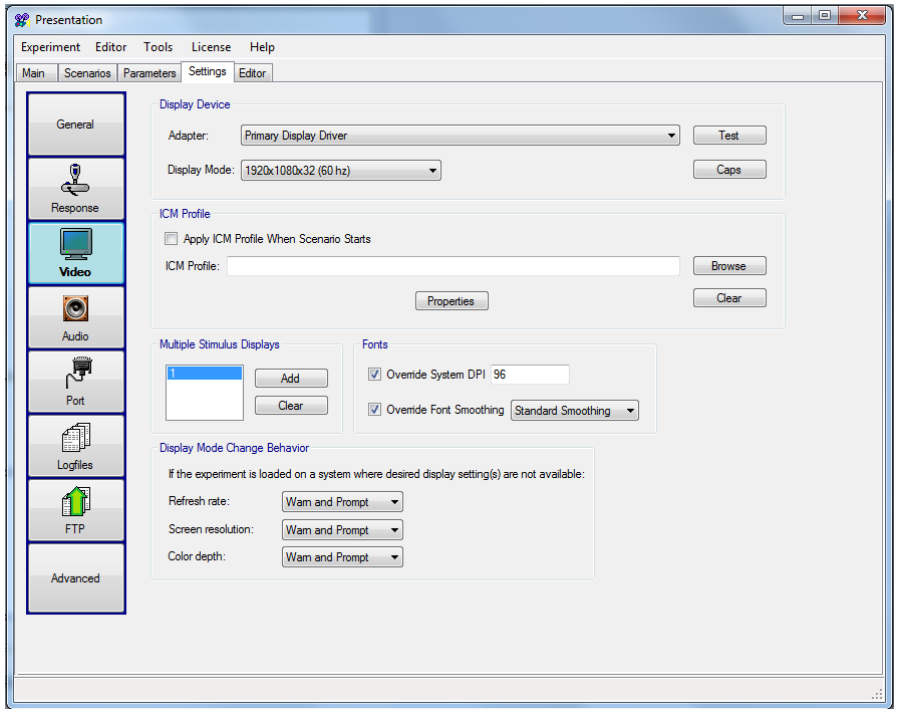
These four buttons should be added to the list under Active Buttons. Test them again, just to be sure. Don't use Button # (up), this refers to the release of the button rather than the click, and we don't need that.



Next, we're going to adjust the Image Display Size.

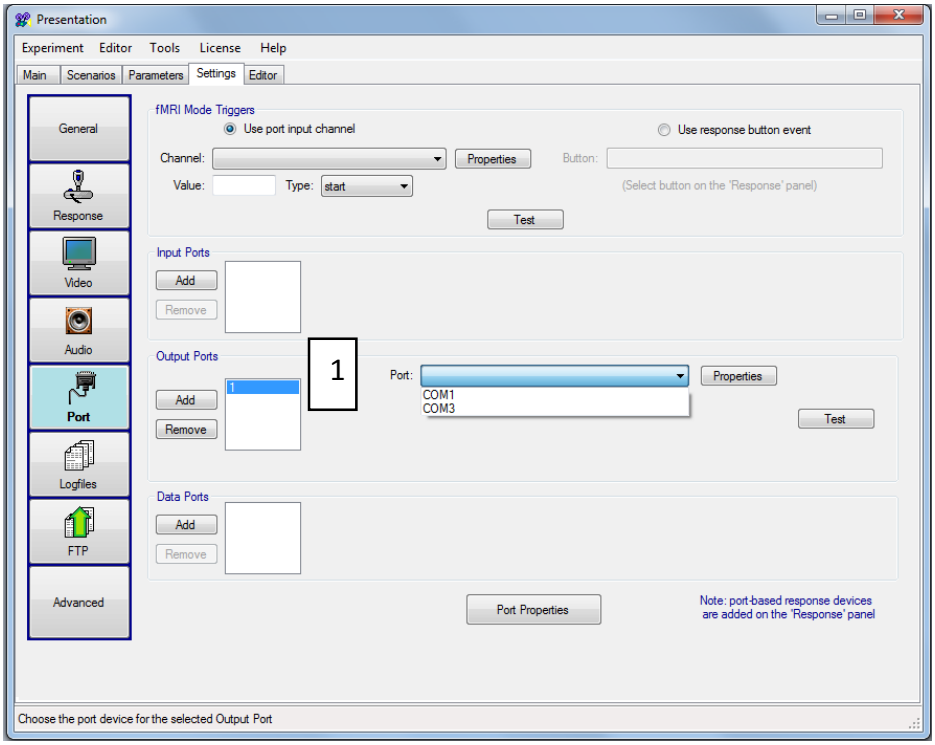
Go to Video.

Click on the tab in front of Display Mode and choose the one that's most adequate for the laptop you're using. If you don't know it, just go to your desktop, press on the right button and then Display > Screen Resolution > Resolution.



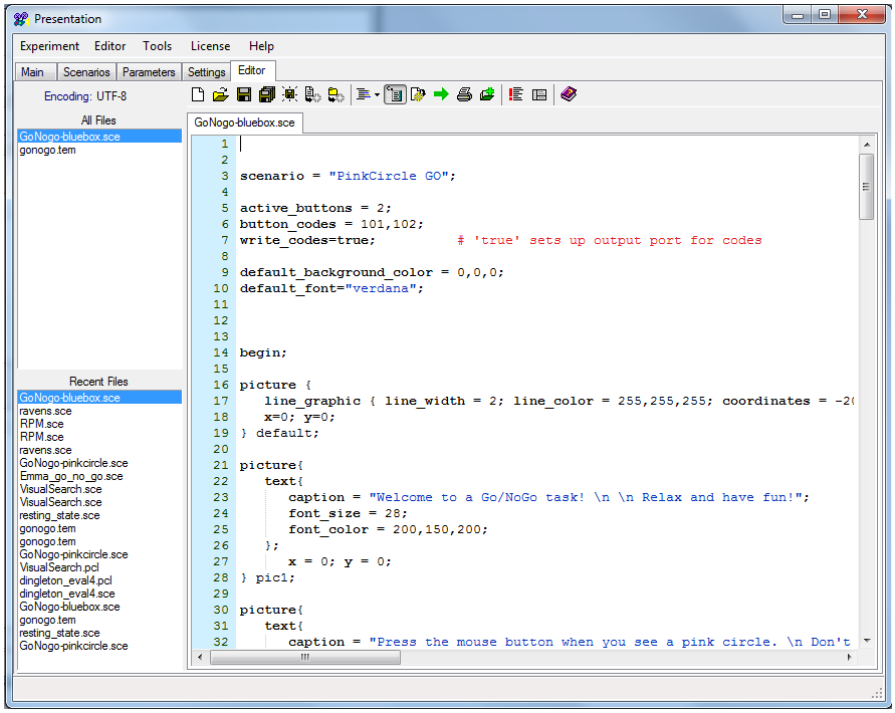
Third, and this is a VERY IMPORTANT step (!)

Go to Port.



Below Output Ports (1) you'll have to have 1 Output Port. Click on the number 1. Then you'll click on the drop down menu and choose **LPT3**. Then press on the Test button. Whenever you press on the button SEND you should see it coming out in the EEG laptop (**where letter F is**).

Finally, you can go to Editor, and run the program (only if you're in the scenario file – you can't run it if you're on the .pcl or the .tem file.) Or you can just go back you the Main tab and click Run (This last option is the best option, because the program will allow you to add a subject number once you hit Run, but it won't from the Editor tab).



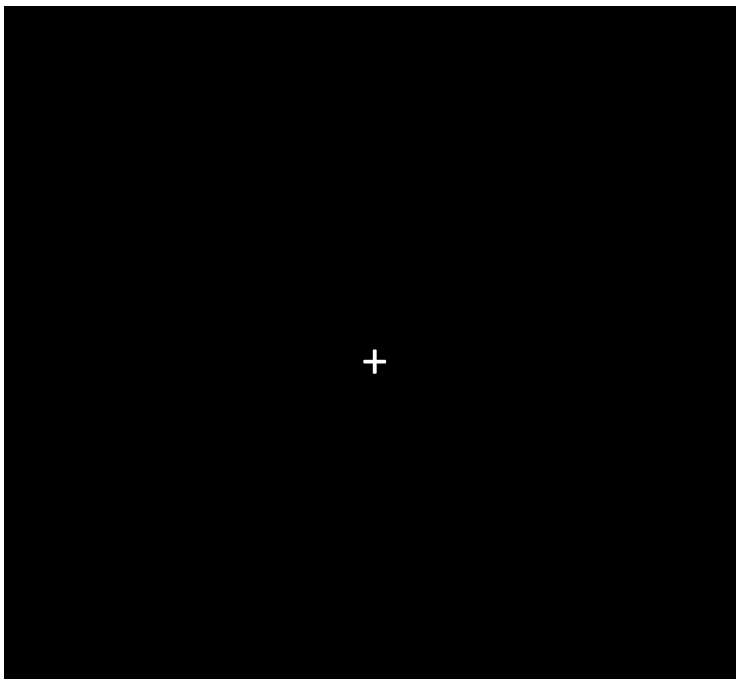
- Resting State (5 min)

  To open the Resting State task, insert the USB drive in the PRESENTATION laptop, go to the USB file on the laptop.

  3M_Study > EEG_tasks > resting_state.sce

  Say:

  "We are going to start with this simple task. Once it begins a cross will appear in the center of the screen. You just have to focus on it for a few minutes. Please try not to move or blink too much."



- Go/No-Go (10 min)

To open the Go/No-Go task, go to the USB file on the PRESENTATION laptop.

3M_Study > EEG_tasks > Go NoGo Bluebox (or Go NoGO pinkcirle [alternate between these two amongst subjects]) > GoNogo-bluebox.exp (or GoNogo-pinkcircle.exp)

Important: Check to see if the port codes are working. If they aren't you won't be able to see any events when you go to analyse the data. To to this, go to

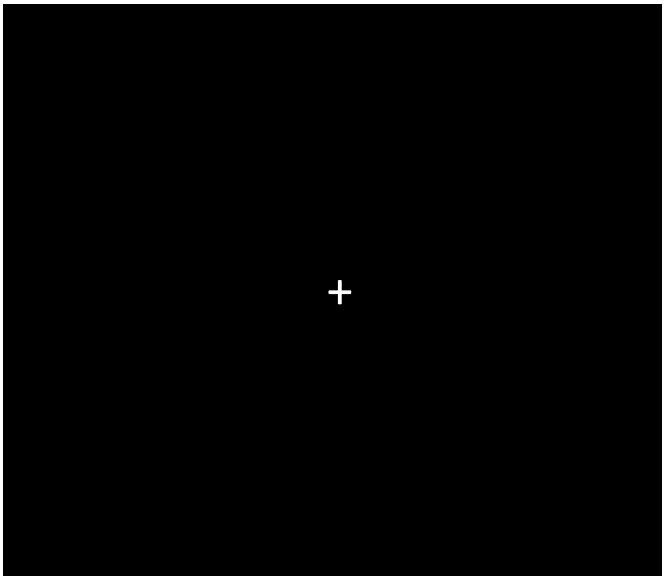
Settings > Port > test

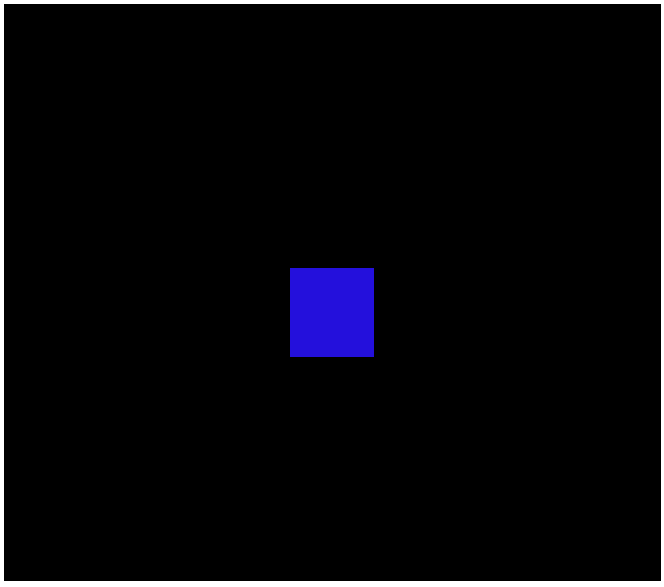
You should be able to see the response underneath the data acquisition window **(F)**. Once this is working, say:

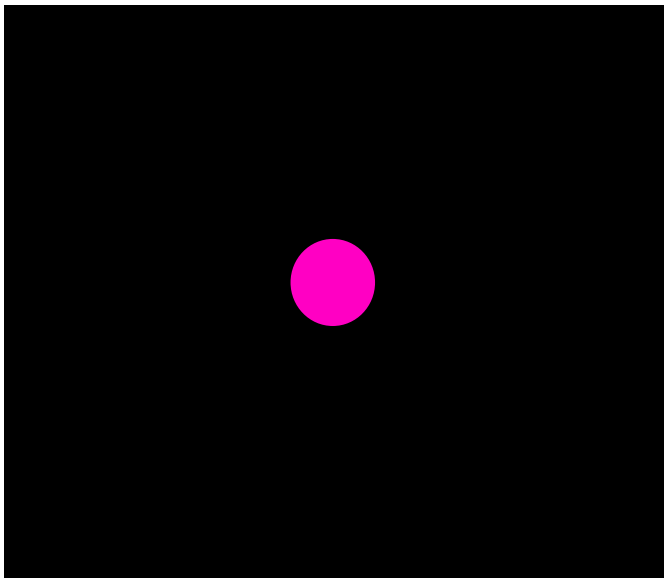
[For Go NoGo Bluebox]
"This second experiment is called a Go/No-go task, and its purpose is to assess the efficiency of response inhibition. To do so, you will have to focus again on the cross that will appear in the middle of the screen, however, throughout this task you'll see some figures appear on the screen, they're either a blue box or a pink circle. (Show them the images below). Press the left button of the mouse if you see a pink circle, don't press the button if you see a blue square. Try to do this as **fast**, but as accurately as you can. Please try not to move or blink too much."

[For Go NoGo pinkcircle]
"This second experiment is called a Go/No-go task, and its purpose is to assess the efficiency of response inhibition. To do so, you will have to focus again on the cross that will appear in the middle of the screen, however, throughout this task you'll see some figures appear on the screen, they're either a blue box or a pink circle. (Show them the images below). Press the left button of the mouse if you see a blue box, don't press the button if you see a pink circle. Try to do this as fast, but as accurately as you can. Please try not to move or blink too much.

Important: To save the EEG acquisition you have to press on Start File and then on Pause Save **(4)**. A window will appear where you'll be able to choose a name for this file and write a small description of the task. You'll also have to tick a box where the option mentions the 8 External electrodes and the 64 Regular electrodes. It will only be saving the recordings when the button **Pause Save is green**! Once the task is over press Pause Save again and Stop (at the top/left of the screen) so that you can start a new file for the next experiment.







- Color Search Task (40 min)

To open the Color Search Task go to the USB file on the PRESENTATION laptop.

Then,
3M_Study > EEG_tasks > ColorSearch > ColorSearch.exp

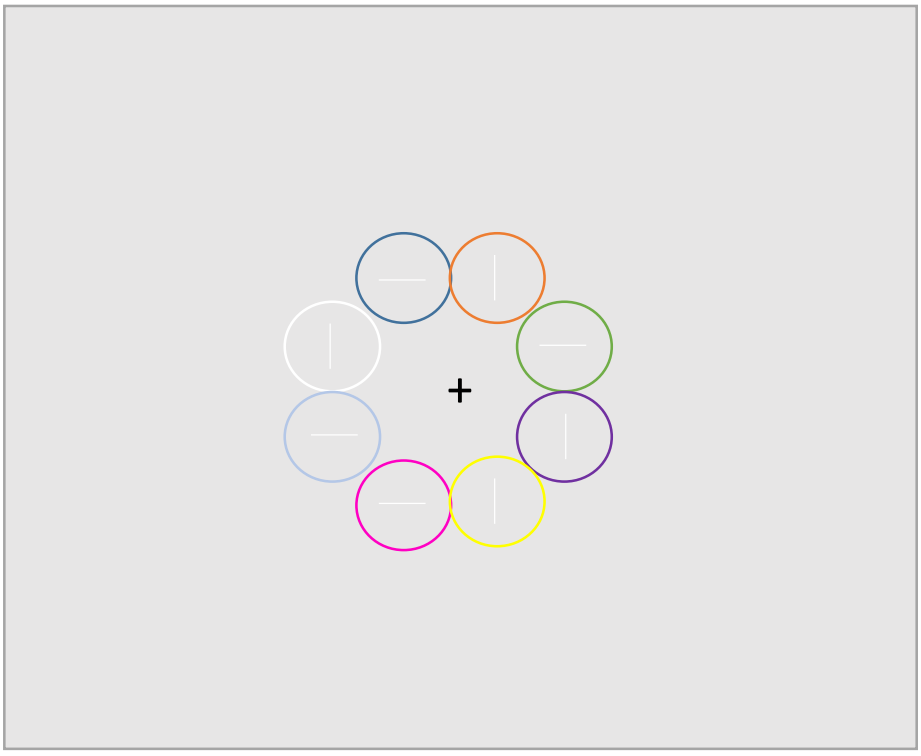
Important: Check to see if the port codes are working. If they aren't you won't be able to see any events when you go to analyse the data. To to this, go to

Settings > Port > test

You should be able to see the response underneath the data acquisition window (F).

To explain this task, say:

"In this experiment, you'll see either 4, 6, 8 or 10 circles, all different colors. (Show them the image below). They'll only be on the screen for a few moments. Without moving your eyes from the fixation cross you'll have to find either the green or the red circle. Once you do, assess if the bar inside the circle is either vertically oriented or horizontally oriented. Press the left button if its vertically oriented and the right button if its horizontally oriented (draw the bar on a post it and glue it to the mouse pad on the laptop above the corresponding button). You will never see the green and red circles together, try to ignore all the other colors. Please try not to move or blink too much. Relax and have fun!"



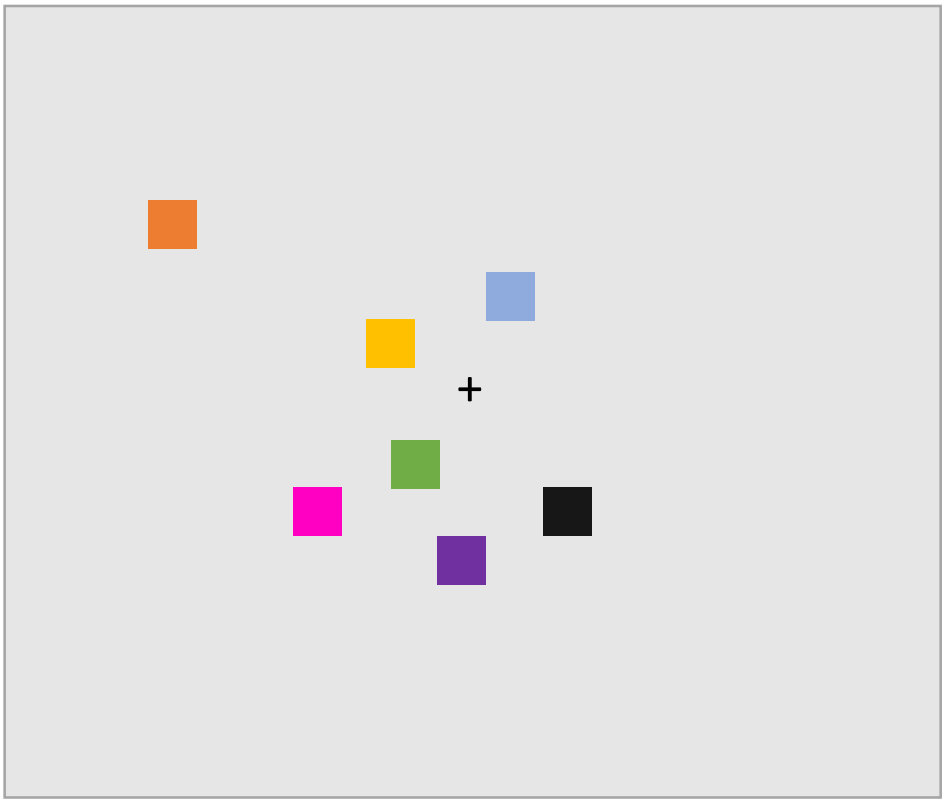
- K Task (5 min)

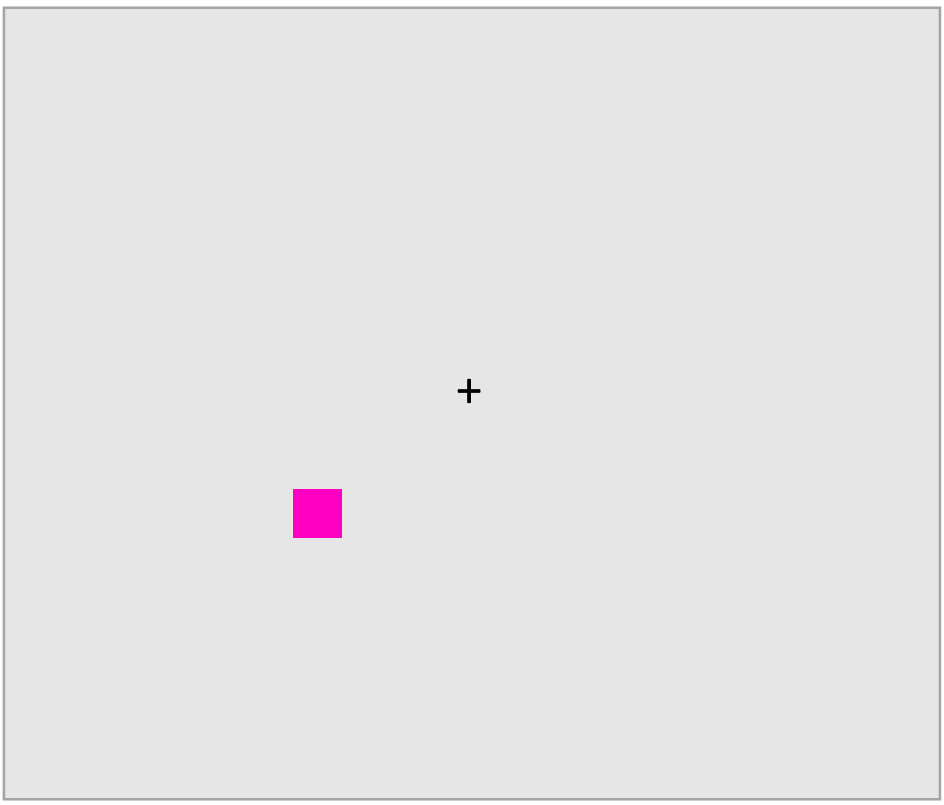
  To open the K Task go to the USB file on the PRESENTATION laptop.

  Then,
  3M_Study > EEG_tasks > ColorSearch > K > Ktask.exp

  This task is a behavioural task. So you don't need to be recording this with the EEG, but it's okay if you do.

  To explain this task, say:
  "You will see a flash of either 2, 4, 6 or 8 coloured squares randomly placed on the screen. Right after that, you'll see one square on the screen. (Show them the image below). You'll have to decide if that square with that colour was positioned there before. If it was, press the left button of the mouse. If it wasn't, press the right button of the mouse. Please try to do this as fast but as accurately possible. If you don't remember if the square was there, you can just guess. Relax and have fun!"





Once every task is completed remember to THANK your participant. This is very important. You're not only representing yourself as a researcher and a scientist, you're also representing the Digital Health Hub. You want the participants to like you, so that if needed, you can use them again in future studies and so that they recommend the study to their friends (this is the best way to find new participants!) , but you also want them to take your tasks seriously.

THE END!

Appendix III - Binfile Codes

```
#779 is 11, 780 is 12 and 870 is 102
bin 1
go trial (correct response)
.{779}{t<200-1000>870}

bin2
go trial (incorrect response)
.{779}{t<200-1000>~870}

bin3
no go trial (correct response)
.{780}{t<200-1000>~870}

bin4
no go trial (incorrect response)
.{780}{t<200-1000>870}
```

Figure A- Binfile for the Go/No-Go task

Figure B- Binfile for the Colour Search task

```
#Condition 1
#Color Search SetSize
#Added 768 to each code
                Bin 1
               4 item Vert LVF
               .{779;780;879;880}{t<100-5000>991:rt<"4item_rt">}
                Bin 2
               4 item Horiz LVF
               .{789;790;889;890}{t<100-5000>991:rt<"4item_rt">}
                Bin 3
               4 item Vert RVF
               .{781;782;881;882}{t<100-5000>991:rt<"4item_rt">}
                Bin 4
               4 item Horiz RVF
               .{791;792;891;892}{t<100-5000>991:rt<"4item_rt">}

                Bin 5
               6 item Vert LVF
               .{799;800;801;899;900;901}{t<100-5000>991:rt<"6item_rt">}
                Bin 6
               6 item Horiz LVF
               .{809;810;811;909;910;911}{t<100-5000>991:rt<"6item_rt">}
                Bin 7
               6 item Vert RVF
               .{802;803;804;902;903;904}{t<100-5000>991:rt<"6item_rt">}
                Bin 8
               6 item Horiz RVF
               .{812;813;814;912;913;914}{t<100-5000>991:rt<"6item_rt">}

                Bin 9
               8 item Vert LVF
               .{819;820;821;822;919;920;921;922}{t<100-5000>991:rt<"8item_rt">}
                Bin 10
               8 item Horiz LVF
               .{829;830;831;832;929;930;931;932}{t<100-5000>991:rt<"8item_rt">}
                Bin 11
               8 item Vert RVF
               .{823;824;825;826;923;924;925;926}{t<100-5000>991:rt<"8item_rt">}
                Bin 12
               8 item Horiz RVF
               .{833;834;835;836;933;934;935;936}{t<100-5000>991:rt<"8item_rt">}

                Bin 13
               10 item Vert LVF
               .{839;840;841;842;843;939;940;941;942;943}{t<100-5000>991:rt<"10item_rt">}
                Bin 14
               10 item Horiz LVF
               .{859;860;861;862;863;959;960;961;962;963}{t<100-5000>991:rt<"10item_rt">}
                Bin 15
               10 item Vert RVF
               .{844;845;846;847;848;944;945;946;947;948}{t<100-5000>991:rt<"10item_rt">}
                Bin 16
               10 item Horiz RVF
               .{864;865;866;867;868;964;965;966;967;968}{t<100-5000>991:rt<"10item_rt">}
```

Appendix IV - Full Scalp Waveforms

Figure A - Controls

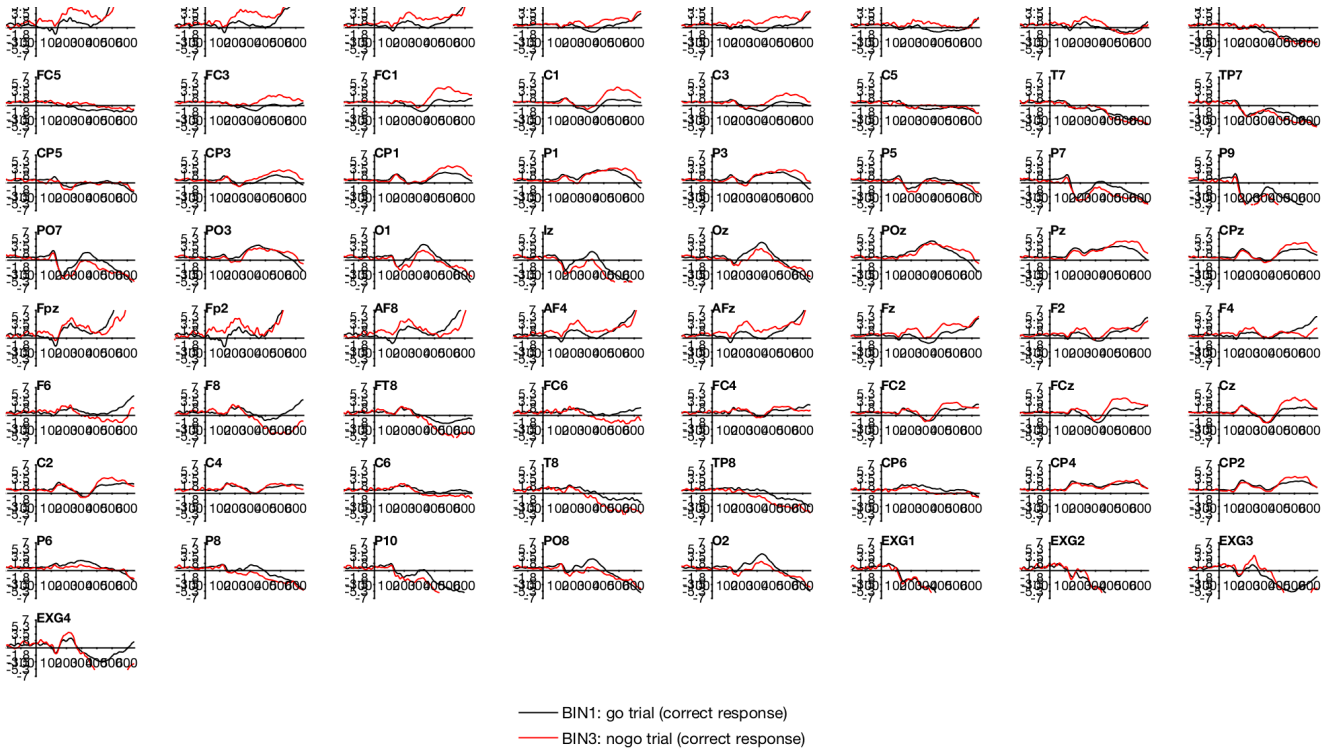


Figure B - Musicians

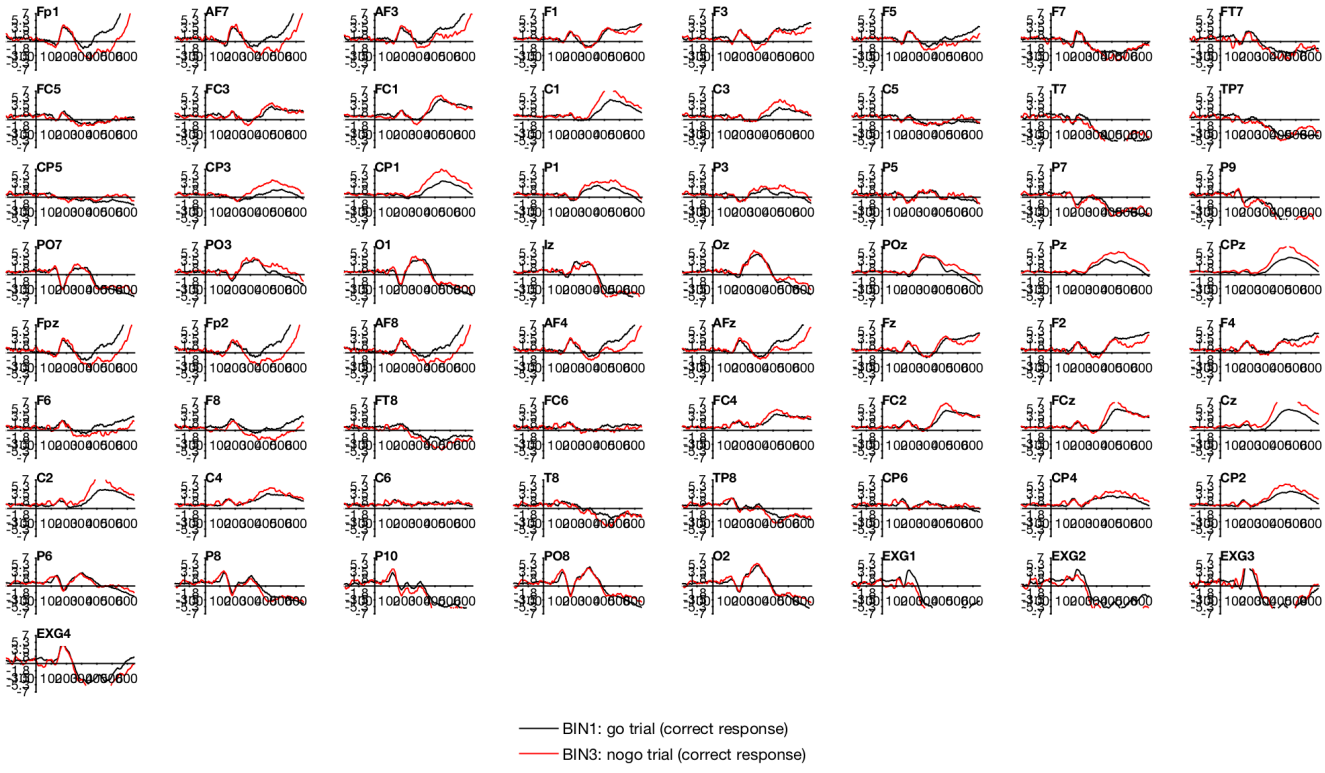


Figure C – Athletes

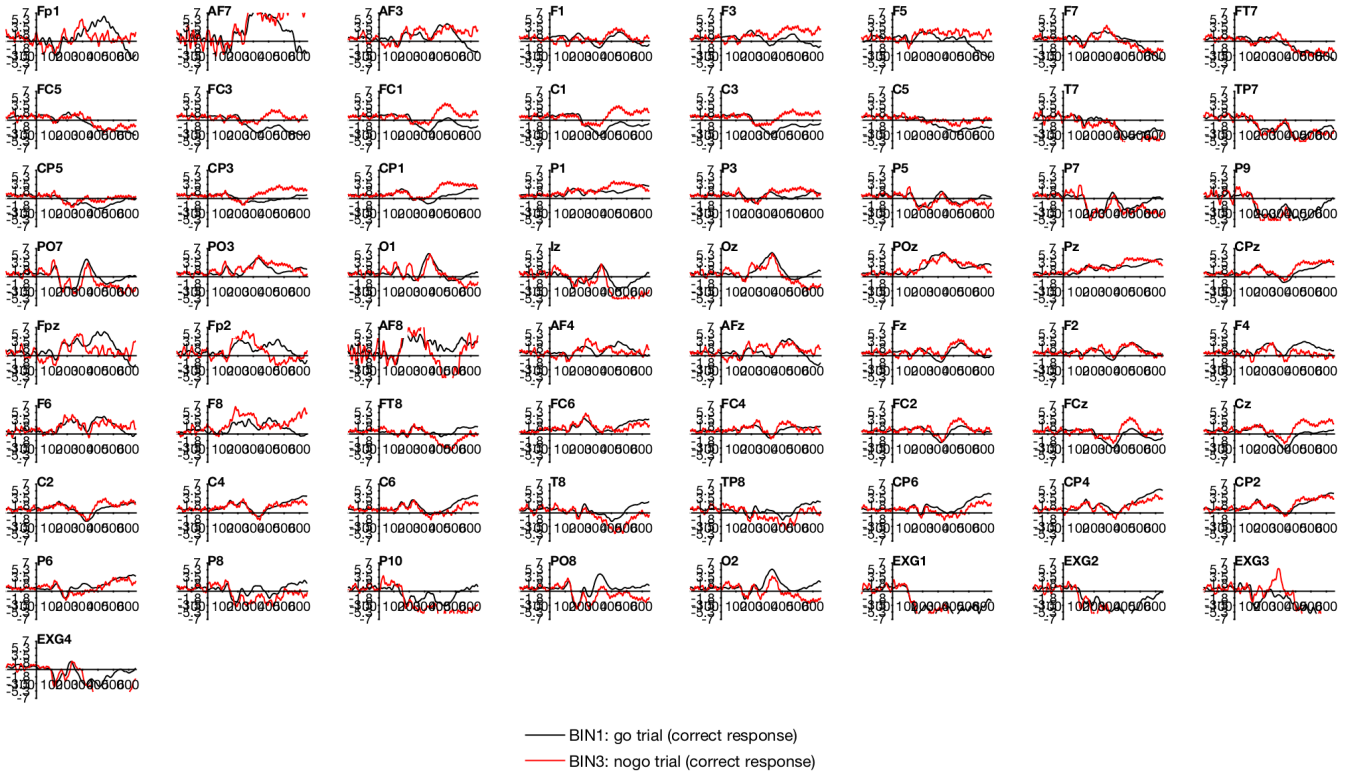


Figure D- Meditators