UNIVERSITAT DE BARCELONA

Non-Invasive Brain Stimulation, Personality, and Cognition

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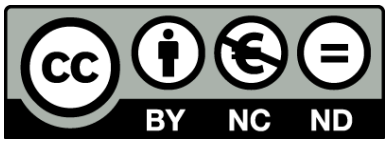

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Non-Invasive Brain Stimulation, Personality, and Cognition

by

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DEDICATION

To my mother. You are the only glimmer of hope that I have had throughout this arduous path. Without your love and constant support, this thesis would not be possible. You are the reason that I am in this path, for always believing in me and that I could do better, and be better. You could not finish your thesis because work, study, and children became too much, so my thesis is a dedication to yours. Even though the topics are not exactly all that similar, the field is. All this work is for you.

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Abstract

This thesis focuses on cognition and how non-invasive brain stimulation techniques (NIBS) can modify it. In addition, we consider personality. Therefore, this thesis analyzes, in depth, the effects of NIBS on cognition, specifically risk decision-making and working memory with emotional interference. We analyzed the neural correlates of risk decision-making, as well as working memory. And the cognitive effects provided by TMS or tDCS. Specifically, we had a particular interest in studying the "believed" disassociation between the dorsolateral prefrontal cortex and the ventrolateral prefrontal cortex. To justify our focus on risk decision-making and working memory as the two cognitive functions studied, we provided exhaustive literature as well as reviews of previous findings.

This thesis consists of two experimental stages. During the first experimental stage, we investigated the effect of applying Multifocal transcranial direct current stimulation (MtDCS) on the left dorsolateral prefrontal cortex (DLPFC) and the left ventrolateral prefrontal cortex (VLPFC) during risk-taking. For this purpose, we used the balloon analogue risk task (BART) and the bomb risk elicitation task (BRET), considering personality. We used a quasi-randomized 3×2×3 mixed factorial and sham-controlled design. Thirty-four healthy adults underwent 3 MtDCS interventions in a counterbalanced order while completing the BART and BRET tasks. The stimulation condition (DLPFC, VLPFC, or sham) was the within-subject factor, and stimulation intensity (1.5 mA or 2 mA) and personality (3 profiles) were the between-subject factors. As expected, participants with a "normative" personality profile behaved more conservatively when compared to the impulsive-disinhibited participants. Participants were more risk-averse after DLPFC inhibition, and this risk-aversion effect was more marked in impulsive-disinhibited participants. Following VLPFC inhibition, participants with a "normative" personality profile behaved more conservatively, i.e., they were more risk-averse. MtDCS influenced risk-taking behavior, depending on personality traits. Left DLPFC

activity is related to risk propensity in impulsive-disinhibited people, while left VLPFC activity is related to risk propensity in people with a normative personality profile.

In the second experimental stage, we focused on working memory and emotional interference. Particularly, we focused on the effect of the DLPFC on emotional interference in working memory. We used repetitive transcranial magnetic stimulation (rTMS) and modulated the DLPFC activity (inhibition and activation) while evaluating working memory (WM) performance. We interfered with the WM performance with emotional, neutral, and digital distractors. However, contrary to our hypothesis, we did not find significant effects. rTMS did not modify the effect of emotional interference on the WM task. And neither did personality. Within this context, our results could serve as a cautionary tale of the limitations that arise when stimulating healthy brains.

Resumen

Esta tesis se centra en la cognición y en cómo las técnicas de estimulación cerebral no invasiva (NIBS) pueden modificarla. Además, se ha tenido en cuenta la personalidad. Hemos analizado en profundidad los efectos de las NIBS en la cognición, concretamente en la toma de decisiones de riesgo y en la memoria de trabajo con interferencia emocional. Hemos analizado los correlatos neurales de la toma de decisiones de riesgo, así como la memoria de trabajo y los efectos cognitivos producidos por la TMS o tDCS. Específicamente, teníamos un interés particular en estudiar la disociación entre la corteza prefrontal dorsolateral y la corteza prefrontal ventrolateral. Para justificar por qué nos hemos centrado particularmente en la toma de decisiones de riesgo y en la memoria de trabajo como las dos funciones cognitivas estudiadas, proporcionamos una literatura exhaustiva, y revisiones de hallazgos anteriores.

Esta tesis tiene dos etapas experimentales. En la primera etapa experimental investigamos el efecto de la aplicación de la estimulación transcraneal multifocal por corriente directa (MtDCS) sobre la corteza prefrontal dorsolateral (DLPFC) izquierda y la corteza prefrontal ventrolateral (VLPFC) izquierda durante la toma de riesgos. Para ello, utilizamos la tarea de riesgo del globo análoga (BART) y la tarea de elicitación del riesgo de la bomba (BRET), teniendo en cuenta las diferencias individuales de personalidad. Se empleó un diseño factorial mixto cuasi-aleatorio 3x2x3 con la sham (estimulación simulada) controlada. 34 adultos sanos se sometieron a 3 intervenciones de MtDCS en un orden contrabalanceado mientras completaban las tareas BART y BRET, con la condición de estimulación (DLPFC, VLPFC, o sham) como el factor intra-sujeto, y la intensidad de estimulación (1.5 mA o 2 mA) y la personalidad (3 perfiles) como factores entre-sujetos. Como se esperaba, los participantes con un perfil de personalidad "normativo" se comportaron de forma más conservadora en comparación con los participantes impulsivos-desinhibidos. Los participantes tuvieron más aversión al riesgo tras la inhibición del DLPFC y este efecto de aversión al riesgo fue más marcado en los participantes impulsivos-desinhibidos. Tras la inhibición de la VLPFC, los participantes con un perfil de personalidad "normativo" se comportaron de modo más conservador, es decir, tuvieron más aversión al riesgo. MtDCS influyó en el comportamiento de toma de riesgos en función de los rasgos de personalidad. La actividad del DLPFC izquierdo está relacionada con la propensión al riesgo en personas impulsivas-desinhibidas, mientras que la actividad del VLPFC izquierdo está relacionada con la propensión al riesgo en personas con un perfil de personalidad normativo.

En la segunda etapa experimental, nos centramos en la memoria de trabajo y la interferencia emocional. En concreto, nos centramos en el efecto del DLPFC en la interferencia emocional en la memoria de trabajo. Utilizamos estimulación magnética transcraneal repetitiva y modulamos la actividad del DLPFC (inhibición y activación) mientras evaluamos el

rendimiento de la memoria de trabajo (MT). Este rendimiento de la MT fue interferido por distractores emocionales, neutros y digitales. Sin embargo, en contra de nuestra hipótesis, no encontramos efectos significativos. La rTMS no modificó el efecto de la interferencia emocional en la tarea de la memoria de trabajo. Tampoco lo hizo la personalidad. En este contexto, nuestros resultados podrían servir de advertencia sobre las limitaciones que surgen cuando se estimulan cerebros sanos.

INTRODUCTION

1. General Framework

In neuroscience, deep brain stimulation in animal models has demonstrated its efficiency in assisting different cognitive processes. Deep brain stimulation also appears to be very effective in compensating for deficits associated with brain injury or aging. In addition, to treat various of disorders in humans, such as chronic pain and Parkinson's disease, practitioners also use these techniques. Consequently, it is effective in facilitating memory. And even in modifying the activity of brain structures underlying this cognitive process.

Electrical stimulation of the hypothalamus in humans facilitates memory and modifies the activity of structures (such as the hippocampus) in the medial temporal lobe (Hamani et al., 2008). However, this technique is invasive.

Therefore, the development of non-invasive brain stimulation (NIBS) techniques, such as transcranial magnetic stimulation (TMS) or transcranial direct current stimulation (tDCS), aims to break new ground. For basic research and for the therapeutic use of the neural substrate of cognitive functions.

TMS is a promising new tool, especially for its applications in cognitive neuroscience (Nevler & Ash, 2015). It offers a wide range of possibilities in both basic and clinical research (e.g., Cantone et al., 2014; Kimiskidis, Valentin, & Kälviäinen, 2014; Rossini et al., 2015b; Wessel, Zimerman, & Hummel, 2015). In its therapeutic application, it is a diagnostic support tool (Fregni & Pascual-Leone, 2007). Moreover, in recent times, there are guidelines – based on evidence – towards its applications as a treatment for different conditions (Lefaucheur et al., 2014a). This is thanks to their ability to induce changes in brain excitability that can last after the duration of stimulation (e.g., Chervyakov, Chernyavsky, Sinitsyn, & Piradov, 2015; A Pascual-Leone, Bartres-Faz, & Keenan, 1999).

Currently, we know that by applying a train of TMS pulses, with the same intensity at a given frequency (repetitive TMS-rTMS), it is possible to increase cortical excitability (rTMS >1Hz/high frequency). And also, to decrease it (rTMS ≤1Hz/low frequency). Recent developments of the TMS stimulation protocol, known as theta-burst stimulation (TBS), are a promising option to use in neuroscientific and psychological research (e.g., Y. Z. Huang, Edwards, Rounis, Bhatia, & Rothwell, 2005; Nyffeler et al., 2006). This is because at reduced stimulation times (around 40 seconds) it can produce long-term effects on cortical excitability compared to those achieved with classical rTMS paradigms (e.g., Nyffeler, Cazzoli, Hess, & Müri, 2009; Nyffeler et al., 2006). However, TMS is not the only NIBS technique that modifies cortical excitability. tDCS can also increase cortical excitability (anodal tDCS) or decrease it (cathodal tDCS) (Rossini et al., 2015b).

Now, let's imagine that a person is running to catch a bus about to leave. Out of nowhere, someone crosses that person's path. The person may stop running or change direction to avoid colliding with the individual crossing his or her path. During the rapid performance of these actions, as described above, it is mandatory to abort certain actions and implement new ones. Different processes related to cognitive control such as reactive and proactive inhibition, switching actions, working memory (WM) are crucial to resolve this type of conflicts.

To avoid particular actions and to set in motion goal-directed behavioral patterns (Nachev, Kennard, & Husain, 2008) we use these three processes in parallel. These processes belong to a larger and more general domain called cognitive control (Gazzaniga, M. S., Ivry, R. B., & Mangun, 2019). Cognitive control goes beyond inhibition or modification of the behavior in question. It is a capacity that allows us to use our perceptions, knowledge, and information about our goals and motivations. This is done to shape the selection of a goal-directed action or thought among multiple possibilities (Obeso, Robles, Marrón, & Redolar-Ripoll, 2013). Cognitive control underlies the temporary maintenance of information received or retrieved

from long-term memory when it is no longer available. Meaning it is no longer the in working memory (Palaus, Viejo-Sobera, Redolar-Ripoll, & Marrón, 2020; Portero-Tresserra, 2020). Moreover, cognitive control processes are of great importance in decision-making (Waskom, Frank, & Wagner, 2017). Therefore, and as seen above, during this thesis we will focus on both processes due to their interconnected nature (Redolar-Ripoll, D., 2021): decision-making, specifically risk and working memory, taking emotions into account.

Cardinal areas in cognitive control (pre-supplementary motor area-pre-SMA-, inferior frontal gyrus-IFG-, subthalamic nucleus, caudate nucleus) participate in a circuit of connection in the prefrontal cortex and basal ganglia (e.g., Aron, Behrens, Smith, Frank, & Poldrack, 2007; Aron & Poldrack, 2006; Kenner et al., 2010; C.-S. R. Li, Yan, Sinha, & Lee, 2008; Rubia et al., 2001; Rushworth, Hadland, Paus, & Sipila, 2002; Zandbelt & Vink, 2010). Previous work has shown the role of the pre-SMA in inhibition and suggested a differential functional role in action switching (Obeso et al., 2013). Showing, furthermore, the importance of connectivity between the IFG and the pre-SMA during inhibition (Obeso et al., 2013). Moreover, in situations where cognitive demand is high, the contribution of the prefrontal DLPFC is cardinal for cognitive control (e.g., Criaud & Boulinguez, 2013; Guse, Falkai, & Wobrock, 2010; Jahfari, Stinear, Claffey, Verbruggen, & Aron, 2010; Stokes et al., 2013). In addition, it is also important in cognitive control processes, for decision-making (Knoch, D., Gianotti, et al., 2006; Knoch, D., Pascual-Leone, Meyer, Treyer, & Fehr, 2006), WM (e.g. , Barbey, Koenigs, & Grafman, 2013; D'Esposito, Cooney, Gazzaley, Gibbs, & Postle, 2006; Fuster, 2009; Stokes, 2015), and people's ability to infer and predict others' behavior, as well as their emotions, intentions, and beliefs (e.g. , Happé, Brownell, & Winner, 1999; Kalbe et al., 2010). Also known as theory of mind (ToM). Various functional investigations have suggested a cascade model for cognitive control. This model predicts an early involvement of the DLPFC in the selection of task-relevant information. Whereas, the dorsal region of the anterior cingulate

cortex (ACC) could be involved in later stages related to the response process (Silton et al., 2010). The DLPFC also contributes to cognitive conflict at early and later stages (after stimulus presentation) (Redolar-Ripoll, D., Viejo-Sobera, Palaus, Valero-Cabre, & Muñoz-Marron, 2016).

2. Non-Invasive Brain Stimulation (NIBS)

Before addressing each of the cognitive functions on which this thesis focuses, it is necessary that we provide an introduction of what a NIBS technique is, its types, as well as an explanation of how it works. This is because in both experiments, we use NIBS techniques to explore cognitive functions. Furthermore, to explore each cognitive function, we mainly focus on studies that have used NIBS to achieve their results.

Since ancient times, the brain, its physiology, its conditions and diseases, have been of great interest to scientists, philosophers, researchers, clinicians, etc.

Neuroscience distinguishes itself as a science that seeks to understand the patterns and circuits of neural activity that causes behavior and mental processes. And one of the methods to achieve this was through direct influence on the brain in living people in a way that was not harmful to them. NIBS techniques, compared to deep brain stimulation, offer the ability to alter and stimulate brain activity (from the surface of the head). Without opening the patient or introducing any tools inside the human body, or damaging it in any way. It can be used as a diagnostic tool, to observe changes in brain activation, connectivity, or inhibition due to disease. And to study the physiology of the brain.

In this context, the goal of cognitive neuroscience is to understand the neural mechanisms underlying cognition (Vosskuhl, Strüber, & Herrmann, 2018). And the idea of being able to stimulate the brain by an external force is something that has been around before the development of NIBS (Guleyupoglu, Schestatsky, Edwards, Fregni, & Bikson, 2013). With NIBS, neuroscience researchers could corroborate their theories by directly modifying brain function. Moreover, their use as a tool in neuroscience research is recent (Zaghi, Acar, Hultgren, Boggio, & Fregni, 2010). Scientists are still investigating its usefulness as a therapeutic tool, but it is also useful for research in healthy individuals. This is because its effects are generally short-lived and do not produce any harm to the subjects.

NIBS are able to transiently modulate cortical excitability. Moreover, their effects can outlast the duration of stimulation (Fisicaro, Lanza, Bella, & Pennisi, 2020). They are used in cognitive neuroscience to modify brain activity. And consequently, modify the subject's behavior (Miniussi, Harris, & Ruzzoli, 2013). In addition, the use of NIBS aims to establish the role of a certain cortical region with a specific cognitive, motor, or perceptual process (e.g., Hallett, 2000; Walsh & Cowey, 2000).

Among NIBS, the most widely used types are TMS and transcranial electrical stimulation (tES) and its direct current modality, tDCS. Both modalities affect neuronal states in different ways. One through magnetic fields -TMS-, and the other through electric current (tES). Both share a similar mechanism. They use supraliminal currents to modify brain excitability. Moreover, NIBS techniques are still an evolving field and new stimulation techniques, such as those using light or even ultrasound as energy input to modify cortical activity, are still being developed and studied (see Table 1).

Table 1 Type of non-invasive brain stimulation techniques

Name	**Energy modality**	**Main uses**	**Focality**	**Invasiveness**	**Advantages**	**Limitations**
Transcranial Magnetic stimulation (TMS)	Magnetic field	Research, evaluation of the nerve integrity, clinical treatment (depression, etc.), cognitive enhancement	Very focal (mm)	Low. fMRI needed beforehand. Placement of the coil before stimulation. Stimulation periods vary depending on the type.	Capable of reaching deeper brain areas. Very promising in the treatment of depression.	It may result in discomfort in some of its modalities and is expensive.
Transcranial electric stimulation (tES)	Electric field	Research, cognitive improvement, clinical treatment (depression), treating motor dysfunctions.	Low focality. Improved with High Definition tDCS (HD-tDCS)	Low. Position of the cap with electrodes and gel. Stimulation duration can vary between 10 min and longer.	Highly portable, easy to use, and cheaper than TMS.	It can produce uncomfortable sensations. Application time tends to be longer.

Name	Energy modality	Main uses	Focality	Invasiveness	Advantages	Limitations
Transcranial static magnetic field stimulation (tSMS)	Magnetic field	Experimental stage	Low	Low. Stimulation periods can be relatively long.	Simpler and with a low cost.	Experimental. Research volume is low.
Transcranial photobiomodulation/Transcranial laser stimulation (TLS)	Infrared light	Research, cognitive enhancement, rehabilitation due to stroke or trauma due to the brain	Relatively	Low. Previous positioning of the laser or LED.	Safe and cheap.	The volume of research is low due to being a recent technique.
Transcranial Focused Ultrasound	Ultrasound waves	Still in the experimental phase.	Very focal. Can reach	Low. Ultrasound waves need to reach	Highly precise, has a higher spatial resolution, and can	It is a recent technique. Low

(tFUS)/Transcranial Unfocused Ultrasound (tUS)		Potential for therapeutic uses.	very deep structures.	the target at the same time.	reach deep structures. Highly accessible.	volume of research.
Caloric vestibular stimulation (CVS)	Water or air (cold or hot)	Research, vestibular function assessment, assessment of brain stem function in comatose patients, post-lesion assessments.	Low	Medium. Irrigation of air or water in the external auditory canal.	Well tolerated, and inexpensive.	Region-specific and unilateral. Low usage in the clinical field.

2.1 NIBS techniques

This section will mention the most commonly used NIBS techniques to date, especially in research.

2.1.1 Transcranial Magnetic Stimulation (TMS)

TMS is a NIBS technique. It is used for stimulation of neural tissue, which includes spinal roots, cerebral cortex, and peripheral and cranial nerves. It is a recently developed technique, introduced in 1985 at the University of Sheffield, UK, by Anthony Barker (Barker, Jalinous, & Freeston, 1985). However, it is based on the principle of electromagnetic induction.

Michael Faraday discovered this principle in 1831. According to this principle, when an electric current passes through a wire, it will generate a time-varying magnetic field. If we place a second wire nearby, this magnetic field will induce an electric flux in the second wire (e.g., Kinsler, 2020; O'Shea & Walsh, 2007). With TMS, the first wire would be the coil used for stimulation and the second wire, the brain region targeted (O'Shea & Walsh, 2007). As the shape of the conductor is that of a coil (solenoid), by Ampère's law, the individual magnetic fields generated through the different turns of the conductor have to pass through the center of the coil. This will increase the strength and create a larger magnetic field (Vidal-Dourado et al., 2014). The field is stronger if there are a larger number of turns in the conductor. This means that the strength of the magnetic field depends on the number of turns of the coil and the strength of the electric current (Vidal-Dourado et al., 2014).

The coil of the transcranial magnetic stimulator is of copper. And it is confined by a plastic housing. This housing connects to a power source composed of capacitors and a thyristor, which manages the current flow. These capacitors can hold and deliver

thousands of amperes in a matter of milliseconds. When the current pulse passing through the coil, placed on the participant's head, is strong enough, and of short duration, it generates rapidly changing magnetic pulses that can enter the scalp and skull. And it reaches the brain with an imperceptible attenuation (Kobayashi & Pascual-Leone, 2003). Thanks to these pulses, it induces a secondary ionic current in the brain.

The electric current needed to generate a magnetic field strong enough to stimulate the cerebral cortex ranges from 7 to 10 kA. It is applied as a single pulse lasting approximately 1 ms. When we met these conditions, it generates a magnetic field of up to 2.5T. This force is similar to that of magnetic resonators. One of the reasons why when applying TMS stimulation, the coil should be as close as possible to the scalp is because the magnetic field strength is inversely proportional to the square of the distance (Weik, 2001). Therefore, the coil should be as close as possible to the location of the stimulation target. However, there are other factors that can affect the magnetic field strength needed to stimulate the cortex. For example, the different resistance of the tissues surrounding the cerebral cortex, the conductance, and excitability or orientation of the neurons in the cortex, or the motor threshold of each individual person (e.g., Ibiricu & Morales, 2009; Klomjai, Katz, & Lackmy-Vallée, 2015; Kobayashi & Pascual-Leone, 2003).

The extent of TMS in the brain depends on the type of coil (Vidal-Dourado et al., 2014). A figure-of-eight coil can reach between 1.5 and 3 cm (e.g., Rossi et al., 2009; Thielscher & Kammer, 2004; Zangen, Roth, Voller, & Hallett, 2005). We need a “H-coil” to achieve stimulation of subcortical areas, about 4 to 6 cm deep (e.g., Bersani et al., 2013; Yiftach Roth, Amir, Levkovitz, & Zangen, 2007).

When we talk about transcranial stimulation, the basis for this to occur is the depolarization of neuronal membranes. We require this to occur, so that it can initiate action potentials. This happens in both TMS and tES techniques. Both stimulate the axons

of neurons. Specifically, the large diameter myelinated axons, because the soma has a higher threshold due to a higher electrical time constant (Burke, Bartley, Woodforth, Yakoubi, & Stephen, 2000). Furthermore, in the brain, induced currents have a directional component. Normally, currents progress parallel to the surface of the brain. Therefore, the stimulation threshold will depend on the direction of this current (Tofts, 1990). And where the axon bents out of the field is where depolarization will normally occur. Therefore, there is a greater change in the electric field (Rossini et al., 2015c). Furthermore, depending on the neuronal circuits targeted, the effect of stimulation will vary. And it is possible to achieve depolarization in regions that are further away from the target site but are anatomically or functionally connected to that target site.

2.1.1.1 Types of coils

There are a variety of coil types. They can have different geometric shapes and sizes. We can include the figure-eight coil, the circular coil, the air-cooled coil, the double-cone coil and more recent coils such as the Hesed coil (Y Roth, Zangen, & Hallett, 2002), the circular crown coil (Lefaucheur et al., 2014b) and the c-Core coil. Eight-shaped coils can provide focused stimulation; this is because the electric field, maximal below their center-"hot spot"-creates a precise area. In the case of double-crown coils, their electric field can extend to cortical layers that lie deeper. In addition, research recommends the use of this coil for stimulation of motor areas of the lower extremities, which are located in the interhemispheric fissure, at great depth (Hovey & Jalinous, 2006). However, this coil is not focal. On the other hand, circular coils cause currents to spread widely under the windings and thus stimulate cortical layers in superficial areas (Klomjai et al., 2015). Furthermore, research usually recommends these types of coils for stimulation of superficial and large motor areas (Klomjai et al., 2015).

Among the mentioned coils, the most commonly used are the circular coil and the figure-eight coil (Kobayashi & Pascual-Leone, 2003).

Figure 1 Most common types of coils. On the left is the 8-shaped coil and on the right is the circular coil. (Adapted from Andoh, J., & Martinotm J.-L., 2012)

The circular coil allows a wider distribution of the electric field, which may allow bihemispheric stimulation (e.g., Pascual-Leone A, Davey N, Rothwell J, Wassermann EM, 2002; Rossini & Rossi, 1998). This coil originally developed with the TMS technique. Its magnetic field is uniform and strong around the circumference of the coil. And it decreases near the outside and the center. It can cover large areas of the brain. However, the created magnetic field is less powerful because it is diffuse. This means that it has a low penetrating power compared to other coils. However, the figure-eight coil allows for more focal stimulation, thus allowing for more detailed cortical representation and mapping (Pascual-Leone A, Davey N, Rothwell J, Wassermann EM, 2002). Hence, greater accuracy. We can achieve this by placing the coil above and parallel to the stimulation site.

However, the size of the coil is also important. If the coil is smaller, the stimulation will be more focal, but it will overheat faster (Rossini et al., 2015c). This will result in shorter sessions, as TMS devices are normally intended to deactivate if it reaches a certain temperature.

In addition, TMS has a low penetration range, so an H-shaped coil is able to reach deeper regions. And to do so in a way that does not overstimulate regions that are superficial. This is achieved by designing a coil which distributes the magnetic field around its surface. But can maintain the strength of that magnetic field up to a given range. In addition, and due to the larger size of this coil, it is normally pre-assembled and in a helmet. This means that it is tailored to focus on certain types of areas and is mostly used to treat psychiatric disorders or in a clinical setting (Bersani et al., 2013). Even so, this improved penetration is the result of an increase in stimulation intensity. However, it is still unlikely to avoid stimulating superficial areas when stimulating a deeper area (Deng, Lisanby, & Peterchev, 2013).

2.1.1.2 Stimulation protocols and paradigms.

Other variables that influence the efficacy of TMS are the intensity administered, the stimulation paradigm and the frequency of stimulation.

2.1.1.2.1 Stimulation Paradigm

In research, TMS studies use different types of paradigms (Valero-Cabré, Amengual, Stengel, Pascual-Leone, & Coubard, 2017). These paradigms aim to establish causality with the cortical areas targeted, and the cognitive tasks employed or measured by physiological signals (Robertson, Théoret, & Pascual-Leone, 2003). Among these modalities we can find: online, offline and chronometric) (Valero-Cabré et al., 2017). In the online modality, participants perform the task/physiological or behavioral measures at the same time as the stimulation. Therefore, it is performed continuously. Its main goal is to expand the knowledge of how a certain area may affect a certain cognitive function. In the offline paradigm, researchers administer the task before and after stimulation. Therefore, it is not applied at the same time. In addition, it is also better if they also

measure the tasks during the recovery period. This is intended to show that, once the stimulation disappears, performance will return to baseline (Valero-Cabré et al., 2017). This paradigm intends to study the long-lasting effects of TMS. Once the stimulation period is over, and how it alters certain cognitive functions.

In the chronometric paradigm, researchers administer TMS stimulation at different time intervals. This is intended to help determine, at what point in a given task, which contribution of a brain area becomes critical. This is done through the use of individual pulses or pulse trains. Typically, pulses of short duration in different time windows, before or after certain stimuli (Valero-Cabré et al., 2017).

At the same time, there are different approaches when using neuroimaging techniques and TMS. They are used concurrently, or at different times. The use of neuroimaging techniques with TMS is due to the need to obtain more information about the effects of TMS stimulation on brain activity. When we use neuroimaging techniques at the same time as TMS, this allows us to obtain temporal and spatial information on how TMS modulates neuronal activity.

However, as noted above, neuroimaging acquired prior to applying TMS is necessary to guide the stimulation to the exact position. This will increase its accuracy. In addition, it will provide information about the activation pattern occurring during the task. Finally, it can also be collected after TMS stimulation. This allows us to observe the brain activation patterns induced by the stimulation. Therefore, it will also provide us with information on the functional reorganization processes that are enhanced by TMS. However, it is important to keep in mind that the effects of TMS are time-limited. This means that neuroimaging techniques must be performed quickly to ensure that we capture these effects.

2.1.1.2.2 Stimulation Intensity

The experimenter or clinician controls the intensity applied during NIBS stimulation. They are the ones who set the energy levels flowing through the coil. In addition, there are several safety guidelines that have studied which intensities are safest to apply (Rossi et al., 2009).

Researchers and practitioners use the motor threshold to determine which stimulation intensity is most appropriate for each participant. This is done prior to stimulation and on an individual basis. The lowest intensity needed to stimulate a motor evoked potential (MEP) of minimum amplitude defines the motor threshold. This can be exemplified by a visible contraction of the first dorsal interosseous muscle of the hand. Depending on the stimulation protocol that is then applied, the muscle should be in a resting state or slightly contracted. When it comes to the resting motor threshold, the MEP amplitude has to be greater than 50 μV. However, for an active motor threshold, it has to be greater than 100 μV (Rossini et al., 2015a). This difference is due to the fact that a stimulation intensity will have greater results when applied to an active brain than when it is in a resting state. This occurs because the magnetic stimulus induces cortical synaptic activity. And this is more productive while the postsynaptic neurons are active when we apply this stimulus. Thus, the motor threshold is normally lower when in an active state. Especially when compared to the resting state, because a lower stimulation intensity is necessary to achieve the same effects on the muscles.

When the induced current penetrates into the brain, its intensity decreases. And for this reason, this is the only possible way to modulate cortical areas by TMS. As mentioned above, it does not stimulate just one particular brain region, but stimulates a brain network. This is because it has a reaction in subcortical and cortical areas that are interconnected (functionally and structurally) with the targeted region.

2.1.1.2.3 Stimulation frequency

There are different frequencies of magnetic pulses that are applied to the cortex. There are different TMS modalities that will create different results/effects on brain activity and, therefore, their uses will have different purposes. We are focusing on the TMS modality that we used on our experimental procedure, TBS.

2.1.2 Repetitive TMS (rTMS) Low frequency/High Frequency

rTMS is a combination of more than two pulses delivered within 2 s or less. In addition, its stimulator is capable of delivering high frequency pulses (1 to 20 Hz) (Rossi et al., 2009). Therefore, the effects of this methodology differ from single pulses. To design the repetitive stimulation patterns, researchers use the usual TMS parameters such as frequency, number of pulses, duration, etc. And because it is more complex, you can find its parameter guidance published in safety guidelines (e.g., Rossi et al., 2009; Wassermann, 1998) and its updates (e.g., Machii, Cohen, Ramos-Estebanez, & Pascual-Leone, 2006; Poreisz, Boros, Antal, & Paulus, 2007). This technique has the potential to modulate functions in a sustain manner when researchers/practitioners administer long trains in consecutive (daily) sessions. However, compared to single-pulse TMS, rTMS has a lower temporal resolution. But it allows modifying the excitability of cortical areas, either by decreasing or increasing it. And thereby also the distal areas linked by functionality (Paus & Barrett, 2004).This allows us to study the integrity of the pathways. Therefore, it is advantageous for localizing brain regions invested in different cognitive functions. In addition, this technique can create transient lesions. This is done by blocking selected neural networks involved in a specific cognitive function for a period of time (Pascual-Leone, Walsh, & Rothwell, 2000). Moreover, it is a very useful tool in the field of neuropsychology and research.

In addition, rTMS allows the configuration of delayed paradigms. We can separate stimulation and tasks in time. This is possible because the effects that rTMS has on cortical excitability last longer than the duration of stimulation. The duration of the effects will vary, depending on the intensity, the stimulation protocol and the duration of the stimulation protocol (di Lazzaro et al., 2011). However, this can also be achieved by modulating another brain area that disputes the same cognitive functions as the target. Or with the (indirect) effects caused by stimulating an area that is connected, functionally, to the targeted region (Luber & Lisanby, 2014).

There are two categories, high-frequency rTMS and low-frequency rTMS. Depending on the category, the effects on cortical excitability will differ.

Low-frequency rTMS (less than 1 Hz) generally has an inhibitory effect on brain activity, and high-frequency rTMS (greater than 1 Hz) increases cortical excitability (Rossi et al., 2009).

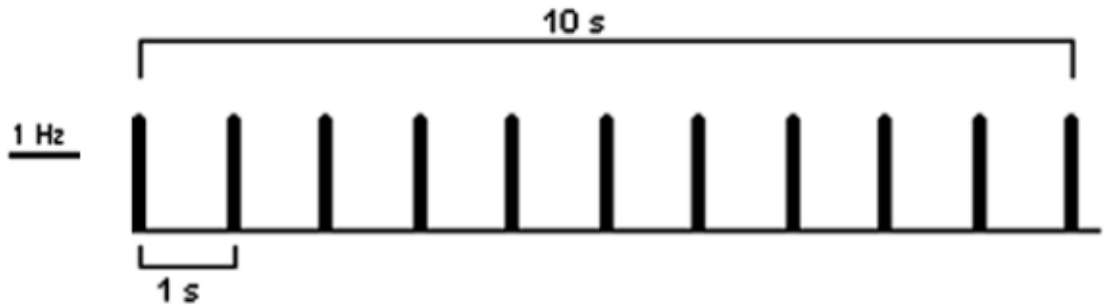


Figure 2 Depiction of an rTMS configuration of low-frequency at 1 Hz. Normally, this approach decreases the excitability of the cortex. (Adapted from Rossi et al., 2009)

Low frequency rTMS is usually applied from 0.1 Hz to 0.9 Hz, with 1 Hz being the most common and using a single pulse train lasting between 10 and 20 minutes. It is biased towards decreasing cortical excitability (Rossi et al., 2009). However, the effects of low-frequency rTMS, compared to high-frequency rTMS do not seem as consistent (de Jesus et al., 2014). On the other hand, high-frequency rTMS application ranges from 5 Hz to

20 Hz, sometimes more, and are applied at intensities ranging from subthreshold to 150% of motor threshold. And while low-frequency rTMS appears to reduce MEP amplitudes, high-frequency rTMS increases them.

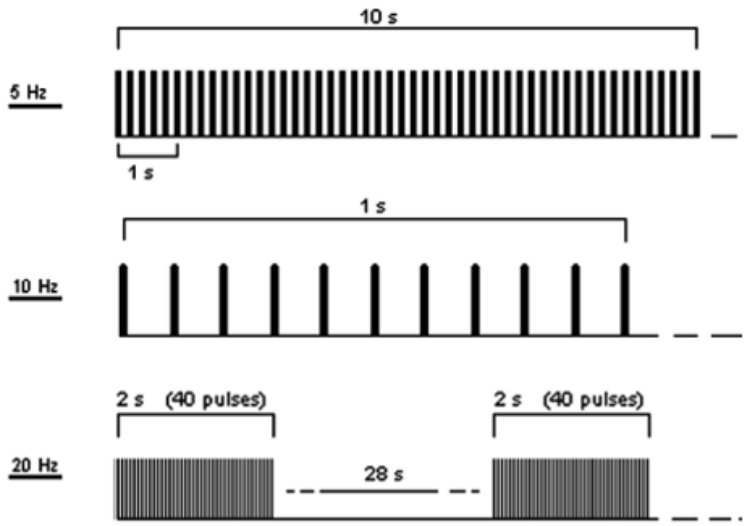


Figure 3 Three high-frequency rTMS modalities, 5 Hz, 10 Hz, and 20 Hz (top to bottom). This configuration of rTMS likely increases cortical excitability. (Adapted from Rossi et al., 2009)

2.1.3 Patterned rTMS Continuous Theta Burst/Intermittent Theta Burst

Theta burst stimulation (TBS) is a form of patterned rTMS. It consists of trains of three pulses (up to 600) at 50 Hz. Huang (Y. Z. Huang et al., 2005) were the first ones that described this method. It is a fast method that conditions the human cortex, and produces modulatory effects on corticospinal excitability, motor cortex, and can also have an impact on different types of behavior. Compared to rTMS, the effects of TBS appear to last longer and have a more potent effect even after a short period of stimulation. Its effects compared to long-term potentiation in the hippocampus of animals (Y. Z. Huang et al., 2005). And it has also shown promising results in the treatment of depression, equal to or greater than high-frequency rTMS (e.g., Bulteau et al., 2017; S. W. Chung, Hoy, & Fitzgerald, 2015). Its excitability changes appear to be better when the TBS protocol consists of sessions separated by time intervals (Goldsworthy, Pitcher, & Ridding, 2012).

To date, it is the most widely used protocol for clinical practice and research due to its better results in maintaining a modulation of the human cortex. TBS has two paradigms that yield opposite results:

2.1.2.1 Continuous TBS (cTBS)

This paradigm intends to induce effects similar to long-term depression (LTD). It consists of three pulses applied at 50 Hz and repeated five times per second, continuously. The total duration of the protocol is 40 seconds. These pulses normally have an intensity of 80% of the active motor threshold (AMT). At 70% of the motor threshold, the cTBS creates an electric field of about 50-80 mV/mm.

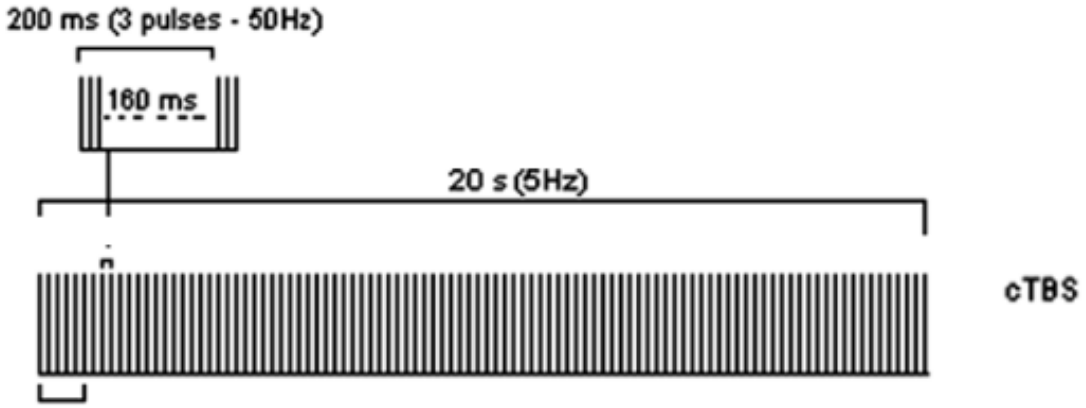


Figure 4 Diagram of cTBS protocol. It delivers a single train that consists of 600 pulses in packages of 3 at 50 Hz. It repeats each package at 5 Hz. (Adapted from Rossi et al., 2009)

2.1.2.2 Intermittent TBS (iTBS)

Unlike cTBS, this paradigm induces effects similar to long-term potentiation (LTP). And unlike cTBS, the pulse trains last two seconds, spaced by eight seconds between trains. Therefore, three pulses at 50 Hz, every 10 seconds, consisting of 600 pulses will consist of 200 seconds in total. Compared to cTBS, iTBS appears to have longer lasting effects on the cerebral cortex (Goldsworthy et al., 2012).

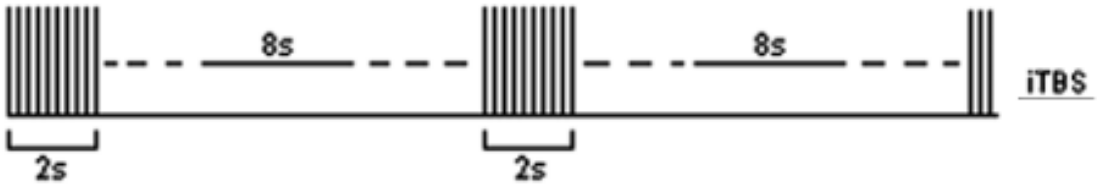


Figure 5 Diagram of iTBS protocol, adapted from a protocol that is used for cTBS is spaced. It is administered for 2 seconds with an 8-second interval (10 seconds in total). This is repeated until it delivers 600 pulses. (Adapted from Rossi et al., 2009).

In general, one of the main advantages that TBS seems to have over rTMS is that its effects seem to last longer, even with shorter stimulation times-20 minutes for iTBS and up to 60 minutes for cTBS (Suppa et al., 2016a). However, we cannot forget that there are still many factors to be taken into account that could affect cortical excitability.

In addition to pattern rTMS there are also other TMS modalities such as Signgle-Pulse TMS, Paired-Pulse/Double Pulse TMS (Cortico-Cortical/Intracortical), Rythmic TMS and Multicoil TMS.

2.2 Transcranial electric stimulation (tES)

The use of electricity in the medical field is a practice that is not new. Practitioners applied in the past to treat diseases.

Initially, animal electricity produced electricity sources (Sarmiento, San-Juan, & Prasath, 2016). One of the earliest reported evidence of electrical stimulation dates back to Ancient Greece (e.g., Cambridge, 1977; Rockwell, 1896). However, the earliest indication in the history of transcranial stimulation seems to come from the Roman Empire (e.g., Cambridge, 1977; Sarmiento et al., 2016). However, intensive study of this subject began in the early 20th century. From there, we understand that transcranial electrical stimulation (tES) includes a variety of non-invasive brain stimulation techniques that, unlike TMS, use electrical currents. Researchers apply these electrical currents to the

brain through the use of electrodes. This technique, like TMS, is for clinical and research purposes. We will focus on the technique used for our experimental procedure.

2.2.1 Transcranial Direct Current Stimulation (tDCS) Cathodal/Anodal

Transcranial direct current stimulation is one of the most widely used. Therefore, like TMS, it is a very promising tool to achieve modulation of motor and cognitive functions (M A Nitsche & Paulus, 2000). And its popularity has increased. Most of the studies dealing with risk decision-making and NIBS used tDCS, as compared to TMS. This technique involves the discharge of a weak direct electrical current by placing one or more electrodes on the subject's scalp. Batteries usually induce this current and is usually applied between 1 and 2 mA and around 5 to 20 minutes, which gives sufficient time for subthreshold currents to flow through the brain (W. Paulus, 2011). There are different setups that can be applied to tDCS. For example, in a setup where we only treat one hemisphere, one electrode will be known as the target electrode and the other as the reference electrode. It is also interesting to note that in some setups, researchers place the reference electrode extra cephalad, such as on the upper arm. But, if we want to use a setup that projects stimulation to two cortices that are in parallel, researches place electrodes in both hemispheres (e.g., Benwell, Learmonth, Miniussi, Harvey, & Thut, 2015; Lindenberg, Renga, Zhu, Nair, & Schlaug, 2010; Thair, Holloway, Newport, & Smith, 2017). When researchers apply stimulation, electrical currents will flow through the electrodes and pass through the brain, completing the circuit established by the position of the electrodes. We can have two types of stimulation, anodal and cathodal. An anodal current will activate behaviors that are associated with the stimulated area, while a cathodal current inhibits behaviors associated with that particular area (e.g., M. A. Nitsche & Paulus, 2000; M. A. Nitsche et al., 2008). Therefore, anodal stimulation will depolarize neurons, which in turn will increase the likelihood of an action potential. In

contrast, cathodal stimulation will hyperpolarize neurons, thereby decreasing the likelihood of an action potential (e.g., Antal, Kincses, Nitsche, & Paulus, 2003; M. A. Nitsche et al., 2008; Priori, 2003). This modulation, as in TMS, is reversible. And it has become in recent years a well-established tool to provide causality between brain and behavior in healthy and unhealthy participants. Compared to TMS, it is easier to use, cheaper and, if damaged, easy to replace. Therefore, this may be one of the reasons why it is a widely used technique. In addition, it offers a home application (Shaw et al., 2017) and may even have the potential to be used alongside pharmacological treatment or as a replacement to accelerate recovery and improvement of cognitive and motor performance (Brunoni et al., 2012b). It has also been successful in treating depression, reducing its symptoms (e.g., Fregni, Boggio, Nitsche, Marcolin, et al., 2006; M. A. Nitsche, Boggio, Fregni, & Pascual-Leone, 2009), improving syntax delays in patients with autism (Schneider & Hopp, 2011) and in reducing hallucinations in patients suffering from schizophrenia (Agarwal et al., 2013).

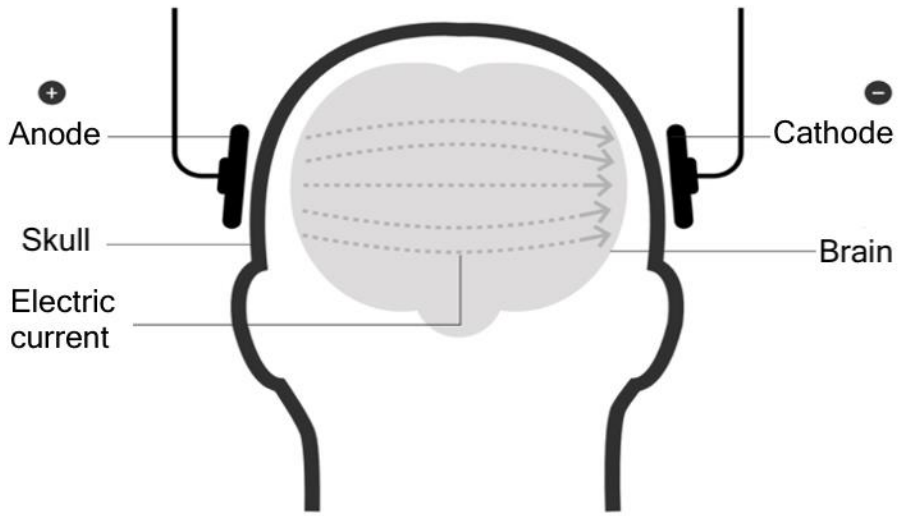


Figure 6 tDCS stimulation. This type of stimulation induces a very low-intensity current, between 1 and 2 mA, which increased cortical excitability under the anode and decreases under the cathode (Adapted from Elena Muñoz Marrón http://cognitive-neurolab.org/)

The application process of tDCS is quite simple. We place the electrodes on a cap since it requires contact with the scalp. This is because there needs to be conductivity maintained throughout the circuit. If impedance levels are high, it usually indicates poor conductivity (Thair et al., 2017). Normally, the monitor will display the levels, as it must remain constant. When it comes to electrode placement, the most commonly used method is the 10-20 EEG International system (Klem, Lüders, Jasper, & Elger, 1999). And today most tDCS machines use neoprene caps with chin straps.

We have to choose, beforehand, what we need to stimulate, and unlike TMS, the target of a tDCS stimulation must be on the cortical surface, as the electrodes do not penetrate into deeper brain regions. In addition, tDCS has a simulated protocol that will be provided as a control measure.

2.2.2 Multifocal Transcranial Direct Current Stimulation (MtDCS)

As for multifocal tDCS (MtDCS), recently, the multifocal solution provides a higher correlation coefficient compared to the classical setup. It is able to hit the target map at various locations (Ruffini, Fox, Ripolles, Miranda, & Pascual-Leone, 2014). It gives us the ability to work with a few extended targets using a variety of imaging modalities (Ruffini et al., 2014). Studies targeting the resting-state motor network found that MtDCS increases cortical excitability beyond traditional tDCS targeting the unilateral motor cortex (D. B. Fischer et al., 2017). However, there is not yet much evidence for the application of MtDCS models to study cognitive functions.

In addition, there are other tES modalities such as transcranial Randome Noide stimulation (tRNS), transcranial alternating Current stimulation (tACS) and high-definition transcranial current stimulation (HD-tDCS).

3. Risk Decision-making

To achieve specific objectives in a changing environment, living organisms make decisions constantly, throughout the course of their lives. As a behavior, each decision involves choosing among possible alternative options. An attentional deployment and cognitive assessment of an internal or external stimulus proceeds each decision. And its expected outcome in a current context. Cognitive control, in that sense, is considered a higher cognitive process involved in value-based decisions, as they require deciding among options that lead to the desired outcome (Busemeyer, Gluth, Rieskamp, & Turner, 2019). Cognitive control involves the use of perceptual inputs, updated data, and knowledge in accordance with internally generated goals achieved through successful behavioral monitoring and selection (Obeso et al., 2013).

Along with the field of psychology (e.g., Edwards, 1954; Evans, Over, & Manktelow, 1993), or economics (e.g., Arrow, 1982; Tversky & Kahneman, 1989; Zefinescu, Ibrahim, Popovic, & Mieila, 2015), neuroscience has placed one of its focus of interest in the study of the neural correlates responsible for value-based decision-making among healthy population (Poudel, Bhattarai, Dickinson, & Drummond, 2017), subjects suffering brain damage (e.g., Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, & Damasio, 2000), or diagnosed with a psychiatric disorder (e.g., Ernst et al., 2003; Glenn, Raine, & Schug, 2009).

At the neurobiological level, it diversifies decision-making along different neural pathways (e.g., Atiya, Rañó, Prasad, & Wong-Lin, 2019; Ernst & Paulus, 2005; Gold & Shadlen, 2007; Khani & Rainer, 2016; Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006; Kurikawa, Haga, Handa, Harukuni, & Fukai, 2018; D. Lee & Seo, 2016; Mohr, Biele, Krugel, Li, & Heekeren, 2010). Value-based decision-making, in this sense,

involves several underlying processes such as valuation of different available options (e.g., Bossaerts & Murawski, 2015; Gutnik, Hakimzada, Yoskowitz, & Patel, 2006; Szrek, 2017), gains and losses (e.g., Sokol-Hessner & Rutledge, 2019; Tom, Fox, Trepel, & Poldrack, 2007; X. Zhang, Liu, Chen, Shang, & Liu, 2017), probability calculus (e.g., Chen, Choi, & Darwiche, 2012; Huang, Friesen, Rao, & Wa, 2011; Troffaes, 2007), and decision uncertainty and confidence (e.g., Atiya et al., 2019; Kurikawa et al., 2018; Pushkarskaya, Smithson, Joseph, Corbly, & Levy, 2015). As a result, the study of value-based decision-making is particularly complex. In addition, researchers believe that considerable individual variability in decision-making behavior exists (Kurikawa et al., 2018).

Disruptions in risky decision-making mark different clinical conditions. Risk decision-making is a type of value-based decision comparable to real-life decisions (Megías, Cándido, Maldonado, & Catena, 2018). These disruptions correlate with a similar pathogenic mechanism: dysregulation of the cortico-limbic system, and of dopamine (DA) transmission. In particular, across several neurological and psychiatric disorders such as Parkinson's disease (Mimura, Oeda, & Kawamura, 2006), schizophrenia (Sterzer, Voss, Schlagenhauf, & Heinz, 2019), and substance use and addictive disorders (DSM-5) (e.g., Clark & Robbins, 2002; Ekhtiari, Victor, & Paulus, 2017). These structural and functional disturbances often progress after frontal lesions (e.g., A Bechara, Damasio, Damasio, & Lee, 1999; Antoine Bechara et al., 1994) or in pathological gamblers (e.g., Antoine Bechara et al., 1994; de Ruiter et al., 2009).

Neuroimaging studies have pointed to different regions of the prefrontal cortex (PFC) as responsible for cost-benefit valuations in relation to risk and rewards, and their resulting decisions (St. Onge & Floresco, 2010). Specifically, dorsolateral (e.g., Brand et al., 2004; Ernst et al., 2002; Fellows & Farah, 2005; Labudda et al., 2008; Manes et al., 2002;

Steinberg, 2008), ventrolateral (e.g., Baxter, Gaffan, Kyriazis, & Mitchell, 2009; H.-K. Chung, Tymula, & Glimcher, 2017; Domenech & Koechlin, 2015; Fellows & Farah, 2007; Z. Guo et al., 2013; Hampshire, Gruszka, Fallon, & Owen, 2008; Wearne, 2018), orbitofrontal cortex (e.g., D. M. Clark et al., 2003; Ernst et al., 2004; Fukui, Murai, Fukuyama, Hayashi, & Hanakawa, 2005; Manes et al., 2002; Rogers, Everitt, et al., 1999; Rogers, Owen, et al., 1999), parietal (Coutlee, Kiyonaga, Korb, Huettel, & Egner, 2016), anterior cingulate cortex (e.g., Ernst et al., 2002; Labudda et al., 2008; Lawrence, Jollant, O'Daly, Zelaya, & Phillips, 2009), and insular cortex (e.g., Bar-On, Tranel, Denburg, & Bechara, 2013; L. Clark et al., 2008; Ernst et al., 2002; B. W. Smith et al., 2009) areas. Research shows that these regions have the most relevance, in this regard. Surprisingly, the specific role, structural and functional relationships of these regions of the PFC with respect to risk decision-making remains unclear.

3.1 NIBS on the study of risk decision-making

Researchers use NIBS techniques in studying the neural basis of risk decision-making (e.g., Blair-West, Hoy, Hall, Fitzgerald, & Fitzgibbon, 2018; Herrmann, Rach, Neuling, & Strüber, 2013; Kelley, Gallucci, Riva, Lauro, & Schmeichel, 2019; Nevler & Ash, 2015; Ouellet et al., 2015a; Tremblay et al., 2014; Viejo-Sobera et al., 2017), including rTMS, tDCS, tACS, and tRNS (e.g., Y.-Z. Huang, Sommer, et al., 2009; Rossini et al., 2015c). NIBS techniques have allowed direct modulations of brain oscillations (e.g., Karabanov et al., 2015; Valero-Cabré et al., 2017). This leads to a functional dissociation of different regions of the PFC from a casual perspective, overcoming the correlational perspective prevalent along with previous neuroimaging studies (e.g., Nevler & Ash, 2015; A Pascual-Leone et al., 1999).

Therefore, NIBS techniques are one way to approach the study of risky decision-making, especially the underlying neural bases (e.g., Ouellet et al., 2015b; Tremblay et al., 2014). TMS and tDCS have provided evidence for the role of the prefrontal cortex in risky decision-making. TMS research has suggested that disruption of the left lateral prefrontal cortex (LPFC) (Figner et al., 2010) and right DLPFC (e.g., Daria Knoch, Gianotti, et al., 2006; Tulviste & Bachmann, 2019b) increases impulsivity and risk-taking behavior. Furthermore, the fact that the intraparietal sulcus appears to play an important role in risk tolerance in decision-making processes marked by uncertainty (Coutlee et al., 2016) may point in the direction of a pivotal role for frontoparietal decision networks.

Research with tDCS has also shown that right anodal/left cathodal tDCS on DLPFC will increase response confidence (Minati, Campanhã, Critchley, & Boggio, 2012), reduce risk-taking behavior (e.g., Cheng & Lee, 2016; Fecteau, Knoch, et al., 2007), and promote conservative strategies that avoid no-reward risk (Ota, Shinya, & Kudo, 2019). Similarly, anodal tDCS in the left DLPFC paired with cathodal tDCS in the right DLPFC in older participants increases the likelihood that they will choose riskier options (Paulo S Boggio, Campanhã, et al., 2010). In addition, both left anodal/right cathodal tDCS and right anodal/left anodal tDCS montages in the DLPFC can lead to risk-averse behavior (Fecteau, Pascual-Leone, et al., 2007). Conversely, the same setups, when compared to sham stimulation reported reduced risk aversion, leading to selecting riskier options (Ye, Chen, Huang, Wang, Jia, et al., 2015), and this is especially shown in the gain frame (Ye, Chen, Huang, Wang, & Luo, 2015). Moreover, it had an asymmetric effect for the right/left DLPFC when participants faced losses and gains.

Researchers observed that in a loss frame, participants tend more toward risk seeking after receiving the right cathodal stimulation of the DLPFC (D. Huang et al., 2017).

Moreover, participants are less inclined toward risk seeking after receiving anodal tDCS on the DLPFC (Ye et al., 2016a).

But, in a gain frame, participants were more inclined toward risk aversion after left anodal stimulation of the DLPFC (D. Huang et al., 2017) and were less prone to risk aversion after right anodal stimulation of the DLPFC (Ye et al., 2016a). Experiments using focalized unilateral cathodal HD-tDCS of the left DLPFC during the balloon analog risk-taking task (BART) decreased risk-averse decision-making (H. Guo, Zhang, Da, Sheng, & Zhang, 2018a). At the same time, studies with tACS, with a frequency of 6.5 Hz and an intensity of 1 mA, showed that stimulation of the left DLPFC increased risk propensity in BART. But had no effect in the sham and right DLPFC stimulation groups groups (Sela, Kilim, & Lavidor, 2012a) (for an overview, see Table 2).

To date, most studies have focused on modulating the DLPFC. Probably because accessing medial or deeper areas associated with risk, such as the orbitofrontal, has been more difficult. However, TMS not only activates neurons under its magnetic pulse, but activated also their projections. This can generate changes in deep regions, connected to specific cortical areas (Baumgartner, Knoch, Hotz, Eisenegger, & Fehr, 2011). Furthermore, the role of the ventrolateral prefrontal cortex (VLPFC) has not yet been fully explored in decision-making. Even though different studies show that the VLPFC is involved in decision-making when win/loss probabilities are unknown from the beginning. And participants have to be learned together with the task, as a function of gains and losses (e.g., De Ruiter et al., 2009; Ernst et al., 2002; Z. Guo et al., 2013). Researchers found that during decision-making, when they explicitly display relevant information (probability, amount of gain and amount of loss), activation occurs mainly in the DLPFC. Which relates to option evaluation (e.g., Camus et al., 2009; Mohr, Biele, Krugel, et al., 2010). Although, in risky decision-making, emotional arousal occurs

(Mohr, Biele, & Heekeren, 2010) that could interfere with the necessary evaluation of different options in known probability decision-making (Camus et al., 2009). Several studies show that the regulation of DLPFC activity is related to the number of risky decisions: more conservative behavior (less risky decisions) associated with increased activity in the right DLPFC with tDCS (Fecteau, Knoch, et al., 2007). Whereas transient inhibition of this area with TMS has led to increased risky behavior (Knoch, Gianotti, et al., 2006). Researchers interpreted this as evidence for a role of the DLPFC in cognitive control (e.g., Daria Knoch & Fehr, 2007; Pripfl, Neumann, Köhler, & Lamm, 2013a). And other studies corroborated this, since they found that increased activation in DLPFC with tDCS is associated with fewer impulsive behaviors in a go-no-go task, as well as with a safer driving style (e.g., Beeli, Casutt, Baumgartner, & Jäncke, 2008; Beeli, Koeneke, Gasser, & Jancke, 2008).

The somatic marker hypothesis (Damasio, 1996) suggests that the sensations previously associated with the different options resumed decision-making and allows an appropriate decision to be made. For this, it is necessary that the person is able to adequately process the emotions associated with the choice made. Hence, the emotional activation present is important and not so much the explicit cognitive processing. Ventral prefrontal areas associate with this type of gain-loss processing (e.g., O'Doherty, Critchley, Deichmann, & Dolan, 2003; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001). In particular, the higher the VLPFC activity, the better the IGT performance (Ernst et al., 2002). Furthermore, de Ruiter et al. (De Ruiter et al., 2009) demonstrated that pathological players show worse performance in PRLT, associated with hypoactivation of the VLPFC. Several studies have demonstrated the involvement of the ventromedial prefrontal cortex (VMF) in uncertain decision-making (Fellows & Farah, 2007). In addition, previous neuroimaging studies have detected a decrease in VLPFC activation associated with

longitudinal decreases in self-reported risk behavior in adolescence (Qu, Galvan, Fuligni, Lieberman, & Telzer, 2015). In addition, adolescents reduced their risk behavior when their mothers were present, which was associated with greater VLPFC enlistment in making safe decisions (Telzer, Ichien, & Qu, 2015). Moreover, neuroimaging studies have shown strong activation for high-risk conditions (Coaster et al., 2011). Different studies have shown a relationship between VLPFC modulation and negative feedback processing in children and adults (van Leijenhorst, Crone, & Bunge, 2006) and with negative emotions (Vergallito, Riva, Pisoni, & Lauro, 2018). This evidence supports the role of the VLPFC in the regulation of negative emotions that could affect risky decision-making. This emotional activation that may be present in decision-making may promote risky behaviors in a context where we need more controlled processing. This activation would not be detrimental, but necessary, especially when dealing with decisions based on previous experiences. Such notion fits with the idea of the existence of two dissociable neural systems (dorsal and ventral) in the prefrontal cortex (Yamasaki & Labar, 2002). In summary, the emotional activation present in decision-making may promote risky behavior in a context where we require more controlled processing (such as when options need to be evaluated). Whereas the same activation would not be detrimental but necessary in decisions based on previous experiences.

Table 2 Transcranial Electrical Stimulation (tES) studies on Risk Taking behavior.

Reference	**tES technique**	**Area**	**Results**
Aksu, S., Soyata, A. Z., İşçen, P., İçellioğlu, S., Saçar, K. T., Aşçı, G., & Karamürsel, S., 2017	tDCS	Unilateral right DLPFC	tDCS could: ▲ Decision-making and punishment sensitivity in gambling ▼ Reward sensitivity in patients with gambling disorder
Alizadehgoradel J, Nejati V, Sadeghi Movahed F, Imani S, Taherifard M, Mosayebi-Samani M, et al., 2020	tDCS	Bilateral DLPFC	Left anodal/ right cathodal DLPFC tDCS: ▲ Risk-taking, as well as other cognitive functions that they tested.
Bell SB, DeWall N., 2018	-	-	Overall, tDCS reduced risk-taking by a small-medium amount.
Benussi, A., Alberici, A., Cantoni, V., Manenti, R.,	tDCS	Unilateral Right DLPFC	Right Cathodal tDCS: ▲ Iowa Gambling Task scores

Brambilla, M., Dell'Era, V., Borroni, B., 2017			
Reference	**tES technique**	**Area**	**Results**
Boggio, P. S., Campanhã, C., Valasek, C. A., Fecteau, S., Pascual-Leone, A., & Fregni, F., 2010	tDCS	Bilateral DLPFC	Left anodal⁄right cathodal stimulation: ▲ Risk choices.
Boggio, P. S., Zaghi, S., Villani, A. B., Fecteau, S., Pascual-Leone, A., & Fregni, F., 2010	tDCS	Bilateral DLPFC	Chronic marijuana users: ▼ Risky decision-making during sham stimulation. Right anodal and left anodal: ▲ Risk-taking Right anodal stimulation on healthy subjects: ▲ Conservative

Reference	tES technique	Area	Results
Cheng, G. L. F., & Lee, T. M. C., 2016	tDCS	Bilateral Prefrontal cortex (PFC)	left cathodal/right anodal: ▼ Risk-taking
Dantas AM, Sack AT, Bruggen E, Jiao P, Schuhmann T., 2021	tACS/Theta Band /Gamma-band	Unilateral PFC	Theta band: ▼ Risk-taking. ▲ Response time.
Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P. S., & Pascual-Leone, A., 2007	tDCS	Bilateral DLPFC and contralateral DLPFC	Right anodal/left cathodal DLPFC: ▼ Risk-taking.
Fecteau, S., Pascual-Leone, A., Zald, D. H., Liguori, P., Théoret, H., Boggio, P. S., & Fregni, F., 2007	tDCS	Bilateral DLPFC	Right anodal/left cathodal and left anodal/right cathodal: ▲ Risk-averse.

Reference	tES technique	Area	Results
Gilmore, C. S., Dickmann, P. J., Nelson, B. G., Lamberty, G. J., & Lim, K. O., 2018	tDCS	Bilateral DLPFC	Risk task: Right anodal/left cathodal ▼ Risk-taking.
Gorini, A., Lucchiari, C., Russell-Edu, W., & Pravettoni, G., 2014	tDCS	Bilateral DLPFC and contralateral DLPFC	Right anodal/ left cathodal in BART: ▲ conservative. During GDT: Cocaine users: Right anodal ▲ Safe behavior Left anodal ▲ Risk-taking. Non-users: Right anodal

			▲ Safe bets.

Reference	tES technique	Area	Results
Guo, H., Zhang, Z., Da, S., Sheng, X., & Zhang, X., 2018	HD-tDCS	Unilateral Left DLPFC	Left cathodal: ▼ Risk decision-making.
He, Q., Chen, M., Chen, C., Xue, G., Feng, T., & Bechara, A., 2016 (Experiment I)	HD-tDCS	Unilateral left DLPFC	Left DLPFC HD-tDCS: ▲ IGT score ▼ The recency parameter in IGT ▼ Delay discounting rate in the ITC task.
He, Q., Chen, M., Chen, C., Xue, G., Feng, T., & Bechara, A., 2016 (Experiment II)	HD-tDCS	Unilateral Right DLPFC	Right DLPFC HD-tDCS: No significant results
He, Q., Chen, M., Chen, C., Xue, G., Feng, T., & Bechara, A., 2016 (Experiment III)	HD-tDCS	Unilateral left DLPFC.	The two groups did not differ in their second assessment of attentional impulsivity.

Reference	tES technique	Area	Results
Huang, D., Chen, S., Wang, S., Shi, J., Ye, H., Luo, J., & Zheng, H., 2017	tDCS	Bilateral prefrontal cortex	Right cathodal: ▲ Risk seeking in the loss frame. Left anodal in the gain frame: ▲ Risk averse
León JJ, Sánchez-Kuhn A, Fernández-Martín P, Páez-Pérez MA, Thomas C, Datta A, et al., 2020 (Experiment II)	tDCS-	Right Orbitofrontal Cortex (rOFC)	Anodal tDCS: ▲IGT performance in women.
Luo J, Ye H, Zheng H, Chen S, Huang D., 2017	tDCS	Bilateral DLPFC	Right anodal/left cathodal DLPFC tDCS: ▲ Conservative. Right cathodal/left anodal DLPFC tDCS: ▲ Risky.

Reference	tES technique	Area	Results
Minati, L., Campanhã, C., Critchley, H. D., & Boggio, P. S., 2012	tDCS	Bilateral DLPFC	Sham stimulation: ▲ Conservative. Right anodal/left cathodal DLPFC: ▲ Response confidence.
Morales-Quezada L, Cosmo C, Carvalho S, Leite J, Castillo-Saavedra L, Rozisky JR, et al., 2015	tPCS (transcranial pulsed current stimulation)	-	tPCS: Has a modest effect on performance facilitation. No significant differences during BART.
Nejati, V., Salehinejad, M. A., & Nitsche, M. A., 2018	tDCS	left DLPFC (l-DLPFC) and right OFC (r-OFC)	Left anodal DLPFC/ right cathodal OFC and right anodal OFC/left cathodal DLPFC: ▼ Risk-taking

Reference	tES technique	Area	Results
Nejati V, Sarraj Khorrami A, Nitsche MA., 2021	tDCS	Left DLPFC and right vmPFC	Anodal right vmPFC tDCS/cathodal left DLPFC tDCS: ▼ Risk-taking ▼ Delay discounting.
Ota, K., Shinya, M., & Kudo, K., 2019 (Experiment I)	tDCS	Bilateral DLPFC	Right anodal/left cathodal tDCS: ▲ Conservative strategy to avoid no rewards.
Ota, K., Shinya, M., & Kudo, K., 2019 (Experiment II)	tDCS	Bilateral DLPFC and contralateral DLPFC	Stimulation did not affect the response time.
Ouellet, J., McGirr, A., Van den Eynde, F., Jollant, F., Lepage, M., & Berlim, M. T., 2015	tDCS	Orbitofrontal cortex (OFC)	Anodal OFC tDCS): ▲ Advantageous decision-making and cognitive impulse control.

Reference	tES technique	Area	Results
Pripfl, J., Neumann, R., Köhler, U., & Lamm, C., 2013	tDCS	Bilateral DLPFC and contralateral DLPFC	Anodal left/cathodal right in the cold version: ▼ Risk taking. Hot version: Smokers: ▲ Conservative Non-smokers: ▲ Riskier
Russo R, Twyman P, Cooper NR, Fitzgerald PB, Wallace D., 2017 (Experiment I)	tDCS	Bilateral DLPFC	Right anodal/left cathodal DLPFC tDCS: ▲ Risk-taking compared to left anodal/right cathodal DLPFC tDCS.

Reference	tES technique	Area	Results
Russo R, Twyman P, Cooper NR, Fitzgerald PB, Wallace D., 2017 (Experiment II)	tDCS	Bilateral DLPFC and Unilateral DLPFC.	No effect for bilateral and unilateral stimulation during BART.
Sela, T., Kilim, A., Lavidor, M., 2012	tACS	Bilateral DLPFC	Left tACS stimulation: ▲ Risk
Soyata AZ, Aksu S, Woods AJ, İşçen P, Saçar KT, Karamürsel S., 2019	tDCS	Bilateral DLPFC	DLPFC tDCS: ▲ Advantageous decision-making and cognitive flexibility in gambling disorders.
Wang Y, Ma N, He X, Li N, Wei Z, Yang L, et al., 2017	HD-tDCS	Rostral anterior cingulate cortex and ventral medial prefrontal cortex	Cathodal HD-tDCS: ▼ Performance in the IGT.

		(rACC/vmPFC) and the posterior cingulate cortex (PCC)	
Reference	**tES technique**	**Area**	**Results**
Weber, M. J., Messing, S. B., Rao, H., Detre, J. A., & Thompson-Schill, S. L., 2014	tDCS	Bilateral DLPFC	tDCS: ▼Resting blood perfusion in the orbitofrontal cortex and the right caudate. ▲Task-related activity in the right DLPFC and anterior cingulate cortex (ACC) in response to losses but not win or increasing risk.
Wen Y, Turel O, Peng Y, Lv C, He Q., 2019, (Experiment I)	HD-tDCS-	Unilateral left DLPFC	HD-tDCS cathodal left DLPFC: ▼ In attitude and intention scores toward risk-behavior.
Wen Y, Turel O, Peng Y, Lv C, He Q., 2019, (Experiment II)	HD-tDCS-	Unilateral left DLPFC	The decrease in attitude toward risk was larger in the HD-tDCS stimulation group compared to sham.

Reference	tES technique	Area	Results
Xiong G, She Z, Zhao J, Zhang H., 2021	tDCS	Unilateral right DLPFC	Anodal right DLPFC: ▲ Preference for ambiguity. No differences in risk choices.
Yang X, Gao M, Shi J, Ye H, Chen S., 2017	tDCS	Unilateral DLPFC and OFC	Right anodal/left Cathodal DLPFC tDCS: ▲ Risk preference. Right anodal/left Cathodal OFC tDCS: ▼ Preference for ambiguity. In the reversed tDCS stimulation, the same reversed effect was found.
Yang X, Lin Y, Gao M, Jin X., 2018	tDCS	Unilateral DLPFC	Right anodal/left Cathodal DLPFC tDCS. ▲ Search duration. ▲ Risk seeking. Mainly driven in female subjects.

Reference	tES technique	Area	Results
Ye, H., Chen, S., Huang, D., Wang, S., Jia, Y., & Luo, J., 2015	tDCS	Bilateral DLPFC	Right anodal/Left cathodal tDCS: ▼ Risk aversion
Ye, H., Chen, S., Huang, D., Wang, S., & Luo, J., 2015	tDCS	Bilateral DLPFC	Right anodal/left cathodal: In gain frame: ▲ Risk options. In the loss frame: ▲ Safe options. Right anodal/left cathodal: ▼ Weighted risk aversion.
Ye, H., Huang, D., Wang, S., Zheng, H., Luo, J., & Chen, S., 2016	tDCS	Unilateral DLPFC	Right anodal DLPFC in the gain frame: ▼ Risk aversion. In the loss frame:

			▲ Risk aversion
Reference	**tES technique**	**Area**	**Results**
Zheng H, Wang S, Guo W, Chen S, Luo J, Ye H, et al., 2017 (Experiment I)	tDCS	Unilateral right DLPFC	Anodal rDLPFC tDCS: ▲ Conservative behavior.
Zheng H, Wang S, Guo W, Chen S, Luo J, Ye H, et al., 2017 (Experiment II)	tDCS	Unilateral right DLPFC	Confirmed that the results of Experiment I were due to the stimulation of the right DLPFC.

*NIBS: non-invasive brain stimulation, tDCS: transcranial direct current stimulation, HD-tDCS: High-Definition transcranial direct current stimulation, tACS: transcranial alternating current stimulation, DLPFC: dorsolateral prefrontal cortex, OFC: orbitofrontal cortex, R: right, L: left, PFC: the prefrontal cortex.

From the studies that have used some type of NIBS technique to study risk decision-making, we have extracted information: tasks, NIBS, protocols, intensity, localization method, target area, etc.

3.1.1 NIBS used for each study

Most of the articles dealing with risk decision-making used tDCS compared to TMS. Only thirteen studies and one poster used TMS (see Table 4), while thirty-seven used some form of tES (see Table 2 and 4).

3.1.2 Timing and protocol

The timing of the task, as well as the procedure, followed a similar structure in almost all studies. They administered all tasks after the stimulation had lasted at least 3-10 minutes. Some studies performed the task before and after stimulation as a control measure.

As for TMS, studies used different protocols, as well as timing. Cho SS et al., 2010 used both iTBS and cTBS protocols in their sample and performed the task during stimulation (Cho et al., 2010). Coutlee, D. et al., 2016 used a paired rTMS protocol with control. They administered the task after the 15 min of stimulation (Coutlee et al., 2016). In contrast, Kapogiannis et al., 2011 used TMS paired with medication. They performed the task before and after stimulation, as well as medication (Kapogiannis et al., 2011). Knoch et al., 2006 used a rTMS protocol as well and in their case, they administered the task after stimulation (Knoch, Gianotti, et al., 2006). Obeso et al., 2021 used a cTBS protocol administering the task after the 40 min of stimulation (Obeso, Herrero, Ligneul, Rothwell, & Jahanshahi, 2021). Studer et al., 2014 followed a cTBS protocol, of only 30 seconds, as well and had participants perform the task after stimulation, however, they also had a training session prior to stimulation (Studer, Cen, & Walsh, 2014). They used cTBS consisting of three pulses at 50 Hz, repeated at 5 Hz (Y. Z. Huang et al., 2005), for 30 seconds, which was equivalent to 450 pulses in each hemisphere.

Tovar-Perdomo et al., 2017 used a high frequency TMS protocol and participants have to perform the task before and after stimulation (Tovar-Perdomo, McGirr, Van den Eynde, Rodrigues dos Santos, & Berlim, 2017). Tulviste & Bachman, 2019 employed low frequency TMS for only 6 min following previous studies (Fitzgerald, Fountain, & Daskalakis, 2006) also with practice before stimulation and task after stimulation (Tulviste & Bachmann, 2019a). Wang et al., 2021 used iTBS as well as 20 Hz stimulation (L. Wang et al., 2021). Wu et al., 2021 used an iTBS protocol by having participants perform the task before and after the last stimulation session (Wu et al., 2021).Yang et al., 2018 also used the iTBS protocol and had the task administered before and after stimulation (C. C. Yang, Khalifa, Lankappa, & Völlm, 2018). Calderon-Moctezuma et al., 2021 did 15 sessions of 50 pulses each of rTMS, performing the task at the end of stimulation. Other studies performed the assessments before and after stimulation (e.g., Kapogiannis et al., 2011; Tovar-Perdomo et al., 2017; Wu et al., 2021). Other studies applied rTMS stimulation for 15 min, within safety guidelines (Wassermann, 1998), with effects lasting several minutes after stimulation (Robertson et al., 2003). Guillaume et al., 2018 used high frequency rTMS, and they performed the tasks before and after stimulation.

It is important to note that most studies had one or two stimulation sessions. The studies that had a variety of sessions were those dealing with a clinical sample.

Regarding tDCS, although the duration of stimulation varied, it never lasted less than 10 min, following tDCS safety guidelines, and taking into account the intensity used for each study (e.g. A. Antal et al., 2017; Iyer et al., 2005; M. A. Nitsche et al., 2003; Poreisz et al., 2007). Most, followed the anodal/cathodal setup, being unilateral or bilateral for the focused area. And as in the TMS studies, the timing of the tasks was before and after stimulation, after simulation, or during stimulation.

3.1.3 Intensity

Intensity varied whether the study used tDCS or TMS techniques. Ten studies and one poster used TMS. Twenty-four studies used transcranial electrical stimulation (tES), either tDCS, HD-tDCS, or tACS.

3.1.3.1 TMS. The intensity varied depending on the type of TMS technique used. Cho et al., 2010 used an intensity of 80% of active motor threshold (AMT) for cTBS and iTBS (Cho et al., 2010). Coutlee et al., 2016 used an intensity of 100% of resting motor threshold for 1 Hz "off-line" rTMS (Coutlee et al., 2016). Kapogiannis et al., 2011 used an intensity for the conditioning pulse set at 65%, and the test pulse at 120% (Kapogiannis et al., 2011) for paired TMS. Knoch et al., 2006 used a rTMS stimulation intensity of 100% of the individual resting motor threshold (MT) (Knoch, Gianotti, et al., 2006) following guidelines. Obeso et al., 2021 used cTBS at an intensity of 80% of the AMT (Obeso et al., 2021). Studer et al., 2014 used cTBS with a stimulation intensity set at 40% of maximum machine power (Studer et al., 2014). Tovar-Perdomo et al., 2017 used HF-rTMS at 120% of MT at rest (Tovar-Perdomo et al., 2017). Tulviste & Bachmann 2019 used low-frequency rTMS with stimulation intensity adjusted to 100% of individual MT (Tulviste & Bachmann, 2019a). Wu et al., 2021 used iTBS at an intensity of 80% of MT (Wu et al., 2021). Yang et al., 2018 used iTBS at an intensity of 80% of the RMT (C. C. Yang et al., 2018). Calderon-Moctezuma et al., 2021 used rTMS at an intensity of 100% of TM (Calderón-Moctezuma et al., 2021). Guillaume et al., 2018 used HF-rTMS at an intensity of 110% of MT (Guillaume et al., 2018).

All TMS studies referenced previous work to justify their intensity as well as frequency. Coutlee, C. et al., 2016 used 900-pulse trains of 1 Hz rTMS ("off-line"). However, Coutlee, C. et al., 2013 only stated that they used rTMS as it was a poster. Knoch, D. et al., 2006 used a 1 Hz rTMS with 900 pulses during their experiment. Studer, B. et al., 2014 used an offline cTBS consisting of three pulses at 50 Hz repeated at 5 Hz 450 pulse-train. And other studies using

cTBS and iTBS used the same intensity (e.g., Obeso et al., 2021; Wu et al., 2021) referencing earlier work (Y. Z. Huang et al., 2005). Tulviste, J. & Bachmann, T., 2019 used a low-frequency (offline) rTMS with 1 Hz 360 pulse trains. One study with rTMS used a frequency of 5 Hz (Calderón-Moctezuma et al., 2021). But paired TMS used a test pulse intensity of 120% (Kapogiannis et al., 2011) referencing the authors' previous work. One study, which used high-frequency rTMS used an intensity of 10 Hz (Tovar-Perdomo et al., 2017) and, like most studies, referenced previous articles.

3.1.3.2 tDCS. Most studies used an intensity of 2 mA. In fact, twenty articles used an intensity of 2 mA, two used 1 mA, one being the tACS study. Ten papers used 1.5 mA. Finally, a single article used 0.45 mA (see Table 4).

3.1.4 Targeted area

Almost all the tES studies targeted the DLPFC, either left, right, or both. Thus, there is a body of evidence that the fact that the DLPFC is involved in risk decision-making. However, a few studies target other areas, such as the right orbitofrontal cortex, orbitofrontal cortex, rostral anterior cingulate cortex, ventromedial prefrontal cortex, and posterior cingulate cortex. With TMS, however, they also target the angular gyrus, intraparietal sulcus, inferior frontal junction, dorsomedial prefrontal cortex, left DLPFC and right DLPFC, in relation to risk decision-making.

3.1.5 Localization Method

When locating the target area, TMS and tES used different methods. In general, the articles using tES (tDCS, HD-tDCS, tACS, etc.) mainly used the International EEG Position System. Most used the International EEG Position System 10-20, while only a few used the International EEG Position System 10-10.

However, as for the studies that used any type of TMS protocol, almost all obtained, prior to stimulation, anatomical MRI images to reach the target area. Only one used the international EEG system (Obeso et al., 2021). Another study noted that they applied stimulation at the F3 position (Tovar-Perdomo et al., 2017). However, one study used the 5-cm method (C. C. Yang et al., 2018) proposed for treatments of patients with depression (Pascual-Leone, Rubio, Pallardó, & Catalá, 1996). Knoch, D. et al., 2006 localized the target area with T1-weighted magnetic resonance imaging (MRI) and vitamin E capsules placed in the previously marked TMS target positions. Tulviste, J. & Bachmann, T., 2019 used a Beam F3 system (Beam, Borckardt, Reeves, & George, 2009) that allowed localization of the DLPFC as structural brain scans were not available. This system took into account the variability of skull size.

3.1.6 Tasks

Researchers use various tasks to measure risk (see Table 3). Because we focused on risky decision-making, we only examined tasks that, according to the literature, specifically measure risk taking. We did not include any tasks that measured other cognitive functions. However, it is important to keep in mind that there is no consensus on which tasks/tools to use when studying risky decision-making. A large percentage of articles used already well-established tasks such as the BART (Lejuez et al., 2002), the Risk Task (Rogers, Owen, et al., 1999), Iowa Gambling Task (Bechara et al., 1994). However, there does not seem to be an agreement on which tasks measure risk in the most efficient way (see Table 3). This lack of consensus poses a problem when investigating risk decision-making.

Here we will describe the most used tasks.

The **Risk Task (RT)**, also known as the gambling paradigm (Rogers, Owen, et al., 1999), aims to give a measure of risky decision-making with few requirements in terms of strategy or working memory (D. Knoch et al., 2006). It consists of 100 trials, presented through six horizontally aligned, pink or blue boxes. The proportion of colors varies from trial to trial.

Researchers instructed the participants to choose in which box was hidden the winning tile. rTMS in the right DLPFC resulted in an increase in riskier choices (D. Knoch et al., 2006) during RT. In addition, left anodal left/cathodal right and right anodal right/cathodal left tDCS in the DLPFC resulted in increased risky choices for left anodal/right anodal rTMS during RT in an older sample. This showed behavioral effects contrary to those seen in a young sample (Boggio et al., 2010). The same combination resulted in fewer risky decisions in chronic marijuana users in the sham group. However, right anodal and left anodal tDCS of DLPFC induced more risky behaviors during RT (Boggio et al., 2010). Moreover, after right anodal stimulation of DLPFC, there was an increase in conservative behavior in healthy subjects while performing RT (Paulo S Boggio, Zaghi, et al., 2010). Anodal right anodal/left cathodal tDCS in DLPFC also decreased risk taking during RT (S. Fecteau et al., 2007). The same version of the task with red and blue box color, combined with the Balloon Analog Risk Task (BART) and right anodal/cathodal tDCS in the DLPFC, resulted in decreased risk-taking in the BART and RT. These results were in a sample of -clinically impulsive-veterans (Gilmore, Dickmann, Nelson, Lamberty, & Lim, 2018).

The **Iowa Gambling Task (IGT)** is a computerized card game. It measures risk-taking, sensitivity to reward and loss, and the tendency to act based on immediate future expectations, ignoring long-term outcomes. An adapted version of the IGT combined with cathodal and anodal tDCS over the right DLPFC resulted in increased IGT scores under cathodal stimulation of the right DLPFC for Parkinson's patients. Hence, decreasing risky decision-making (Benussi et al., 2017). The same task, combined with rTMS (5 Hz) in the dorsomedial prefrontal cortex (DMPFC) resulted in cognitive improvement. And influencing decision making-including risky decision making-while decreasing the severity of borderline personality disorder (BPD) symptomatology. Which they measured through the Borderline Symptoms List (BSL), Clinical Global Impression Scale for BPD (CGI-BPD), Borderline Evaluation of Severity over Time

(BEST), Hamilton Depression Rating Scale (HDRS), Hamilton Anxiety Rating Scale (HARS), and Barratt's Impulsiveness Scale (BIS). They determined neuropsychological effects by using a stop-signal task (SST), the Wisconsin Card Sorting Test (WCST), and the IGT (Calderón-Moctezuma et al., 2021). IGT combined with the go-no-go task (measuring inhibitory responding) and high-frequency rTMS over the left DLPFC resulted in better inhibitory control in the go-no-go task. Also in improved BIS cognitive impulsivity scale, and increased good choices during IGT in patients suffering from Bulimia Nervosa (BN) (Guillaume et al., 2018). IGT with the Slot Machine Simulation task -which is a three-barrel simulation of a slot machine-along with paired pulse TMS in the motor cortex and two different medications (pramipexole and levodopa) resulted in increased risk behavior during the IGT task. This happened in patients diagnosed with Parkinson's when taking medication. In addition, pramipexole increased risk behavior in patients who showed a lower paired TMS reaction during low expectancy. However, it is important to note that this study focused more on the effect of medication on risk taking in Parkinson's patients than on TMS (Kapogiannis et al., 2011). Participants who received cTBS in the left and right DLPFC showed a decrease in direct accumulation of additional information in the IGT. Whereas cTBS in the right DLPFC resulted in increased sensitivity to reinforcement leading to risk avoidance in the IGT (Obeso et al., 2021). Another study using a battery of tasks-including the IGT, BART, etc. -combined with Hf- rTMS in the left DLPFC showed improvement for depression and anxiety in patients diagnosed with major depressive disorder (MDD). But no improvement for decision-making (Tovar-Perdomo et al., 2017). Other studies using IGT in patients suffering from schizophrenia have also shown that iTBS in the left DLPFC improved decision-making. They showed an increased activation in high-risk conditions during IGT, of theta spectrum power in the FPZ, FZ, FCZ, and CZ (Wu et al., 2021). In a preliminary study, another combination of task-including IGT- with right DLPFC anodal tDCS showed improved decision-making, sensitivity

to punishment, and decreased sensitivity to reward in participants suffering from gambling disorder (Aksu et al., 2017). Another gambling disorder study, right anodal/left anodal tDCS on DLPFC using IGT and WCST, showed increased cognitive flexibility and advantageous decision-making during tasks in gambling disorders (Soyata et al., 2019). IGT paired with the intertemporal choice task (ICT)-to measure delay discounting-and combined with anodal HD-tDCS on the left DLPFC showed an increase in the IGT score. And a decrease in the delay discounting rate for the IGT, thus decreasing risk taking (Q. He et al., 2016). A study comparing the sexes showed that anodal tDCS in the right orbitofrontal cortex (rOFC) enhanced risky decision-making in women during IGT compared to men (León et al., 2020). Anodal tDCS in the orbitofrontal cortex (OFC) enhanced advantageous decision-making during IGT and BART (fewer risky choices) and cognitive impulse control during the color Stroop, Stop signal task, but not on attentional levels during the continuous performance task (Ouellet et al., 2015a). Cathodal HD-tDCS in rostral anterior cingulate cortex, ventromedial prefrontal cortex (rACC/vmPFC), and posterior cingulate cortex (PCC) decreased performance during the IGT but not in the RDT (Y. Wang et al., 2017).

The **Risky-Gains Task (RGT)** (M. P. Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003) and the **Balloon Analog Risk Task (BART)** (Lejuez et al., 2002) are two well-established tasks. During the RGT, it asks participants to make judgments rapidly to decide whether they would take a reward or wait for a larger reward that has a risk of punishment. The BART consists of a balloon that participants inflate, with a burst point randomly set between pumps 1 and 128. A combination of both tasks and left cathodal/right anodal in the PFC resulted in reduced risk taking in a rush context and influenced by baseline impulsivity (Cheng & Lee, 2016). Right anodal/left cathodal and left anodal/right anodal tDCS in the DLPFC produced more risk aversion during BART (Fecteau, Pascual-Leone, et al., 2007). Cathodal HD-tDCS over the left DLPFC resulted in less risk-averse decision-making during BART (H. Guo et al.,

2018a). tACS stimulation over the left DLPFC increased risk during BART. They used a modified version of BART (Sela, Kilim, & Lavidor, 2012b). tDCS over anodal right DLPFC/cathodal left DLPFC increased task-related activity in the right DLPFC and ACC to losses, but did not increase risk during BART. tDCS in this study, however, decreased connectivity between the right ACC and the brain (Weber, Messing, Rao, Detre, & Thompson-Schill, 2014). The tPCS showed no significant differences between active and sham stimulation during BART (total points gained, the mean number of pumps) (Morales-Quezada et al., 2015). However, DLPFC right anodal/left anodal tDCS had increased risk-taking compared to left anodal/right cathodal tDCS during a battery of risk tasks (IOWA, BART, Cambridge Task) (Russo, Twyman, Cooper, Fitzgerald, & Wallace, 2017). Anodal left/cathodal right DLPFC tDCS improved performance on the risk-taking task, as well as a variety of other cognitive functions tested on a variety of tasks (N-Back, Go/No-Go, WCST, BART) (Alizadehgoradel et al., 2020).

Table 3 Used risk-taking tasks in NIBS studies. The main text includes descriptions of the task.

Risk-taking task	**Measure type**	**Description**
Roulette Betting Task (modified)	Behavioral Task	Measures sensitive risk, taking into consideration the risk adjustments based on the chances of winning.
Risk Task	Behavioral Task	Assesses risk decision-making involving little strategy and working memory.
Self-Paced Choices (Uncertain/Certain)	Behavioral Task	Measures of risk with uncertain/certain options in a self-paced manner.

Game of Skill Task-Minimum TB®	Behavioral Task	Blends fine motor action with elements of risk. Measures risk behavior while balancing gain or lose potential.
Iowa Gambling Task	Behavioral Task	Assess the propensity to act on immediate prospects and disregard lasting consequences.
Slot Machine simulation Task	Behavioral Task	Measures gambling and reward expectation.
Risky-gains task	Behavioral Task	Measures inclination for risky behavior, compromising large losses for large gains.
Balloon Analogue Risk Task	Behavioral Task	Assesses risk behavior. It correlates with measures of sensation seeking, impulsivity, and deficiencies in behavioral constraint.
Game of Dice Task	Behavioral Task	Measures risk-taking in a context of reinforcement and punishment.
Multiple Price List	Behavioral Task	Assessment of the degree of risk aversion simpler and clearer.
Gambling task	Behavioral Task	Assess decision-making in Parkinson's patients in a gut feeling context.
Go/No Go Task	Behavioral Task	Measures inhibitory control.
Tower of Hanoi	Behavioral Task	To assess cognitive planning, problem-solving, and attention shifting.

Delay Discounting Task	Behavioral Task	Measures of risk decision-making, subjective value judgments, and ability to delay gratification.
Chocolate delay discounting task	Behavioral Task	Measures of risk decision-making, subjective value judgments, and ability to delay gratification.
Selective timing task under risk	Behavioral Task	Measures risk-taking strategy.
Columbian Card Task (Hot and Cold)	Behavioral Task	Hot CCT assesses risk-taking influenced by affective processes. Cold CCT risk-taking by deliberative processes.
Paired Lottery Choices	Behavioral Task	Measures the degrees of risk aversion without requiring strategy or working memory.
Risk Measurement table	Behavioral Task	Assessment of risk preferences without requiring working memory or strategy.
Risk Decision Task	Behavioral Task	Measures risk-decision. Participants know the possibility of winning or losing.
Adjusting Amount Task	Behavioral Task	Measures of risk decision-making, subjective value judgments, and ability to delay gratification.
The search game	Behavioral Task	Measures risk attitude
Two colour-choice Task	Behavioral Task	Measures preferences for risk and ambiguous choices.

Information Sampling task	Behavioral Task	Measures cognitive impulsivity
Maastricht Gambling task	Behavioral Task	Measures risk decision-making
Risk/ambiguity decision-making task	Behavioral Task	Measures preferences for pure risk and ambiguity.
Risk Game	Behavioral Task	Measures risk decision-making.
Twelve risky scenarios	Behavioral measures	Measures attitude towards risk

3.1.7 Individual differences

Of the articles reviewed, those dealing with a clinical sample took into account individual differences before, during and after testing. Especially studies that dealt with gambling disorders (e.g., Aksu et al., 2017; Soyata et al., 2019), Parkinson's (Benussi et al., 2017), schizophrenia (Wu et al., 2021), bulimia nervosa (BN) (Guillaume et al., 2018), MDD (Tovar-Perdomo et al., 2017), BPD (Calderón-Moctezuma et al., 2021), veterans (Gilmore et al., 2018), cocaine users (Gorini, Lucchiari, Russell-Edu, & Pravettoni, 2014), and smokers (Pripfl, Neumann, Köhler, & Lamm, 2013b). All took into account impulsivity levels, depression levels, psychological assessments, anxiety, etc. However, because they were either dealing with a clinically impulsive sample or comparing it to a control, those individual differences did not show any significance in how it affected stimulation.

Some studies pointed to the role of individual differences in terms of risk-taking when dealing with a healthy sample. Coutlee, C.G., et al., 2016 explained that they assessed individual differences by making strong experimental controls. The reason for this control was previous evidence pointing to the relationship of the intraparietal sulcus to individual differences in risk propensity (Huettel, Stowe, Gordon, Warner, & Platt, 2006). Fecteau, S. et al., 2007 also justified the selection of a certain dependent measure for the BART, as it aims to circumvent the limitations of individual differences that may occur in burst trials (e.g., Aklin, Lejuez,

Zvolensky, Kahler, & Gwadz, 2005; Lejuez et al., 2002). This was also used as a justification in Weber, M.J. et al., 2014. And it was also pointed out by Fecteau S et al., 2007. They chose as dependent measures for BART, the adjusted mean pumps, as it is believed to avoid the influences of individual differences that occur in trials where there is a burst.

To address individual differences and personality, Guo, H. et al., 2018 tested emotional state, impulsivity, and sensation seeking as between-subjects control variables. They used the Positive Affect and Negative Affect Scale (PANAS), the behavioral Inhibition System and Behavioral Approach System scale (BIS/BAS), and the Sensation Seeking Scale- 5 (SSS). Pripfl, J. et al., 2013 explored the role of individual differences by selecting samples of smokers and non-smokers, leading to the conclusion that they should be considered in decision-making. Gilmore CS et al., 2018 also used the Barrat Impulsiveness Scale (BIS-11) to measure self-reported impulsivity, as well as other studies (Q. He et al., 2016). The BIS-11 is a 30-item self-report that describes impulsive and non-impulsive behavior. Higher scores translate into higher impulsivity. Studies that focused solely on clinical samples did take into account clinical assessments or even psychological assessment (e.g., Calderón-Moctezuma et al., 2021; Tovar-Perdomo et al., 2017), however, it did not influence the results.

Sela, T. et al., 2012 examined whether individual differences (including gender and trait motivation) could influence tACS performance and effectiveness. However, they did not find that it affected performance in their study. Other studies measured baseline impulsivity, showing that this baseline impulsivity did influence the effect of NIBS on reducing risk taking (Cheng & Lee, 2016). Leon JJ et al., 2020 discuss the need for individualized NIBS protocols, noting that there are indeed individual differences that have an effect on tDCS outcomes.

3.1.8 Gender differences

Some articles analyzed gender bias in risk decision-making with respect to NIBS (e.g., Boggio, Campanhã, et al., 2010; Boggio, Zaghi, et al., 2010; Fecteau, Knoch, et al., 2007; Fecteau,

Pascual-Leone, et al., 2007; H. Guo et al., 2018a; Sela et al., 2012a). Almost no studies found significant differences regarding gender.

Fecteau, S. et al., 2007 mentioned that the differences found between their study and previous studies could stem from a gender difference (Shirley Fecteau, Pascual-Leone, et al., 2007). Fecteau, S. et al., 2007 reached the same conclusion. These authors pointed out the fact that they cannot rule out variables such as gender differences, as it could influence the lateralized effect of DLPFC. Boggio, P.S. et al., 2010 compared the data from the referenced study with previous data from healthy participants (Fecteau, Knoch, et al., 2007). They found a significant difference in age between the two groups when they combined the data from the subgroups. One study, however, did focus on gender differences and found that anodal tDCS in rOFC increased risk taking in women (León et al., 2020). In addition, this study pointed to the importance of individual differences in NIBS protocols.

Another study also found that participants after receiving right anodal/left cathodal DLPFC tDCS stimulation changed their attitude toward risk. In this particular case, they sought a higher acceptable point. Hence, to receive a higher benefit. This effect was mainly significant in female participants, which means that women increased their acceptance point (X. Yang, Lin, Gao, & Jin, 2018).

Table 4 Description of the research in risk decision-making with TMS

Reference	TMS Protocol	Targeted Area	Main results
Calderón-Moctezuma AR, Reyes-López J V., Rodríguez-Valdés R, Barbosa-Luna M, Ricardo-Garcell J, Espino-Cortés M, et al., 2021	rTMS-Sham- 100% of MT	Dorsomedial prefrontal cortex (DMPFC)	rTMS DMPFC: Cognitive ▲ In decision-making (risk also). ▼BPD symptomatology.
Cho SS, Ko JH, Pellecchia G, Van Eimeren T, Cilia R, Strafella AP., 2010	iTBS/cTBS-Sham-80% of the active motor threshold	Right DLPFC	cTBS right DLPFC: ▼ Impulsive decision-making.
Coutlee, C., Kiyonaga, A., Korb, F., et al., 2013	rTMS	Frontal and parietal cortex	Preliminary. Parietal TMS ▼Risky decision-making.

Reference	TMS Protocol	Targeted Area	Main results
Coutlee, C. G., Kiyonaga, A., Korb, F. M., Huettel, S. A., & Egner, T., 2016	rTMS-Control-1Hz- 100% of resting motor threshold	Intraparietal sulcus (IPS) and the inferior frontal junction (IFJ) and interhemispheric fissure at the vertex as control	Stimulation of the IFJ: ▼ Decision times. Stimulation of the IPS suppressed risk-taking: ▼ Risks ▼ Expected rewards.
Guillaume S, Gay A, Jaussent I, Sigaud T, Billard S, Attal J, et al., 2018	High frequency rTMS-Sham- 110% of MT	Left DLPFC	Within-group: ▲ Inhibitory control in the go/no-go task and the BIS cognitive impulsivity subscale. rTMS group: ▲ Good choices on the Iowa gambling task.
Kapogiannis D, Mooshagian E, Campion P, Grafman J,	Paired TMS-Control-conditioning pulse set at 65%, and the test pulse at 120%	Motor cortex	Reward expectation modulated the response to paired TMS (controls), not in unmedicated patients.

Zimmermann TJ, Ladt KC, et al., 2011			One dose of pramipexole restored this effect of reward: By ▲ the paired TMS response amplitude during low expectation. Pramipexole and levodopa: ▲ Risk-taking behavior on the IGT. Pramipexole: ▲ Risk-taking behavior in patients with lower paired TMS response amplitude during low expectation.
Knoch, D., Gianotti, L. R. R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., & Brugger, P., 2006	rTMS-Sham-100% of MT	Right and left prefrontal Cortex	rTMS of right DLPFC: ▲ Risky decision-making.

Reference	TMS Protocol	Targeted Area	Main results
Obeso I, Herrero MT, Ligneul R, Rothwell JC, Jahanshahi M. A., 2021	cTBS-Sham- 80% of the AMT	Right and left DLPFC	cTBS to the left and right DLPFC: ▼Directed exploration on the IGT compared to sham. Right DLPFC cTBS: ▲ Sensitivity to reinforcers, which resulted in the avoidance of risky choices ▲ Advantageous choices.
Studer, B., Cen, D., & Walsh, V., 2014	rTMS (cTBS)-Sham/Control- 40% of maximum machine output	Angular Gyrus (AG) and Premotoral cortex (PMC) as the control condition	cTBS of AG affected decision-making tasks requiring visuospatial attention by disturbing the relationship between decision latencies and the probability of winning/losing.
Tovar-Perdomo S, McGirr A, Van den Eynde F,	HF-rTMS-120% of the resting MT	Left DLPFC	Hf-rTMS: Improved depression and anxiety scores No improvement in decision-making scores.

Rodrigues dos Santos N, Berlim MT., 2017			

Reference	**TMS Protocol**	**Targeted Area**	**Main results**
Tulviste, J., Bachmann, T., 2019	low-frequency rTMS-Sham-100% of individual MT	Right DLPFC	rTMS stimulation to the right DLPFC increased risk-taking: ▲ Frequency of ceiling hits, compared to sham.
Wang L, Wu X, Ji G-J, Xiao G, Xu F, Yan Y, et al., 2021	iTBS/20 Hz Stimulation-Sham	Left DLPFC	iTBS and 20 Hz: ▲ In safe options ▼ In risky options iTBS stimulation: ▲ Subjects' use of positive feedback in the GDT and RGT

			iTBS group had a stronger risk reduction following negative feedback
Reference	**TMS Protocol**	**Targeted Area**	**Main results**
Wu Y, Wang L, Yu F, Ji GJ, Xiao G, Feifei X, et al., 2021	iTBS-Sham- 80% of the RMT	Left DLPFC	Under high-risk conditions left DLPFC iTBS: ▲ Activation of the theta spectrum power in the FPZ, FZ, FCZ, and CZ. Long-term iTBS: ▲ Decision-making ability of schizophrenia.
Yang CC, Khalifa N, Lankappa S, Völlm B., 2018	iTBS-Sham- 80% of the RMT	Left DLPFC	iTBS over left DLPFC had no significant changes compared to sham in cognitive impulsivity.

4. Emotional Inference on working memory

WM is the capacity that allows us to temporarily maintain information that we recently perceived or retrieve long-term memory when this information is no longer around us (Quak, London, & Talsma, 2015). It is therefore an internal representation of this information. Working memory can be retained a certain number of times (from seconds to minutes) through repetition, and can be manipulated as a means to direct our behavior and achieve a goal. It is indispensable in our daily lives as it is the basis of our cognition in a multitude of aspects: reasoning, language comprehension, planning, and special planning among others (D'Esposito et al., 2006).

Research has identified the DLPFC as an area that combines emotion and cognition (Song et al., 2017). Thus, it is necessary with regard to response inhibition, especially after refusals (Goldstein et al., 2007), and for the updating and support of emotional information needed in working memory (e.g., J. R. Gray, Braver, & Raichle, 2002b; Perlstein, Elbert, & Stenger, 2002). Furthermore, through selective attentional mechanisms, the left DLPFC is involved in resolving conflicts between stimuli (Nee, Wager, & Jonides, 2007). Besides, there also appears to be a connection between the DLPFC and the dACC. Thus, dACC connectivity predicts DLPFC activation, especially in trials dealing with cognitive conflicts (Mohanty et al., 2007).

Research points to the fact that executive control of information processing and temporal management of information recently received or retrieved from long-term memory depends on a network that includes a variety of brain regions (D'Esposito et al., 2006). Studies, with humans and other species, point to the crucial role of the prefrontal cortex in the proper functioning of that network, and thus in working memory, organization, and executive control of our behavior (Fuster, 2009). It is crucial to keep in mind that the prefrontal cortex encompasses one third of the neocortex, and communicates with almost all cortical and

subcortical regions. This gives it a unique position to control and manipulate different cognitive processes (Guse et al., 2010).

Executive functions refer to a set of higher cognitive processes such as problem-solving, mental planning, behavioral inhibition, action control, etc. And it is the main function of the executive system to motorize the processes and regulate them according to the demands of the environment. WM, however, constitutes the storage of limited and dynamic information mandatory for the functioning of higher cognitive functions mediated by the prefrontal cortex. The brain area that maintains these functions is the prefrontal cortex, so brain stimulation of this area might improve its performance.

This is the reasoning on which different researchers base their investigations. However, the results, for the most part, are not highly significant. Hence, the efficacy of TMS and tDCS as tools to improve executive functions remains a challenge. Some classic tasks for assessing executive functions (e.g., Trail Making Test (TMT), Stroop task, Tower of Hanoi, Tower of London, WCST, go/no-go paradigm) assess the effects of TMS and tDCS on a variety of executive components.

Previous research studied the performance of healthy subjects on an analogical reasoning task using rTMS on the left DLPFC. This produced a higher speed of execution (shorter response time), although the accuracy of responses was unchanged (Boroojerdi et al., 2001).

Also, in behavioral planning, studies showed that stimulation with tDCS on the DLPFC in healthy subjects during the Tower of London improved their task planning, up to one year (Dockery, Hueckel-Weng, Birbaumer, & Plewnia, 2009). Stimulation of the left DLPFC facilitated cognitive flexibility and conceptual tracking (assessed using the TMT-B) (Moser et al., 2002). In addition, another study assessed performance on the Stroop task and WCST after high-frequency rTMS on the left DLPFC. They found no effect on performance (Wagner, Rihs, Mosimann, Fisch, & Schlaepfer, 2006). However, other studies did find improved

performance following a Stroop-like task in healthy subjects with rTMS on the left DLPFC (M.-A. Vanderhasselt, De Raedt, Baeken, Leyman, & D'haenen, 2006). In addition, five sessions with tDCS on the left DLPFC in patients with depression showed improvement in this task (Fregni, Boggio, Nitsche, Rigonatti, & Pascual-Leone, 2006).

In addition, other studies showed that after a single stimulation with tDCS, accuracy, but not speed of execution, was improved in tasks such as emotional go/no-go in patients with major depression (Boggio et al., 2007). These results were similar to those found in other studies employing low-frequency rTMS on the right DLPFC (Bermpohl et al., 2006). The same author also verified the negative effect of low-frequency rTMS on the left DLPFC during the same type of tasks (Bermpohl et al., 2005).

Regarding WM and NIBS, several researchers demonstrated an improvement in WM following stimulation of the left DLPFC (e.g., Boggio et al., 2006; Boggio, Rocha, da Silva, & Fregni, 2008; Fregni, Boggio, Nitsche, Rigonatti, et al., 2006; Fregni et al., 2005; Jo et al., 2009; Mottaghy, Gangitano, Krause, & Pascual-Leone, 2003; Mull & Seyal, 2001; Ohn et al., 2008; Osaka et al., 2007). Some of these studies focused on healthy subjects and how tDCS modulated working memory, obtaining positive results with unilateral anodal tDCS on the left DLPFC, showing improved accuracy in the n-back task (but not speed) (e.g., Fregni et al., 2005; Jo et al., 2009; Ohn et al., 2008). And being able to maintain that effect for at least 30 min (Ohn et al., 2008). A previous study showed an improvement in working memory after five sessions of tDCS of the left DLPFC in patients with major depression (Fregni, Boggio, Nitsche, Rigonatti, et al., 2006). On the other hand, other studies showed that decreasing left DLPFC excitability with paired pulse TMS worsened working memory (Osaka et al., 2007).

Likewise, other studies showed that performance on n-back tasks after single-pulse TMS and low-frequency rTMS on the left DLPFC increased the number of errors in that working memory task (e.g., Mottaghy et al., 2003; Mull & Seyal, 2001).

However, researchers also study WM in patients with Parkinson's disease. They found that anodal tDCS on the left DLPFC improved working memory (Paulo S Boggio et al., 2006).

In order to direct behavior towards a certain goal, it is necessary to maintain and manipulate information relevant to the tasks we are performing, and everything seems to depend mainly on executive processes and working memory. Distracting stimuli challenge our ability to maintain attention on information relevant to our goal. Within this type of stimuli, those that are emotional in nature are the most potentially distracting. This is because such stimuli are capable of easily capturing attention, relocating resources in the processing of information from our environment, and therefore, deteriorating the cognitive execution that is being carried out. At present, there is still much we do not know about the neural systems that mediate this deteriorating effect that emotion has on working memory. Several investigations with patients with depression have shown increased emotional distractibility and decreased ability to maintain interest in relevant information in such patients. This suggests that these conditions could be a consequence of altered interactions between the neural systems of executive processing and WM and the neural systems of emotional processing (e.g., Drevets & Raichle, 1998; Mayberg, 1997). In neural systems related to WM and executive processing, the DLPFC appears to be critical for maintaining active information relevant to achieving a specific goal toward an ongoing task. Increased activity in that region during WM-related tasks associated with increased performance of subjects subjects (e.g., Fuster, 1997; E. E. Smith & Jonides, 1999; Yamasaki & Labar, 2002). In addition, fMRI studies also studied the brain systems involved in the cognitive interference of distractor stimuli with emotional content (Dolcos & McCarthy, 2006). They showed that emotional distractors decreased DLPFC activity in subjects performing a WM task, and that reduction associated with impaired task performance. In addition, they also observed a marked pattern of lateralization in the right hemisphere. It showed the link between the impairing effect of emotional distractors on working memory and

cognitive-affective interactions between neural systems associated with executive processing and the links of the neural system with the processing of emotional information.

Recently, research showed that the impairment on WM produced by left DLPFC inhibition depends on the cognitive load of the task (Schicktanz et al., 2015). Still, there seems to be no consensus whether the role of DLPFC on WM can be dissociated by domains.

On this issue, a study conducted with TMS by Sandrini and colleagues (Sandrini, Rossini, & Miniussi, 2008) found that the role of DLPFC appeared to lateralize in a WM task (n-back) for its spatial (right hemisphere) and verbal (left hemisphere) versions. A recent study showed the dissociation of spatial WM and verbal WM following modulation of right DLPFC activity (Fried, Rushmore, Moss, Valero-Cabré, & Pascual-Leone, 2014). This previous work demonstrated that inhibition of the right DLPFC decreased spatial performance and increased verbal performance. Thus, it provided evidence for domain-dissociated contributions of DLPFC on WM and the potential use of TMS for the study of cognitive control mechanisms.

In contrast, it was possible to show that the application of 5-Hz rTMS over the right DLPFC produces a reduction in the functional connectivity of that region with the left hippocampus during a WM task. But not in the resting state (Bilek et al., 2013). This decoupling produced between these structures could point to the possible role of the DLPFC in limiting WM interference, which could be hippocampus-dependent cognitive processing.

Emotion can both enhance and impair a variety of features of behavior and cognition, therefore making it a double-edged sword. Thus, information of an emotional nature tends to be better remembered in episodic long-term memory (e.g. , Barsegyan, McGaugh, & Roozendaal, 2014; Dunsmoor, Murty, Davachi, & Phelps, 2015). Different fMRI studies investigated synergistic interactions between emotion and memory. And they showed that the enhancing effects of emotion on episodic memory associate with increased activity of a ventral neural system of emotional processing (which includes the amygdala, among other regions and structures). And

a neural system of memory that includes the hippocampal formation (e.g., Dolcos et al., 2013; Dolcos, LaBar, & Cabeza, 2004; Kensinger & Corkin, 2004). However, emotional information tends to impair WM maintenance. Just to be able to direct a behavior, to achieve a given goal, it is necessary to maintain the relevant information, avoiding the interferences that may be created by distracting stimuli. Such stimuli, of an emotional nature, are particularly powerful. They can easily focus our attention by redirecting resources to the processing of emotional information. Thus, impairing the cognitive performance that takes place.

At present, little is known about the neural systems that mediate this impairing effect of emotion on WM.

The impairment effect of emotion on WM has been related to different patterns of activity in brain regions associated with a dorsal neural system of cognitive control and a ventral neural system of emotional processing. In this sense, emotional distractions increase activity in regions of the ventral system (such as the amygdala or ventrolateral prefrontal cortex) and reduce activity in regions of the dorsal system (such as the DLPFC) (e.g., Denkova et al., 2010; Dolcos, Diaz-Granados, Wang, & McCarthy, 2008; Dolcos et al., 2013; Dolcos, Miller, Kragel, Jha, & McCarthy, 2007; Dolcos & McCarthy, 2006). As noted, within the neural systems associated with WM, the DLPFC appears to be critical for maintaining active information relevant to achieving a specific goal in a running task (e.g., Criaud & Boulinguez, 2013; Jahfari et al., 2010; Stokes et al., 2013). Increased subject performance associates with increased activity in this region during WM tasks (E. E. Smith & Jonides, 1999). Regarding the ventral system, a study with TBS showed that WM impairment produced by emotional distraction could be causally associated with VLPFC activity (e.g., Redolar-Ripoll, Viejo-Sobera, Palaus, Valero-Cabré, et al., 2015; Redolar-Ripoll, Viejo-Sobera, Palaus, Valero-Cabre, & Marrón, 2015). Consequently, the activation pattern that different studies have observed in DLPFC is associated with WM maintenance (e.g., Dolcos et al., 2013; Dolcos & McCarthy, 2006).

4.1 NIBS on the study of emotional interference on cognition

As we have previously mentioned cognitive control-cognition-allows responses that are adaptive to the situation, flexible, and even enable goal-focused behavior (Kuehne, Schmidt, Heinze, & Zaehle, 2019). However, researchers explored emotions, and how they affect (enhancing or impairing) our cognitive performance extensively, in humans and animals. Especially since we can point out that stimuli that are emotionally perceivable drive our actual everyday behavior (Nummenmaa, Hyönä, & Calvo, 2006). The investigation of the mechanisms that enable emotionally salient stimuli, which are processed primarily through the posterior orbitofrontal cortex (pOFC) and the amygdala, are of importance. In addition to the contribution of prefrontal and parietal brain regions (Dolcos, Wang, & Mather, 2014). Therefore, based on previous evidence, tantalizing experiences could play a role in activating processes that promote memory consolidation, as well as initiate processes that are endogenous (Redolar-Ripoll et al., 2003). Furthermore, the strength of this reinforcement could reflect the emotional significance of the stimuli (McGaugh, 2015). However, positive stimuli are not the only ones that can cause a modification of cognitive performance. Negatively emotionally charged distractors can also cause increased arousal, which will decrease cognitive performance (Iordan, Dolcos, Denkova, & Dolcos, 2013).

In general, there are two brain regions that have been mainly related to evaluative and regulatory processes of cognitive control, which are the anterior cingulate cortex (ACC) (e.g., Kuehne et al., 2019; Posner & DiGirolamo, 1998), and the PFC, mainly the ventrolateral and dorsolateral (Miller & Cohen, 2001). Research has shown that regions of the prefrontal cortex tend to be involved in processes having to do with regulation and control, for maintenance of task demands, top-down control, and even adjustments in behaviors, etc., (e.g., Banich et al., 2000; Egner, 2011; MacDonald, Cohen, Stenger, & Carter, 2000). However, the ACC has been

associated with processes that have more to do with evaluative control, such as the monitoring of processing conflicts in a high-error conflict trial context (e.g., Kerns et al., 2004; Kuehne et al., 2019). The interrelationship of these two regions, PFC and ACC, emphasizes the dynamic nature of cognitive control processes (MacDonald et al., 2000). In particular, researchers think that the aforementioned regions create a "feedback loop" where each region has a function. The ACC is responsible for evaluating and detecting conflicts caused by errors or interference, and thus signals when an adaptation in control is necessary to achieve goal-oriented behavior. To this end, it acts as an enforcer of the PFC control (e.g., M M Botvinick, Braver, Barch, Carter, & Cohen, 2001; Matthew M Botvinick, Cohen, & Carter, 2004; Van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). However, in situations where emotional stimuli establish our behavior, conflicts of an emotional nature arise due to the disruption of emotional stimuli that are goal-relevant and emotional stimuli that are goal-irrelevant. Conflict control mechanisms usually suppress this emotional conflict, which optimizes goal-oriented behavior (e.g., Carter & van Veen, 2007; Egner, Delano, & Hirsch, 2007; Miller, 2000). Therefore, emotional stimuli have to be restrained and resolve the emotional conflict (e.g., Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006).

Research with NIBS has addressed this emotional conflict over cognitive control. One of the tasks used to investigate is a variant of the classical Stroop paradigm (Kuehne et al., 2019). This is the face-word Stroop task, which allows direct investigation of processes in the control of emotional conflict. In the aforementioned research, HD-tDCS combined with electroencephalogram (EEG) was used to study how anodal stimulation of the left DLPFC will impact electrophysiological and behavioral responses during a face-word (emotional) Stroop task (Kuehne et al., 2019). Their results showed that the left DLPFC could play a causal role in processing emotional conflict while performing the aforementioned task (Kuehne et al., 2019).

Likewise, they observed that the shortage in cognitive control may also be related to psychopathology of psychiatric-like illnesses (e.g., Goschke, 2014; Ottowitz, Tondo, Dougherty, & Savage, 2002). For example, people affected by depression tend to have increased attention and memory for stimuli with negative emotional content (B. P. Bradley, Mogg, & Williams, 1995). Research demonstrated that anodal DLPFC tDCS stimulation can increase cognitive control in the efficiency with which subjects process information under conditions that are frustrating (Wiegand, Sommer, Nieratschker, & Plewnia, 2019). In this experiment, they used an adaptive 2-back version of the Paced Auditory Serial Addition Task (PASAT). Thus, they found that active enhancement of stimulation during the task improved performance gains and also associated with effect stabilization (e.g., Plewnia, Schroeder, Kunze, Faehling, & Wolkenstein, 2015; Wiegand et al., 2019). This was also in line with the idea that anodal tDCS might have positive effects on cognitive control in the presence of distracting negative information (Wolkenstein & Plewnia, 2013). Subsequent research went even further, trying to differentiate between negative and positive supportive material (M. A. Vanderhasselt et al., 2013). For their study, they assessed cognitive control for information of an emotional nature with the Cued Emotional Control Task (CECT). They observed that after left anodal stimulation of the DLPFC, the most negative N450 amplitudes along with reaction times were faster when they hindered a habitual response to happy expressions compared to sad expressions (M. A. Vanderhasselt et al., 2013). Therefore, this resulted in greater cognitive control related to positive stimuli, especially compared to negative stimuli (M. A. Vanderhasselt et al., 2013).

Likewise, research has tried to study this from the point of view of anxiety. Anxiety, especially increased anxiety, associates with reduced recruitment of control mechanisms targeting cues that are emotionally arousing, likely aversive, and also threat-related (Mathews & Mackintosh, 1998). Furthermore, when anxiety increases even in healthy participants, it appears to reduce

the involvement of prefrontal areas (Bishop, Duncan, Brett, & Lawrence, 2004). Researchers have linked the PFC to mechanisms underlying emotion regulation (inhibition) (e.g., Balconi & Ferrari, 2013; A R Hariri, Bookheimer, & Mazziotta, 2000; Kalish & Robins, 2006). However, in patients suffering from pathological anxiety levels it shows an impairment of this emotional inhibition, which may result in an attentional bias directed to potentially aversive cues (Zwanzger, Fallgatter, Zavorotnyy, & Padberg, 2009). Along these lines, rTMS in the left DLPFC appears to influence memory retrieval (Balconi & Ferrari, 2013). Participants suffering from high levels of anxiety benefited more from left frontal stimulation, which in their case decreased negative bias (Balconi & Ferrari, 2013). Therefore, they concluded that activation of the left DLPFC promotes memory retrieval of emotional information that is positive (Balconi & Ferrari, 2013).

Hf-rTMS also appears to obtain results in the study of emotional and cognitive processing. For example, Hf-rTMS in the left DLPFC can improve task-switching abilities in individuals with depression (M. A. Vanderhasselt, de Raedt, Baeken, Leyman, & D'Haenen, 2009). In addition, that same protocol showed the ability to modify attentional processing of stimuli that were emotional in a sample of healthy women (De Raedt et al., 2010). In the study using a healthy sample, Hf-rTMS of the right DLPFC resulted in a defective disconnection of faces that were negative. However, stimulation of the left DLPFC decreased engagement to the same stimuli (De Raedt et al., 2010). They also observed that, at the neuronal level, modifications in the PFC activity followed the aforementioned effects (De Raedt et al., 2010). Thus, research suggests that rTMS modulates a neural network that is involved in emotion regulation. And through this, weaken the negative effect of adverse events (e.g., De Raedt et al., 2010; Möbius et al., 2017). A variety of different studies have also linked PFC to the regulation of emotions that are negative (e.g., Johnstone, Van Reekum, Urry, Kalin, & Davidson, 2007; Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner et al., 2004; Phan et al., 2005). Similarly, Hf-rTMS

has mood-lowering effects after Hf-rTMS stimulation (Möbius et al., 2017). Their results oppose the previous view that stimulation on the left DLPFC protected against the influence of negative mood states. However, they hypothesize that, because they are using a healthy sample, this protocol might increase susceptibility to procedures that induce certain mood states (Möbius et al., 2017).

However, DLPFC is not the only region that researchers studied in relation to emotion and emotional interference. Both the DLPFC and the VLPFC appear to be important structures that are involved in emotional regulation (Zhao et al., 2020), and more so in social contexts. A synthetic review has located crucial brain regions involved in emotional regulation in the PFC (Ochsner, Silvers, & Buhle, 2012). Specifically, both the DLPFC and the VLPFC are crucial in reappraisal (Buhle et al., 2014) and also in distractibility (Kohn et al., 2014). DLPFC and VLPFC tend to be jointly stimulated throughout reappraisal (e.g., Morawetz, Bode, Derntl, & Heekeren, 2017; Ochsner et al., 2012). Specifically, reappreciation has typically entangled with VLPFC, whereas DLPFC tends to correlate with distractibility (e.g., Dörfel et al., 2014; Moodie et al., 2020). In addition, previous research found that HD-tDCS stimulation of the right VLPFC showed an involvement of the right VLPFC in handling distracting stimuli and thus leads to better WM for distractors, likely due to its part in reappreciation. In addition, they found a casual role that suggested that the left VLPFC may be effective when dealing with negative stimuli in certain scenarios (Weintraub-Brevda, 2018).

As explained above, during the performance of a goal-oriented task, stimuli, in this case emotional stimuli, can distract us from the task at hand. However, it can also lead to memory enhancement for those particular emotional stimuli (Dolcos et al., 2013). In general, when there is an interruption due to emotional stimuli, there tends to be an improvement in episodic memory (EM) due to that stimulus, however, the task at hand tends to drift away from the WM (Dolcos & McCarthy, 2006). There are certain cases in which individuals manage to handle

these emotional stimuli and also maintain the neural information from the WM (Dolcos, Kragel, Wang, & McCarthy, 2006). Thus, neuroimaging studies have also shown that the left VLPFC is associated with the preservation of information in the WM when confronted with negative stimuli (e.g., Dolcos et al., 2013, 2006). This could be achieved by suppressing the processing of such distractors (Phan et al., 2005). Studies comparing brain activity for neutral or negative stimuli showed a more pronounced activation in the left VLPFC (e.g., Chuah et al., 2010; García-Pacios, Garcés, del Río, & Maestú, 2017). However, success in WM tasks has also been related to left VLPFC activation in neutral stimuli (Kwon, Reiss, & Menon, 2002). In addition, other research has seen a correlation between activity in the right VLPFC and retention of information during WM and recall of negative stimuli later (Dolcos et al., 2013).

5. Personality in cognition

We understand by individual differences those traits that differentiate people (Williamson, 2018). The Encyclopedia of Social Psychology describes them as enduring psychological traits (Baumeister & Vohs, 2007). This characteristic helps us in differentiating individuals. Hence, it defines each person by his or her individuality (Williamson, 2018). In addition, Hans Eysenck provided a description of personality that included its neuropsychological causes (Eysenck, 1967). One of Eysenck's theories proposed that the variability found in cortical arousal influenced certain dimensions of personality (Eysenck, 1967). Therefore, it implies that cognition could be a part of personality.

They are characteristics that help us differentiate one person from another and shape each person's sense of self. Some of the more substantial individual differences are gender, intelligence, personality, values, etc. Their study is of major interest to personality psychologists (Williamson, 2018). And they should be taken into account in different fields of psychology (Williamson, 2018).

Individual differences also imply that people may approach or solve the same task differently (Solso, 1988). Therefore, individuals diverge in their cognitive performance (e.g., Boogert, Madden, Morand-Ferron, & Thornton, 2018; Solso, 1988). It is only recently that researchers considered its importance. Recognizing these variations-in humans and animals-gives us the opportunity to study the mechanisms, evolution, and development of cognition.

Several authors suggested that differences in personality, characterized by individual differences in behavior over time and contexts (Dall, Houston, & Mcnamara, 2004), could create variations in how people act and gather information (e.g., Griffin, Guillette, & Healy, 2015; Sih & Del Giudice, 2012). Research supports the notion that personality is related to cognitive abilities (Rammstedt, Lechner, & Danner, 2018). Early theorists have pointed to the

need to study personality traits in addition to cognitive abilities. Traits that are socially valued, and social skills could be linked to cognitive ability positively (Thorndike, 1940). In addition, research suggested that a portion of "non-intellectual traits" be covered in the IQ test. This is due to the belief that it could improve prediction performance in real life (Wechsler, 1950). Also, Philip E. Vernon included an "X" determinant for personality traits and interests in his model of the structure of educational abilities (Vernon, 1950).

An abundant part of this research has focused on a guide to the Big Five foundation. Research considers the Big Five one of the most validated and widely used personality models. Its associations between the Big Five personality traits and cognitive abilities are robust (Ackerman & Heggestad, 1997). Research has found that between five and ten percent of the variance in cognitive ability could be explained by the Big Five personality traits (Furnham, Dissou, Sloan, & Chamorro-Premuzic, 2007). In particular, openness to experience, and emotional stability appear to show positive links with measures of cognitive functions such as intelligence (e.g., Ackerman & Heggestad, 1997; Chamorro-Premuzic, T.; Furnham, 2005; Moutafi, Furnham, & Crump, 2003; von Stumm & Ackerman, 2013; Zeidner, M.; Matthews, 2000). Certain personality qualities promote the attainment of skills and knowledge (Chamorro-Premuzic, T.; Furnham, 2005). In investment theory, traits such as curiosity for intelligence can translate their basic cognitive abilities into knowledge gain (e.g., Ackerman, 1996; von Stumm & Ackerman, 2013). In addition, personality traits can be related to cognitive abilities in the way they influence an individual's behavior when performing a task (test taking, etc.). For example, in the context of a major final test, a neurotic person might suffer from high test anxiety, which would interfere with his cognitive processing during the test, thus affecting his performance (Moutafi, Furnham, & Tsaousis, 2006).

We can distinguish two trends guiding personality models. One comes from H.J. Eysenck's biological theory of personality. He saw cognition as a secondary factor to more basic neural

processes. However, he initiated the use of tasks that measured performance to test personality theories. To test indicators of the arousal theory of personality traits, he used tasks that required memory and attention. This encouraged the use of cognitive psychological models as a bias to predict personality effects.

Another was the social learning theories of personality by Walter Mischel and Albert Bandura. They emphasized that social learning builds internalized cognitive structures. Social learning focuses more on the cognitive representation of the person.

As for the roots of personality research in cognitive neuroscience, we can say that it came from an interest in psychophysiological correlates of information processing (G Matthews, 2012). Research found differences between introverts and extroverts in the amplitude of P3—a potential event-related component elicited in the decision-making process—that could reflect the updating of WM (Stenberg, 1994). Therefore, these differences could be associated with differences in performance during WM tasks.

Thanks to brain imaging research, the study of personality in cognitive neuroscience has increased. Studies, using techniques such as functional magnetic resonance imaging, show that variations in performance could be a causation of individual differences in neurological functioning. As noted above, anxiety could be related to attentional functioning as well as extraversion (e.g., Matthews & Zeidner, 2012; Moutafi et al., 2006).

In this context, biological theories of personality placed certain traits in subcortical systems. Modern cognitive neuroscience exemplifies this in how extraversion might be related to increased dopaminergic activity and reward areas (e.g., DeYoung, 2013; R. Fischer, Lee, & Verzijden, 2018; Smillie & Wacker, 2014). Other structures as well, such as the amygdala or anterior cingulate cortex, have been the subject of interest for how they relate to individual differences and the processing of emotional information (e.g., Haas, Omura, Constable, &

Canli, 2007; Krause-Utz et al., 2014; Kujawa et al., 2016; Rolls, 2019; F. L. Stevens, Hurley, & Taber, 2011).

5.1 Personality in risk decision-making

Personal characteristics influence human decisions, i.e., personality, and cognitive systems. Individual differences in the functioning of both elements produce different decision-making behaviors (Neisser, 1967).

A large part of the decisions we make every day is a trade-off between an expected reward and an expected risk. For example, a woman considering whether to use protection with a man she just met, evaluating the possibility of contracting a sexually transmitted disease. Or a very clear situation. A smoker who is faced every day with nicotine addiction versus the possibility of risking lung or heart disease, as well as the disapproval of his current non-smoking partner.

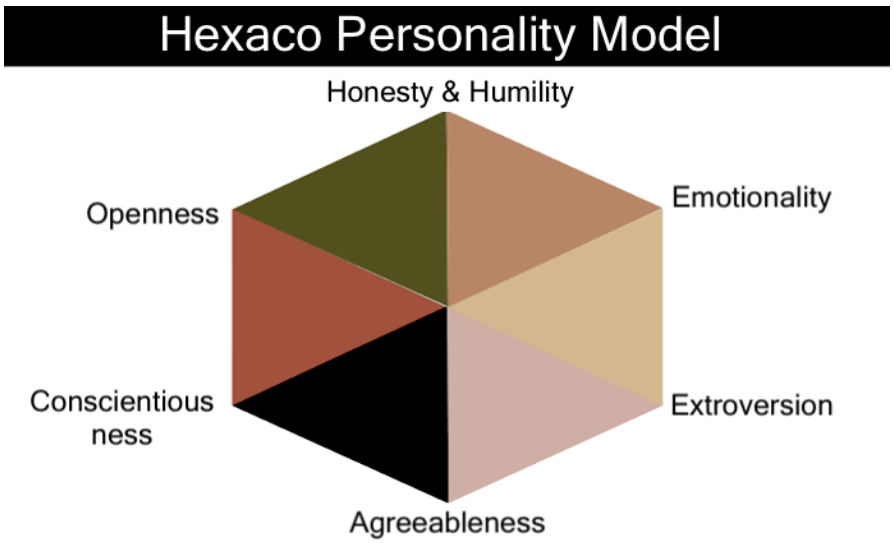
In such situations, we can say that certain personality traits might attract more risk-taking. Such as sensation seeking and impulsivity (M Zuckerman, 2000). Sensation seeking is "a trait defined by the pursuit of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of that experience" (M Zuckerman, 1994). And impulsivity is the predisposition to insert oneself into situations quickly on the cues of a possible reward. Regardless of the possibility of losing the reward and/or punishment. In addition, it can be seen as a deficit in the inhibition of danger-seeking behavior when it involved a reward (M Zuckerman, 2000).

As mentioned above, in the study of risky decision-making, researchers use certain questionnaires to assess preexisting impulsive behavior such as the Barrett impulsivity scale (BIS 11) (Patton, Stanford, & Barratt, 1995). Or evaluate urgency, premeditation (lack of), perseverance (lack of), sensation seeking, positive urgency, impulsive behavior scale (UPPS-

P) (Whiteside & Lynam, 2001). The BIS 11 measures the personality construct of impulsivity, and the UPPS measures different aspects of impulsive personality.

Among the personality traits that have been related to risk behavior, the dark triad and the HEXACO stand out in current personality models.

Studies have shown that emotionality dimensions associate with higher risk perception and high conscientiousness with lower benefit perception (e.g., Hampson, Andrews, Barckley, Lichtenstein, & Lee, 2000; Nicholson, Soane, Fenton-O'Creevy, & Willman, 2005; J. A. Weller & Thulin, 2012; J. Weller & Tikir, 2011). Likewise, research reported unique patterns of domain-specific relationships between HEXACO dimensions and risk attitude (J. Weller & Tikir, 2011). In other studies, involving risky decision-making tasks involving potential losses or gains, HEXACO dimensions predicted risk-taking in both domains (losses and gains). Honesty-Humility associated with greater risk for both situations (J. A. Weller & Thulin, 2012). Evidence also suggests that Honesty-Humility scores positively associated with non-gambling subjects over gambling subjects when it involved addiction (McGrath, Neilson, Lee, Rash, & Rad, 2018). Awareness also was the strongest positive predictor of decision-making performance, just as openness, likely contributes to competent decision-making (J. Weller, Ceschi, Hirsch, Sartori, & Costantini, 2018).



F**igure 7** Dimensions of the HEXACO personality model. Model based on a six-dimensional model of the personality of humans. (Adapted from Expert Program Management, https://expertprogrammanagement.com/2020/04/hexaco-personality-model/)

Similarly, previous research reported that increased risk-taking on BART significantly predicted higher self-reported psychopathy (Hunt, Hopko, Bare, Lejuez, & Robinson, 2005a). This is consistent with studies that observed that the percentage of risky decisions made during the Cambridge Decision-Making Task correlated differentially with psychopathy scores (Sutherland & Fishbein, 2017). Also, brain imaging studies of decision-making revealed activation in neural regions associated with emotional regulation (e.g., Hughes, Dolan, & Stout, 2016; Livet, 2010).

5.2 Personality in emotional inference on cognition

In our day-to-day lives, we depend on a good resolution of emotional interference. This is crucial for completing a variety of tasks: work, studying, paying attention, completing assignments, etc. But, as individuals, and from experience, we are aware that not everyone reacts to, processes and handles emotions in the same way. You may break up with your partner and be able to go to work and do all your daily tasks without shedding a tear. But your best friend may need the day off, or your colleague may cry inconsolably at work. Therefore, we assume that to complete our daily work, efficient emotional interference is mandatory (Song et al., 2017). Moreover, it is necessary to remember that cognitive control is the ability to organize action and mind, matching them with task-specific task-related goals. These may consist of different executive processes, such as WM updating, error monitoring, maintenance, attention shifting, inhibition, reaction conflict, etc. (e.g., Banich et al., 2009; Miyake et al., 2000). When, for a given reason, while processing task-relevant information, a powerful distractor-emotional interference- interrupts this information, this is known as cognitive

conflict (e.g., LeDoux, 2000; Mathews, 1990). This cognitive conflict, which arises from emotional interference, can affect our ability to complete those tasks that require cognitive control (e.g., Etkin et al., 2006; Song et al., 2017).

Several studies suggest that emotion and cognitive control are brain functions that may share neural circuits (e.g., Mueller, 2011; Pessoa, 2008b; Shackman et al., 2011; Song et al., 2017). In this regard, evidence has suggested that brain areas, related to cognitive control (DLPFC) play an important role in emotion processing (Okon-Singer, Hendler, Pessoa, & Shackman, 2015). Cromheeke and colleagues produced a meta-analysis consisting of 43 studies focusing on tasks that mixed emotion with cognitive control tasks (e.g., Stroop, n-back, go/no-go task) (Cromheeke & Mueller, 2014). This meta-analysis investigated the neural mechanisms resulting from the interaction of cognition and emotion. During a Stroop -emotional- task, there was a significant increase in brain activation for negative words. Specially compared to neutral words, in the inferior frontal gyrus (IFG), ACC, middle frontal gyrus, superior and inferior temporal gyrus, and fusiform gyrus (Mohanty et al., 2005). In addition, more fMRI studies similarly reported increased activation in prefrontal areas, which are also key in cognitive control (e.g., Hart, Green, Casp, & Belger, 2010; Malhi, Lagopoulos, Sachdev, Ivanovski, & Shnier, 2005; Mitterschiffthaler et al., 2008; Rey et al., 2014). Other studies have reported activation of other areas of emotional interference during cognitive control. Such as the insula (Chechko et al., 2013), the postcentral gyrus (Veroude, Jolles, Croiset, & Krabbendam, 2013), the praecuneus (Rahm, Liberg, Wiberg-Kristoffersen, Aspelin, & Msghina, 2013), and the precentral gyrus (Chechko et al., 2012).

However, this inconsistency in findings across studies may be due to various factors, such as the degree of task difficulty, materials, parameters, etc. A more recent meta-analysis also focused on emotional interference and cognitive control and measured primarily with the Stroop task (Song et al., 2017). They found a pattern of brain activation consisting of the

medial/superior frontal gyrus, insula, fusiform gyrus, DLPFC and IFG and dACC. Furthermore, when the task has additionally intense emotional interference, it resulted in increased brain activity in the precuneus, medial/superior frontal gyrus, fusiform gyrus, DLPFC, IFG, and dACC (Song et al., 2017).

The consensus is that emotions do have an effect on our cognitive abilities, and can affect and disrupt cognitive control. However, we must consider, at the same time, how personality traits can modify and influence the impact of this emotional inference. The reaction to similar emotional stimuli may vary from person to person (e.g., a breakup). Hence, it is important to consider how personality is related and how it can influence emotion, leading to individual differences in how we process emotions (e.g., Balconi & Mazza, 2010; Balconi, Vanutelli, & Grippa, 2017; Bendall, Eachus, & Thompson, 2016). Several studies demonstrated this (e.g., Hoshi et al., 2011; Ozawa, Matsuda, & Hiraki, 2014). They found that some individuals showed increased activity in their PFC regardless of emotional valence, whereas other participants showed the same activation but depending on emotional valence. There are many possible explanations for this, which could be related to personality differences (Sugi et al., 2020).

Numerous studies have used the WM task as a cognitive task to amplify the effects of emotional stimuli (e.g., Hart et al., 2010; Kopf, Dresler, Reicherts, Herrmann, & Reif, 2013; Ozawa et al., 2014; Sugi et al., 2020; Van Dillen, Heslenfeld, & Koole, 2009a). And researchers used different values of emotional stimuli to study the impact of emotional stimuli on cognitive task performance. For example, when we inhibit task-irrelevant emotional information, it enrolls lateral prefrontal areas (e.g., Beauregard, Lévesque, & Bourgouin, 2001; Blair et al., 2007). Thus, it appears that emotional processing and working memory have a link to the DLPFC (Owen, McMillan, Laird, & Bullmore, 2005). And emotional input seems to have an effect on working memory tasks. When researchers displayed stimuli just before the task, it could lead

to poor working memory performance (e.g., Brosch, Scherer, Grandjean, & Sander, 2013; Dolcos & McCarthy, 2006).

A recent study pointed out the importance of personality traits in studying the impact caused by emotional stimuli (Sugi et al., 2020). They divided their sample group according to their scores on the inhibition/Behavioral activation system (BIS/BAS) (Sugi et al., 2020), a scale commonly used in emotional research. It measures two general motivational systems aimed at underlining behavior. It is based on Carver and White's reinforcement sensitivity theory of personality (Carver & White, 1994). The BIS is intended to regulate motivation as a means of avoiding undesirable stimulation. Therefore, it is related to sensitivity to negative emotions. On the other hand, BAS is related to sensitivity toward positive emotions (e.g., Carver & White, 1994; J. A. Gray, 1970). Therefore, research understands BIS and BAS as personality traits (e.g., J. A. Gray, 1994; J. R. Gray, 2001).

Sugi and colleagues found that changes in oxygenated hemoglobin concentration showed an interaction between emotional balance and personality. Activity in the right DLPFC was higher in the group assigned to BIS than to BAS in positive valence (Sugi et al., 2020). In addition, activity in the right DLPFC increased for the BIS group after negative stimuli (Sugi et al., 2020). Thus, it raised the idea that individual personality differences in cognitive tasks and emotional interference need to be taken into account (e.g., J. R. Gray, 2001; Sugi et al., 2020). Individuals with neuroticism also demonstrated the effects of personality, anxiety, depression, and even low extraversion. They were more sensitive to emotional conflicts when processing emotional expressions (e.g., Frühholz, Prinz, & Herrmann, 2010; Holtmann et al., 2013).

Therefore, in recent years, there has been an interest in how personality affects emotional interference, and how, consequently, it may affect cognition.

5.3 NIBS and Personality

To begin with, we were interested to see how a type of individual difference might modify the response to NIBS techniques and how. There is not much research on how personality traits might influence the response to NIBS. As stated above, in a very cursory manner, studies of risk decision-making showed that impulsivity or risk-taking propensity may be a deciding factor in how an individual reacts to risk. And it is mentioned in studies regarding anxiety and using NIBS, or the treatment of personality disorders. For example, some studies found that, for borderline personality disorder patients, when a right anodal/left cathodal tDCS was placed in the DLPFC, it reduced aggression, and impulsivity (Lisoni et al., 2020). Another study points to the importance of assessing certain brain areas to explore anxiety-related personality traits while performing a creative task (Xiang et al., 2021). Furthermore, other studies found that subjects who scored higher in introversion had more permeability to the modulation effects of tDCS stimulation of the left DLPFC compared to extraverts. Thus, reemphasizing the role of the left LPFC in emotion regulation, thus pointing to the weight of personality traits (e.g., Choi, Scott, & Lim, 2016; Peña-Gómez, Vidal-Piñeiro, Clemente, Pascual-Leone, & Bartrés-Faz, 2011). However, it has not been widely studied.

Regarding NIBS and individual differences in personality, their investigation is still sparse, but previous research suggested that individual differences may affect both risk-taking and NIBS (e.g., Scheres & Sanfey, 2006; Y. Zhang, Chen, Hu, & Mai, 2019). And with respect to how individual differences, in general, modulate NIBS techniques, there are important insights into the nature of tDCS-induced neuronal excitability in relation to individual difference variability in performance enhancement (Falcone, Wada, Parasuraman, & Callan, 2018). These studies shed some light on the apparent unreliability found in tDCS research (e.g., Brunoni et al., 2012a; Horvath, Carter, & Forte, 2014). These findings align with those of the work of Hsu,

Juan, & Tseng (2016) who found that individual differences modulate one's responsiveness to tDCS (Hsu, Juan, & Tseng, 2016). Therefore, literature hints that individual factors could be behaviorally relevant (A R Hariri, 2009). Some findings suggest that variability in tDCS efficacy might be systematically related to individual differences in sensitivity to brain stimulation (Labruna et al., 2019). Individual differences in anatomical and physiological characteristics could influence the efficacy of both simulations (TMS and tDCS), so we surmise that there is a relationship between individual differences in response to NIBS techniques (Labruna et al., 2019). Other studies have measured the correlation of individual differences and brain stimulation with the ratio of GABA (inhibitory) and glutamate (excitatory). Finding that individual differences in the effect of brain stimulation on response selection learning associates with basal levels of cortical excitability in PFC, but not in visual cortex (Filmer, Ehrhardt, Bollmann, Mattingley, & Dux, 2019). Stimulation affected subjects who showed higher levels of inhibition in the PFC to a large extent in the aforementioned study. In addition, evidence showed that some individual difference dimensions have a greater impact when combined with WM training and tDCS (e.g., Au et al., 2016; Ke et al., 2019; L. M. Li, Uehara, & Hanakawa, 2015). Subjects who started with a higher baseline ability in sham were more inclined to improve further over the course of training (Katz et al., 2017). This is consistent with previous studies, the results of which indicate the need to assess individual differences in the development of cognitive interventions and training protocols (e.g., M. A. Nitsche & Paulus, 2000; Scheldrup, Dwivedy, Fisher, Holmbald, & Greenwood, 2016).

Researchers also studied this issue in video game training, with results saying that continued practice magnifies ability-based inter-person differences, uncovering individual differences in memory plasticity (Lövdén, Brehmer, Li, & Lindenberger, 2012). We can also say, that there are separate subgroups of experimental subjects that respond differentially to stimulation (e.g., Krause & Cohen Kadosh, 2014; López-Alonso, Cheeran, Río-Rodríguez, & Fernández-Del-

Olmo, 2014; Lövdén et al., 2012; Wassermann, 2002). Falcone et al., 2018 give insight into the nature of neuronal excitability induced by NIBS techniques (tDCS) and how it relates to individual difference variability.

Turning to the use of NIBS and how it might influence personality per se, NIBS are a group of techniques that allow researchers, etc., to temporarily modify brain functions (Iwry, Yaden, & Newberg, 2017). Thus, the authors raise concerns regarding issues of fairness and even the possibility of risk toward cultural norms (e.g., Farah et al., 2004; Iwry et al., 2017; J., 2007). They point out that if NIBS techniques can influence cognition, they could also influence personality and belief systems (Iwry et al., 2017). This is because NIBS have the potential to modulate reasoning, emotion, attention, and even social behavior (Hamilton, Messing, & Chatterjee, 2011).

Therefore, we believed that depending on personality, NIBS techniques might affect individuals differently. Research has also shown that techniques such as rTMS have effects on disorders such as borderline personality disorders. In particular, showing improvement in impulsivity, anger, and affective instability (Reyes-López et al., 2018).

6. Objectives and hypothesis

Based on the previous sections, studies and results, our main objective for this thesis is to study the effects of NIBS on cognition, especially on cognitive control.

As seen above, during this thesis we will focus on both processes due to their interconnected nature (D. Redolar-Ripoll, 2021): decision-making, specifically risk and working memory, taking emotions into account.

Hence, we focus on risk decision-making and working memory as our main areas of interest. In addition, we take into consideration individual differences in personality. Furthermore, we are interested in testing the dissociation between DLPFC and VLPFC.

From there, the specific objectives of each experimental procedure are as follows:

Experiment I: to stimulate the DLPFC and the VLPFC separately with tDCS while performing risk tasks. In addition, we will take into account personality differences. Our main goal in this experimental procedure is to observe whether there are differences in the reaction of the participants depending on where we apply the stimulation. In addition, to take into account whether personality affects the way NIBS modulates cognition.

Based on these objectives, we propose the following hypothesis:

Experiment I:

(a) Cathodal MtDCS of the left DLPFC and left VLPFC modifies risk propensity.

(b) Participants showing higher scores on the dark triad are more likely to make risky decisions.

(c) Individual personality differences (in addition to the dark triad) moderate the impact of MtDCS on risky decision-making.

Note that, given the exploratory nature of hypothesis (c), we cannot make any explicit predictions about its directionality.

Experiment II: we aimed to define the role of the left DLPFC in the temporal involvement in executive information processing. In addition, we aimed to study the involvement of the left DLPFC in executive processing and working memory by cortical modulation through a NIBS approach. We tested two rTMS protocols: excitatory (iTBS protocol) and inhibitory (cTBS) (Sandrini, Umiltà, & Rusconi, 2011). Therefore, we aimed to analyze the involvement of the left DLPFC in the mediation of cognitive interference by emotional distraction. To do so, we used a previously adapted WM behavioral paradigm (Dolcos & McCarthy, 2006). In summary, to analyze the implications of left DLPFC on executive function and WM by modulating cortical excitability with iTBS and cTBS. To delve into the efficacy of TMS in cortical modulation and modulation of cognitive functions underlying the stimulated area. And to

analyze the implications of DLPFC in mediating cognitive interference by emotional distractors. In addition, we also wanted to test whether personality differences would modify NIBS stimulation.

Our hypothesis were as follows:

Experiment II:

(a) While processing surrounding information, internal signals from the downstream information flow interact with upstream sensory information, making it possible for behaviorally and task-relevant stimuli to be selectively perceived and encoded in short-term memory. Meanwhile, we discard the irrelevant stimuli. We hypothesize that activation of the DLPFC will be crucial at the initial stages of this type of information processing. At later stages of selection, associated with response-related processes, it will be less important.

(b) The application of a stimulation protocol (iTBS) of the DLPFC will increase the efficiency in the execution of working memory tasks and executive functions. Minimizing, even, the harmful effects caused by the presence of distracting stimuli of an emotional nature.

(c) Regarding the exploration of personality and how NIBS stimulation might modify it, due to the exploratory nature of the profiles we cannot make any explicit predictions.

EXPERIMENTAL WORK

7.1 Experiment I: Risk-taking, MtDCS, and personality

For this first experiment, we investigated the effect of the application of Multifocal Transcranial Direct Current Stimulation (MtDCS) on the left DLPFC and left VLPFC on risk taking. For this purpose, we used the balloon analog risk task (BART) and the bomb risk elicitation task (BRET), taking into account individual personality differences.

7.1.1 Material and methods

7.1.1.1 Participants

Thirty-four healthy right-handed university-educated volunteers (21 women and 13 men, mean age 29.21±9.72 years) participated in the study. None were taking medication of any kind, had previous or current neurological disorders, or had a history of psychiatric illness, drug, or alcohol abuse. All met internationally established safety criteria for tDCS (e.g., Bikson et al., 2017; M. A. Nitsche et al., 2003). The local ethics committees of the Universitat Oberta de Catalunya and the institutional review board (IRB 00003099) of the University of Barcelona approved the study, which complied with the tenets of the Declaration of Helsinki. All participants gave written informed consent and received financial compensation for their participation at the end of the study.

7.1.1.2 Experimental design and general procedure

We based the study on a 3×2×*n* mixed factorial design. The between-subjects factors were personality *n*, determined by latent profile analysis (LPA), and stimulation intensity (1.5 mA or 2 mA). Stimulation condition (DLPFC: cathodal F3, return AF3, FC1, FC3, FC5, and F5; VLPFC: cathodal F7, return FP1, F3, FC5, FT7, and F9; sham) was the within-subject factor. The study consisted of 3 sessions over 3 days (1 session/type of stimulation per day), with DLPFC, VLPFC, and sham stimulation applied in a randomized, counterbalanced order. To

explore whether the MtDCS-induced effect on risk decision-making was dependent on stimulation intensity, we randomly assigned participants to an intensity (1.5mA or 2mA) that we maintained across sessions. During each session, participants performed 2 computerized risk decision-making tasks, namely BART and the bomb risk elicitation task (BRET), in a randomized, and counterbalanced order.

Before the first session, participants completed 2 personality tests (see below) aimed at profiling their personalities; we also informed participants that the more points they accumulated during the tasks, the better they would be paid. At the end of each session, we asked participants to rate mood and pain/discomfort on a 4-point visual analog scale.

After they completed all sessions, we requested that they identify the sham sessions. This was necessary in order to confirm whether the somatosensory sensation induced by the stimulation and reported by our participants was equivalent in active and sham conditions.

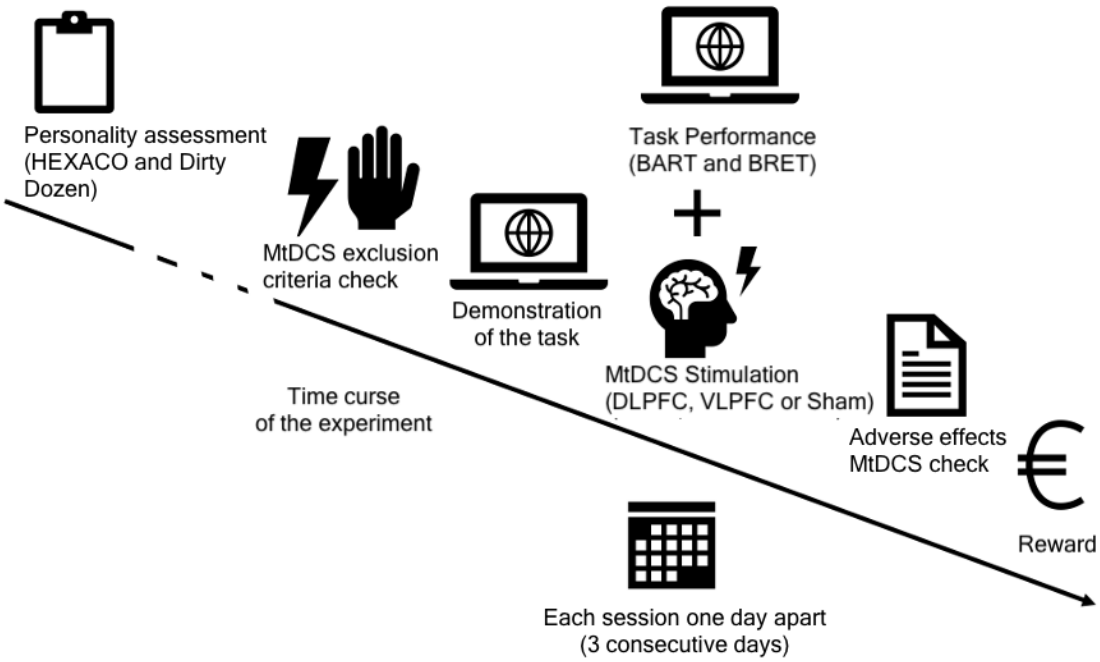


Figure 8 Representation of the experimental procedure. Prior to the experimental sessions, participants underwent a personality assessment (HEXACO-60 and dark-triad/dirty-dozen instruments), were

checked against the exclusion criteria, and had the tasks demonstrated to them. Participants followed the same procedure during the different stimulation (DLPFC, VLPFC, and sham), held one day apart. We randomized the risk decision-making tasks (BART and BRET) order for all sessions and participants. The average time for both tasks combined was 10 minutes. The conduction time of each experimental session was 50 minutes: first 10 minutes we informed participants of the procedure and rated their mood pre-experiment, 20 minutes of stimulation (inside those 20 minutes the last 10 minutes participants performed both tasks). And the last 10 minutes consisted of post-experiment mood and adverse MtDCS effects assessment and financial compensation (last session). (Source prepared by the author)

7.1.1.3 Personality questionnaires

We administered all personality questionnaires through the Qualtrics platform. To achieve a balance between bandwidth and fidelity, we used two personality questionnaires:

7.1.1.3.1 HEXACO. We assessed broader dimensions of personality using HEXACO-60, which consists of 60 questions assessing 6 scales, each consisting of 10 items (Ashton & Lee, 2009), namely honesty-humility, emotionality, extraversion, agreeableness, conscientiousness, and openness to experience. Research duly validated its psychometric properties, including internal consistency levels, inter-item correlations and test-retest reliability (e.g., Ashton & Lee, 2009; Roncero, Fornés, García-Soriano, & Belloch, 2014). Previous studies have conducted generalization meta-analyses to test the internal consistency of the HEXACO dimensions. Showing high reliability for all versions of HEXACO-PI (Moshagen, Thielmann, Hilbig, & Zettler, 2019). In this meta-analysis, reliability estimates (Cronbach's alpha) averaged, across all versions and languages from .80 for Openness to .84 for Extraversion (Moshagen et al., 2019). With similar results for another study with small sample retest reliability after seven months (n=31), with scores ranging from .72 to .92 (Henry, Thielmann, Booth, & Kingdom, 2021).

7.1.1.3.2 **Dark triad-dirty dozen.** The Dark Triad-Dirty Dozen is a 12-item personality inventory that simultaneously assesses the 3 dark triad traits associated with personality: Machiavellianism (e.g., “I have used deception or lying to get what I want”), psychopathy (e.g., “I tend to have no remorse), and narcissism (e.g., “I tend to want others to admire me”). This inventory, despite its brevity, has excellent psychometric properties, more than adequate temporal stability and internal consistency, and excellent validity (Jonason & Webster, 2010). In particular, the corrected test-retest correlation for the Dirty Dozen Dark Triad was .91, ranging from .71 to .88 for the subscales (Jonason & Webster, 2010). In addition, a Turkish form of the same questionnaire showed a Cronbach's alpha coefficient of .79 for Machiavellianism, .71 for psychopathy, and .87 for narcissism (Satici, Kayış, Yilmaz, & Çapan, 2018).

Interestingly, high self-reported psychopathy has been related to higher risk-taking during BART (Hunt, Hopko, Bare, Lejuez, & Robinson, 2005b).

7.1.1.4 Multifocal transcranial direct current stimulation.

The main reason we used tES NIBS instead of TMS, as in the second experiment, is because we did not have fMRI scans, nor did we have the budget to obtain them. Therefore, MtDCS was the best option.

For MtDCS we used a STARSTIM 8 5G wireless hybrid EEG/tCS 8-channel system (NE, Neuroelectrics, Barcelona, Spain), with a constant current DC neurostimulator and 6 NG Pistim electrodes. The hybrid electrode allows clear access to the scalp, allowing good control of impedance values. The NG Pistim electrodes consist of 2 parts: the fastener (superior part) and the threaded washer (inferior part). A sintered Ag/AgCl pellet of 12 mm diameter makes up the fastener. It has a rear-fill aperture and a circular contact area of approximately π cm^2.

To reduce the excitability of the left VLPFC, we placed the cathode according to the international EEG 10-10 system (Jurcak, Tsuzuki, & Dan, 2007) at F7, while the other 5

(return) electrodes were at FP1, F3, FC5, FT7, and F9; for the left DLPFC, we placed the cathode at F3, while the other 5 (return) electrodes were at AF3, FC1, FC3, FC5, and F5 (e.g., H. Guo, Zhang, Da, Sheng, & Zhang, 2018b; Nikolin, Loo, Bai, Dokos, & Martin, 2015). Once the neoprene cap was in place, we separated the hair underneath the electrodes, and we cleaned the scalp with alcohol to remove any remaining oil. Once we exposed the scalp, we filled the fastener component with conductive gel (Sigma Gel, Parker Laboratories, New Jersey, USA) using a curved syringe. We applied the current for 20 minutes and the tasks started after 10 minutes of MtDCS.

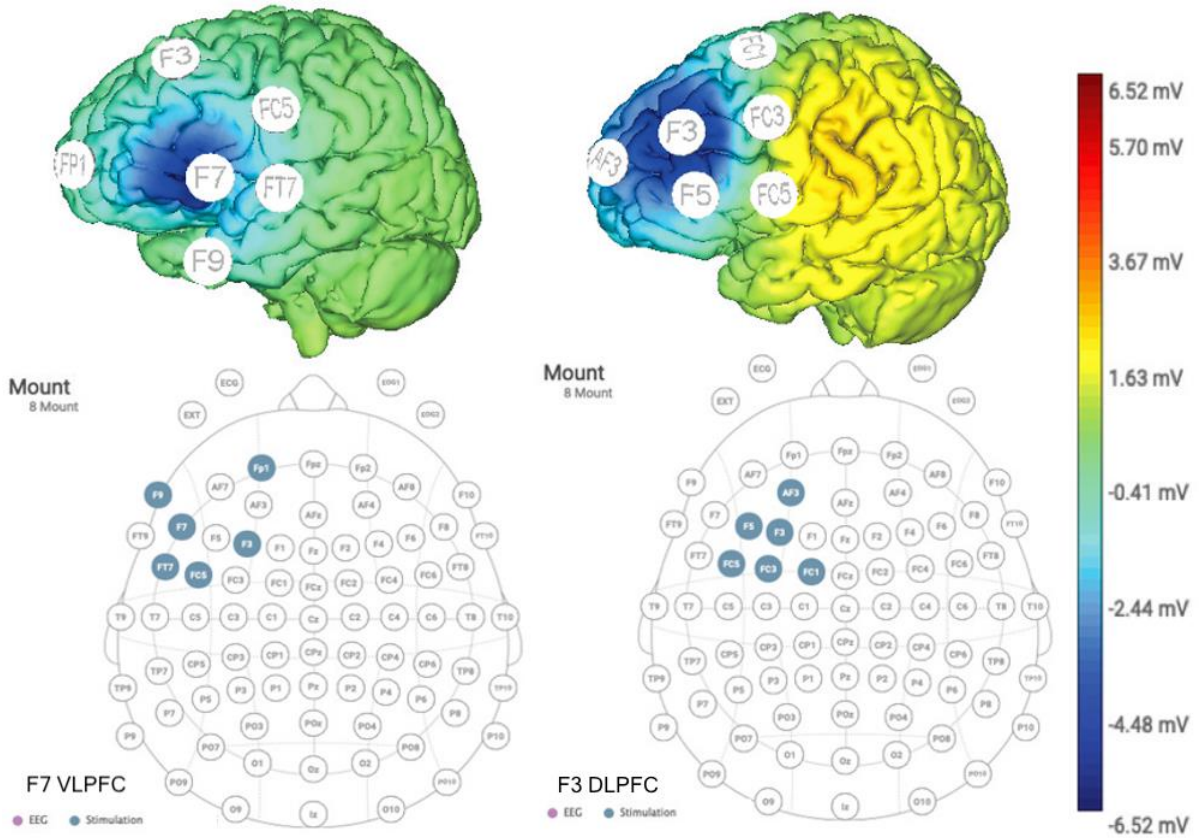


Figure 9 MtDCS montage. We placed six NG Pistim electrodes as follows: left DLPFC (cathodal F3, return AF3, FC1, FC3, FC5, and F5), and left VLPFC (cathodal F7, return FP1, F3, FC5, FT7 and F9). The upper part of the figure shows computational models of the MtDCS montages used. The approximate location of the cathodes (F3 and F7) shows the lowest voltage magnitude. The scale bar on the right shows the color codes for current intensity values (mV). The realistic head model included

in NIC 2 software (Neuroelectrics, Barcelona, Spain) shows the voltage distribution, which is based on the Colin27 dataset. Methods for the generation of this head model and for electric field calculation can be found in (Miranda, Mekonnen, Salvador, & Ruffini, 2013). (Source prepared by the author)

For sham, the current acted for the first second and was turned off after 30 seconds; this was a control procedure to measure reactions without stimulation, with participants blinded if they received stimulation (e.g., Ambrus et al., 2012; Fonteneau et al., 2019; Garnett & Den Ouden, 2015; Palm et al., 2013). No participants reported side effects (e.g., itching, pain, headache, etc.) after stimulation.

7.1.1.5 Risk decision-making tasks

We measured risk decision-making with the well-established computerized tasks BART and BRET. The order of the tasks, which were run in Inquisit (Millisecond software), was counterbalanced. Based on the information provided above, we chose the BART task because it is a well-established task in the study of risk decision making. In addition, studies that dealt with dark triad measures used it. Likewise, we selected the BRET as it is a recently developed task that research hardly used and measures a different dimension of risk. Therefore, it might be interesting to see the validity of the BERT in comparison with a well-validated task, such as the BART.

BART is a behavioral measure of risk-taking. Performance on this task correlates with scores on measures of sensation seeking, impulsivity, and deficits in behavioral restraint (Lejuez et al., 2002). In short, BART is a useful instrument in the assessment of risk-taking widely used in previous literature (e.g., Gilmore, Dickmann, Nelson, Lamberty, & Lim, 2017; Gilmore et al., 2018; Nejati, Salehinejad, & Nitsche, 2018; Petrova & Garcia-Retamero, 2016; Russo et al., 2017; Seaman, Stillman, Howard, & Howard, 2015; Sela et al., 2012a). On the other hand, BRET is a behavioral measure of risk attitudes (e.g., Crosetto & Filippin, 2013; P. He, 2018; Nielsen, 2019). This task, although much less used in previous literature, allows estimating

both risk aversion and risk seeking very accurately, and is not affected by the degree of loss aversion (e.g., Crosetto & Filippin, 2013; P. He, 2018; Nielsen, 2019). The two tasks differ in their approach to measuring risk: BRET is more appropriate with temporal risk decisions (Crosetto & Filippin, 2013), whereas BART has convergent validity with real-world risk-related situations (Fecteau, Pascual-Leone, et al., 2007).

7.1.1.5.1 BART. We used a modified version of BART (Lejuez et al., 2002), called autoBART (Pleskac, Wallsten, Wang, & Lejuez, 2008), in which participants inflated a series of 30 balloons. We informed participants beforehand that they could pump 127 times and that the balloon had a probability of popping, set at 1/128 for the first pumping, 1/127 for the second, and so on until the balloon popped. Participants indicated in a text box how many times they were to inflate the balloon to the maximum of 127 pumps. For each pump, participants earned one point, and if the balloon popped, the points reset to zero for that trial. Previous studies showed that the adjusted average number of pumps of unexploded balloons (mean number of pumps on trials that the balloon did not explode) (AVP) indicated a higher propensity to take risks (e.g., Aklin et al., 2005; Cheng, Tang, Li, Lau, & Lee, 2012; H. Guo et al., 2018a; Lejuez et al., 2002). Hence, we calculated AVP, total gains (TE), and desired pumps (WP, i.e., the total number of times the participant wanted to pump the balloon across all trials) as dependent variables.

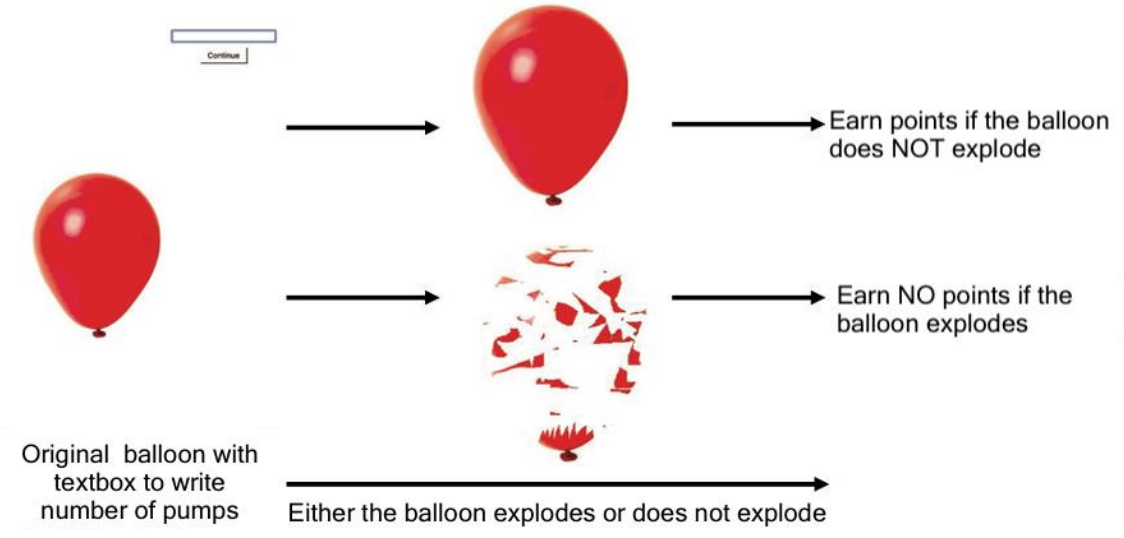


Figure 10 BART. We instructed participants to achieve as many points as possible by inflating a series of 30 balloons but are warned of the probability of the balloon bursting. Shown a balloon and a text box, they are instructed to indicate how many times to inflate the balloon (maximum 127 times). (Source prepared by the author)

7.1.1.5.2 BRET. We used the dynamic version of BRET (e.g., Crosetto & Filippin, 2013; P. He, 2018; Nielsen, 2019).We presented participants a grid with 25 cells, one of which contained a randomly placed parcel bomb programmed to explode if picked up (neither the experimenter nor the participants were aware of the location of the bomb). Participants performed 30 trials. The task began with participants sequentially removing the parcels one at a time (starting with the top left parcel) until they decided to press the start-stop button. The more parcels collected, the greater the probability of picking up the bomb. Participants earned 4 points for each non-pump parcel removed. We calculated the mean number of parcels collected across all trials (MPC) and total points (TP) as dependent variables.

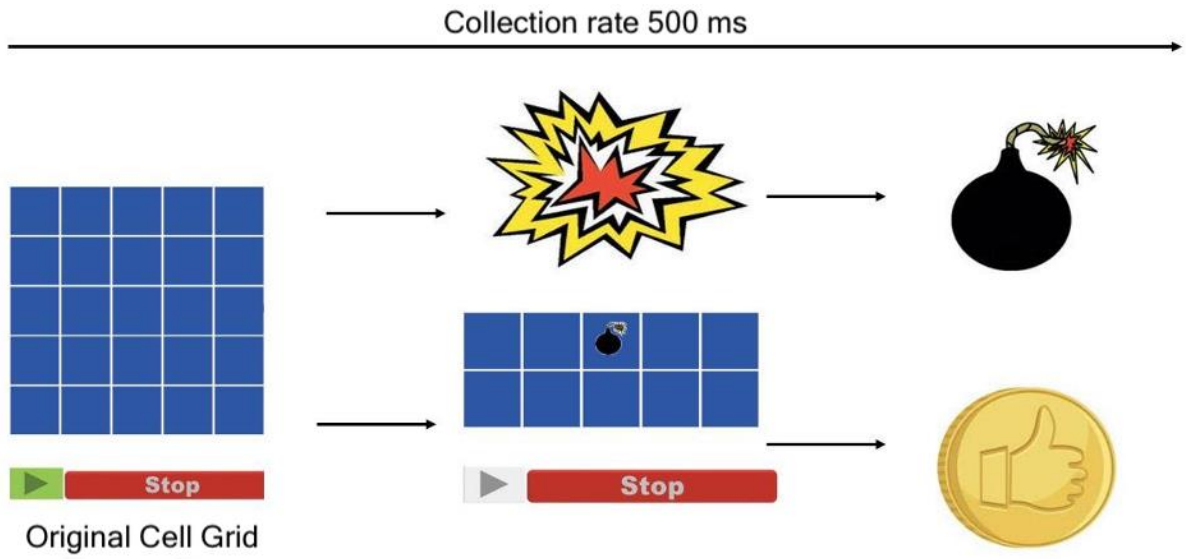


Figure 11 BRET task. In 30 separate trials, we presented participants with a start-stop button and a 25-cell grid containing a parcel bomb randomly placed in one of the cells and programmed to explode if collected. Participants sequentially remove parcels one by one and press the start-stop button to avoid collecting the bomb. The collection rate is 500 ms. (Source prepared by the author)

We created a points to euros conversion for each task to motivate participants to accumulate as many points as possible to achieve a higher reward. We programmed both tasks so that the maximum combined point and euro conversion, for both tasks, was 30 euros. The average financial reward for both tasks was €22. However, we rewarded all participants with the same financial compensation of 30 euros, at the suggestion of the university ethics committee.

7.1.1.6 Data analysis

We carried out the main analyses considering the independent variables as categorical variables and the dependent variables as continuous variables. The categorical variables were MtDCS (3 levels: DLPFC, VLPFC, and sham); personality (3 levels, based on the results of the LPA, see Results); and stimulation intensity: (2 levels: 1.5 mA and 2 mA). The continuous variables were AVP, TE, and WP for BART, and MPC and TP for BRET. We used a mixed design to test differences between independent groups (personality and stimulation intensity) as we subjected participants to repeated measures (MtDCS). We performed mixed analyses of

variance with the corresponding contrast analyses (simple for the between-group effect, and polynomial for the within-group effect). Furthermore, we used the Shapiro-Wilk and Levene tests to verify we were working with random samples from normal populations with the same variance, and we used the Mauchly test to test the sphericity assumption.

We calculated effect-size measurements (Cohen's d and eta-squared–η2-) and its corresponding confidence intervals (CI) for a better understanding of the relative magnitude of the experimental variables. In order to obtain a confidence interval that was equivalent to the ANOVA F test of the effect (which employs a one-tailed, upper tailed, probability) we applied a CI of 90% following previous literature (e.g., Clay, 2014; Lakens, 2014; Steiger, 2004).

In addition, given the small sample size that could potentially limit the statistical power of the study, we performed Bayesian analyses to determine whether a non-significant effect indicated the absence of an intervention effect (Biel & Friedrich, 2018). In particular, we tested the relative plausibility of the alternative hypothesis (H_1) over the null hypothesis (H_0), i.e., the presence and absence, respectively, of the effects of MtDCS, personality, and stimulation intensity on BART and BRET performance. We calculated the Bayes factor expressed as BF10, using the homologous Bayesian tests from the analyses described above, for a 95% credible interval. As we had no prior data with which to establish informed prioritization, we used the default Cauchy prior width of 0.707 provided by JASP 0.12.2 (JASP-Team, 2020). We compared the models used for the analyses with the model containing the overall mean and random factors, referred to as the null model.

To classify participants by personality profile, we conducted a latent profile analysis (LPA) of the personality data. LPA, which retrieves latent clusters from the observed data and groups individuals into clusters with similar characteristics relative to a set of measured variables (e.g., Flaherty & Kiff, 2012; Oberski, 2016; Steinley & Brusco, 2011), shows additional patterns of relationships over and above regression analyses (Stanley, Kellermanns, & Zellweger, 2017).

We determined the number of participants in each class entirely empirically, as there are no a priori assumptions about the number of individuals in each class. We performed frequentist analyses with SPSS version 23 (IBM Software Group, IL, USA) and STATA version 16 (StataCorp LLC, USA), while we performed Bayesian analyses with JASP computer software, version 0.12.2 (JASP Team, Amsterdam, The Netherlands). Finally, we used RStudio 1.1.463 and the tidyLPA package (version) (M. Rosenberg, N. Beymer, J. Anderson, & A. Schmidt, 2018) to perform LPA of the personality data.

7.1.2 Results

7.1.2.1 Latent profile analysis

We used the LPA results as independent variables to test hypotheses b) and c). To evaluate the best-fit profile, we examined 3 models and selected a 3-class model by comparing interpretability and statistical robustness (sample-adjusted Bayesian information criterion (SABIC) 1795.729).

Table 5 Descriptive analysis of personality data.

Personality measures	N	Min	Max	Mean	Std. Deviation
Narcissism	34	4.00	20.00	9.73	3.74
Psychopathy	34	4.00	15.00	8.09	2.97
Machiavellianism	34	4.00	16.00	10.09	3.83
Openness to Experience	34	27.00	47.00	37.15	5.18
Conscientiousness	34	27.00	49.00	37.35	5.49
Agreeableness	34	17.00	49.00	31.47	7.59
Extraversion	34	15.00	46.00	32.70	7.43
Emotionality	34	19.00	46.00	32.03	6.73
Honesty/Humility	34	20.00	46.00	33.76	7.27

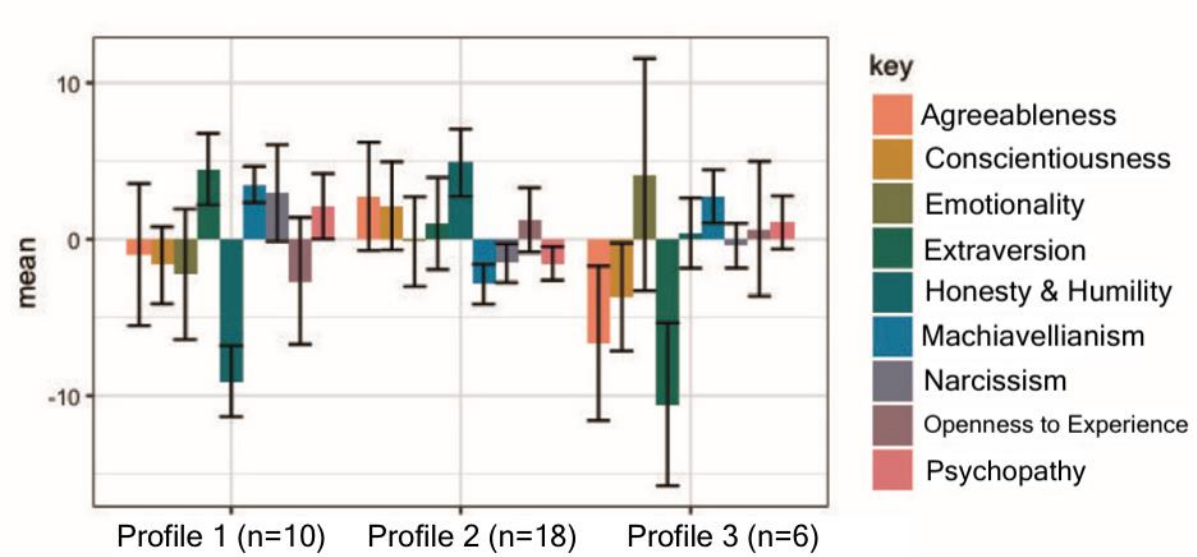
We compared this profile with 2- and 4-profile models with a higher BIC, and lower Entropy. The 3-profile latent model exhibited the best trade-off between SABIC, BIC, and Entropy (e.g., Araújo, Gomes, Almeida, & Núñez, 2019; Criterion, 2015; I Vrieze, 2012; Stanley et al., 2017). Mean Cohen's d between classes (expressed as multivariate Mahalanobis' distance) was 0.53. Taking into account this effect size, our sample size (n=34), and the number of indicators used (k=8) to classify participants, we run a number of simulations to estimate our observed power. Results indicated that SABIC yielded correct classifications in 98% of replications (after 1,000 replications). In small size samples, SABIC clearly outperforms BIC (in these simulations, BIC yielded correct classifications only in 17% of replications (https://osf.io/m79pg/, Gallardo-Pujol, in preparation).

Table 6 Results for competing latent profile analysis models of personality data.

Model	AIC	BIC	SABIC	Entropy
1 (2 profiles)	1883.08	1925.82	1812.28	.86
2 (3 profiles)	1872.88	1930.88	1795.73	.92
3 (4 profiles)	1872.27	1945.53	1838.44	.91

Note. AIC=Akaike's Information criterion; BIC= Bayesian information criterion; SABIC= Sample-size Adjusted Bayesian information criterion.

We also show the means of the dimensions for each personality profile, identifying 3 profiles for interpretation and labeling (see Annex Table A7).



Note. Mean values for this plot are not standardized. Error bars indicate standard error.

Figure 12 Personality profile estimation. The personality profile model is specified by passing arguments to the *variance* and *covariance* arguments. In this model, we fixed the equal variances and covariance to 0 by default. (Source prepared by the author).

Profile 1 (*n*=10), consistent with dark triad behaviors (K. Lee & Ashton, 2014), scored high on Machiavellianism, narcissism, psychopathy, and extraversion, and low on agreeableness, conscientiousness, emotionality, honesty-humility, and openness to experience, and was therefore labeled an impulsive-uninhibited group. Profile 2 (*n*=18), reflecting a pattern of centered and homogeneous means, was labeled the normative group. Finally, profile 3 (*n*=6), which scored around the mean on the dark triad, was low in extraversion and agreeableness, and high in emotionality. It was labeled as the inhibited/emotional group, and we expected it to be risk averse (see in Annex Table A8 and Table A9).

We also report correlations between dependent variables and personality dimensions (see Annex table A10).

7.1.2.2 Risk decision-making tasks

The Shapiro-Wilk test indicated that the dependent variables (BART: AVP, TE, and WP; BRET: MPC and TP) were normally distributed in the 3 MtDCS conditions (DLPFC, VLPFC,

and sham), whereas the Levene's test showed equality of variances for the same 3 conditions. For the repeated-measures analysis, Mauchly's test indicated that the variances of the differences between all possible pairs of within-subject (MtDCS) conditions were equal (it assumed sphericity).

We observed no significant main effect of stimulation intensity on the dependent variables (BART: AVP, TE, and WP; BRET: MPC and TP) for any personality profile or for any MtDCS condition, suggesting that stimulation intensity did not modify risk-taking during the BART and BRET trials.

7.1.2.2.1 BART

In relation to the AVP dependent variable, a mixed-design analysis of variance showed a significant main effect (within-group effect) of the stimulation condition (MtDCS: $F_{(2,56)}$=3.15, p=0.05; observed power=0.58; η^2=.10, 90% CI [0.00-0.22]; polynomial contrast $F_{(1,28)}$=8.02, p=0.008; observed power=0.78; η^2=.22, 90% CI [0.03-0.41]). Specifically, the planned post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) showed a higher AVP for the sham stimulation than for the DLPFC stimulation ($t_{(27)}$=2.37, p=0.02; Mean difference (Mdiff) =4.63; Cohen's d=.57, 95% CI[0.71-1.07]).

There was no significant main effect for personality (between-group effect). Although the interaction between personality and stimulation condition was not statistically significant, for personality profile 1, we found a pronounced tendency toward significance regarding the differences between the 3 MtDCS conditions ($F_{(2, 27)}$=3.14, p=0.059; observed power=0.55; η^2=.189 90%, CI [0.00-0.35]).

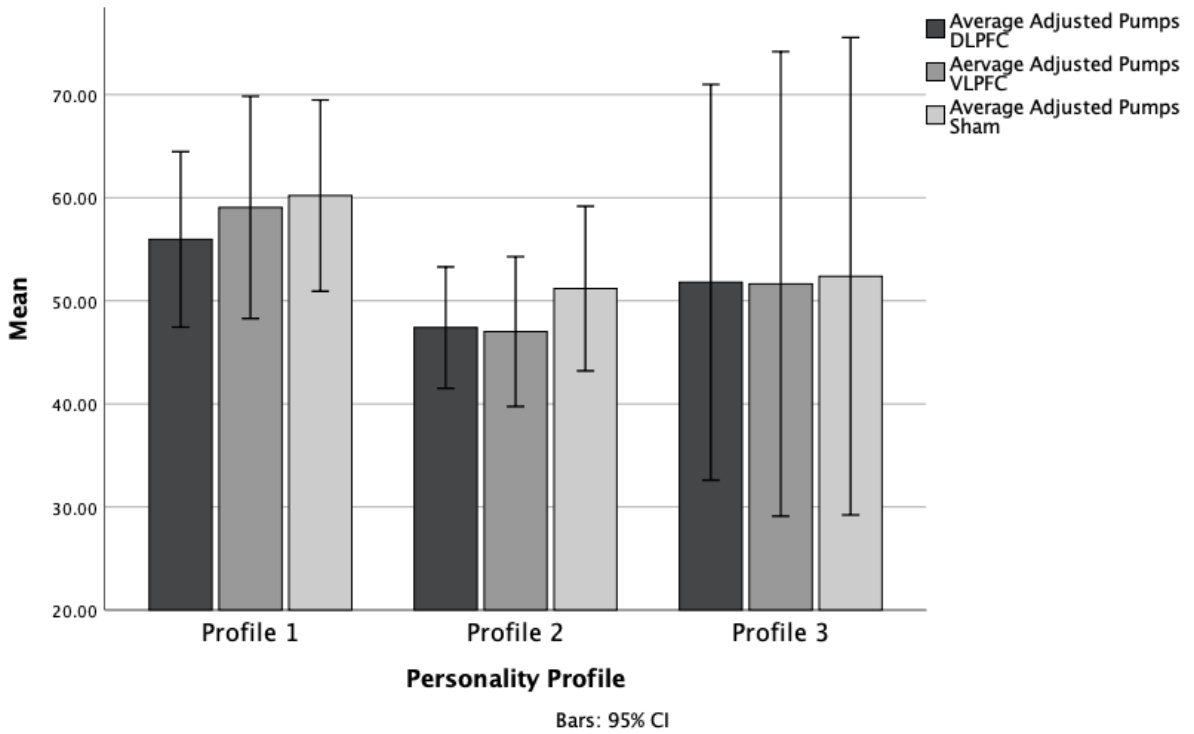


Figure 13 Graphic distribution of the adjusted average of pumps for BART. Comparison of the means of the independent groups (DLPFC, VLPFC, and Sham) by personality profiles. The figure represents the arithmetic means of each group, plotting the 95% confidence interval (CI) of the mean. As we can see in the figure, subjects from profile 1 showed a stronger tendency towards significant effects between sham, DLPFC, and VLPFC. DLPFC: Dorsolateral Prefrontal Cortex, VLPFC: Ventrolateral Prefrontal Cortex. (Source prepared by the author)

Specifically, the post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) revealed higher AVP for the sham stimulation than for the DLPFC stimulation ($t_{(27)}$ =2.05, p=0.05; Mdiff=9.30; Cohen's d=.49 95%, CI[-0.00-0.99]). For personality profile 2, despite the fact that the analysis of variance showed significant differences between the 3 MtDCS conditions ($F_{(2,27)}$=3.75, p=0.04; observed power=0.63; η^2=.22, 90% CI [0.01-0.38]), the post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) did not point to significant differences in any of the comparisons.

Regarding TE, although a mixed-design analysis of variance showed no significant main effect for MtDCS (within-group effect), it did show a significant main effect for personality (between-group effect) ($F_{(2,28)}$=6.1, p=0.006; observed power=0.85; η^2=.30, 90% CI [0.06 – 0.46]). The Bonferroni corrected post-hoc test showed higher TE values for personality profile 1 than for personality profile 2 ($t_{(28)}$=2.59, p=0.01; Mdiff=168.21; Cohen's d=1.02, 95% CI[0.19-1.83]).

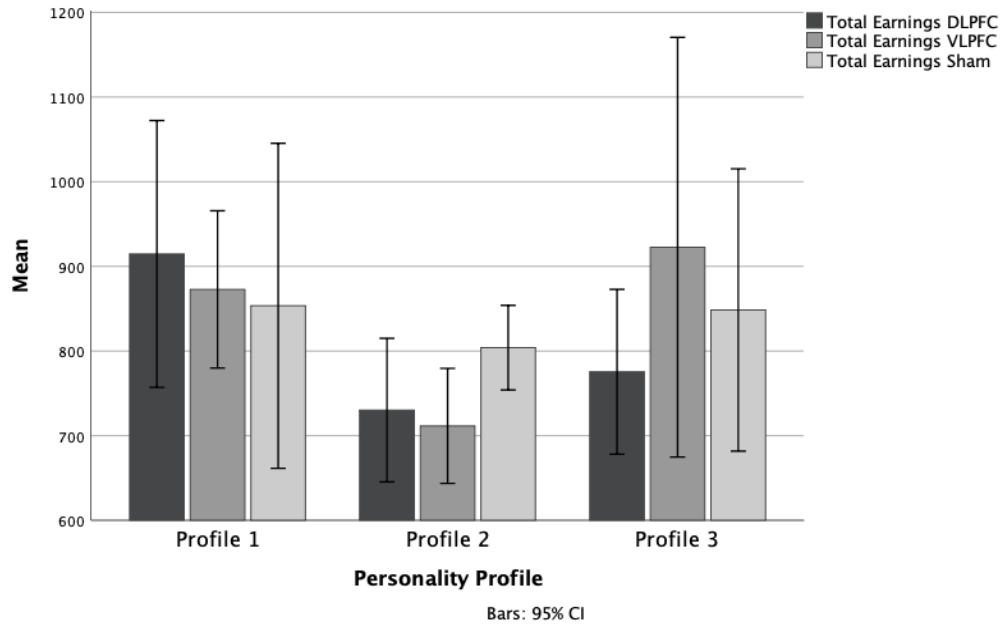


Figure 14 Graphic distribution of total earnings for BART. Comparison of the means of the independent groups (DLPFC, VLPFC, and Sham) by personality profiles. The figure represents the arithmetic means of each group, plotting the 95% confidence interval (CI) of the mean. There were significant effects based on personality. Profile 1 showed significantly higher TE values than profile 2. DLPFC: Dorsolateral Prefrontal Cortex, VLPFC: Ventrolateral Prefrontal Cortex. (Source prepared by the author)

There was significant interaction between the stimulation condition and personality, indicating that the effect of the stimulation on TE depended on the personality profile (MtDCS x personality: $F_{(2,28)}$=3.52, p=0.04; observed power=0.60; η^2=.20, 90% CI [0.00-0.37]). Specifically, for MtDCS and VLPFC, we found significant differences between the 3

personality profiles ($F_{(2,28)}$=7.71, p=0.002; observed power=0.92; η^2=.35, 90% CI [0.09-0.51]). After VLPFC inhibition, the Bonferroni corrected post-hoc test produced lower TE values for personality profile 2 than for personality profiles 1 and 3 ($t_{(28)}$=2.56, p=0.02; Mdiff=261.56; Cohen's d=1.01, 95% CI[0.19-1.82] and $t_{(28)}$=2.62, p=0.014; Mdiff= 217.58; Cohen's d=1.24, 95% CI[0.25-2.20] respectively).

A mixed-design analysis of variance showed a marked tendency toward significance regarding the differences in WP for the within-group effect (MtDCS: polynomial contrast $F_{(1,28)}$=3.92, p=0.057; observed power=0.48; η^2=.12, 90% CI [0.00-0.31]).

Although the analysis of variance showed no significant main effect for personality (between-group effect), we found significant differences between the 3 MtDCS conditions for personality profile 1 ($F_{(2,27)}$=3.59, p=0.04; observed power=0.61; η^2=.21, 90% CI [0.00-0.38]). Specifically, the Bonferroni corrected post-hoc test showed a significant tendency for higher WP values for the sham stimulation than for the DLPFC stimulation ($t_{(27)}$=1.99, p=0.056; Mdiff=322.28; Cohen's d=.48, 95% CI[0.01-0.97]).

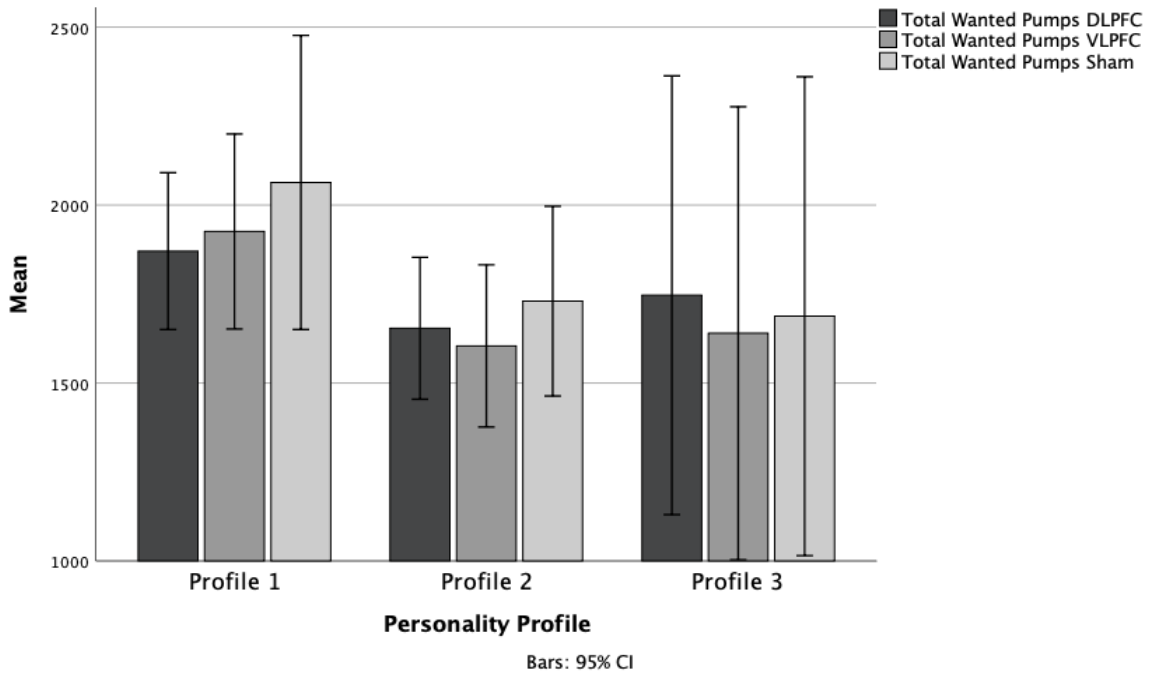


Figure 15 Graphic distribution of wanted pumps for BART. Comparison of the means of the

independent groups (DLPFC, VLPFC, and Sham) by personality profiles. The figure represents the arithmetic means of each group, plotting the 95% confidence interval (CI) of the mean. Profile 1 showed significantly higher WP values for sham compared to DLPFC stimulation. DLPFC: Dorsolateral Prefrontal Cortex, VLPFC: Ventrolateral Prefrontal Cortex. (Source prepared by the author)

7.1.2.2.2 BRET

In relation to the MPC dependent variable, a mixed-design analysis of variance showed a main effect bordering on statistical significance (within-group effect) for the stimulation condition (MtDCS: $F_{(2,56)}$=3.04, p=0.056; observed power=0.57; η^2=.09, 90% CI [0.00-0.21]; polynomial contrast $F_{(1,28)}$=8.50, p=0.007; observed power=0.80; η^2=.23, 90% CI [0.04-0.42]; MtDCS x personality: polynomial contrast $F_{(2,28)}$=3.34, p=0.050; observed power=0.58; η^2=.19, 90% CI [0.00-0.36]). Specifically, the Bonferroni corrected post-hoc test showed that MPC was significantly higher for the sham stimulation than for the DLPFC stimulation ($t_{(27)}$=2.45, p=0.02; Mdiff=1.208; Cohen's d=.59, 95% CI[0.09-1.09]).

Although the analysis of variance showed no significant main effect for personality (between-group effect), we found significant differences between the 3 MtDCS conditions for personality profile 1($F_{(2,28)}$=4.56, p=0.02; observed power=0.73; η^2=.24, 90% CI [0.02-0.41]). Specifically, the Bonferroni corrected post-hoc test was higher for the sham stimulation than for the DLPFC stimulation ($t_{(28)}$=2.57, p=0.02; Mdiff=2.79; Cohen's d=.62, 95% CI[0.12 – 1.12]).

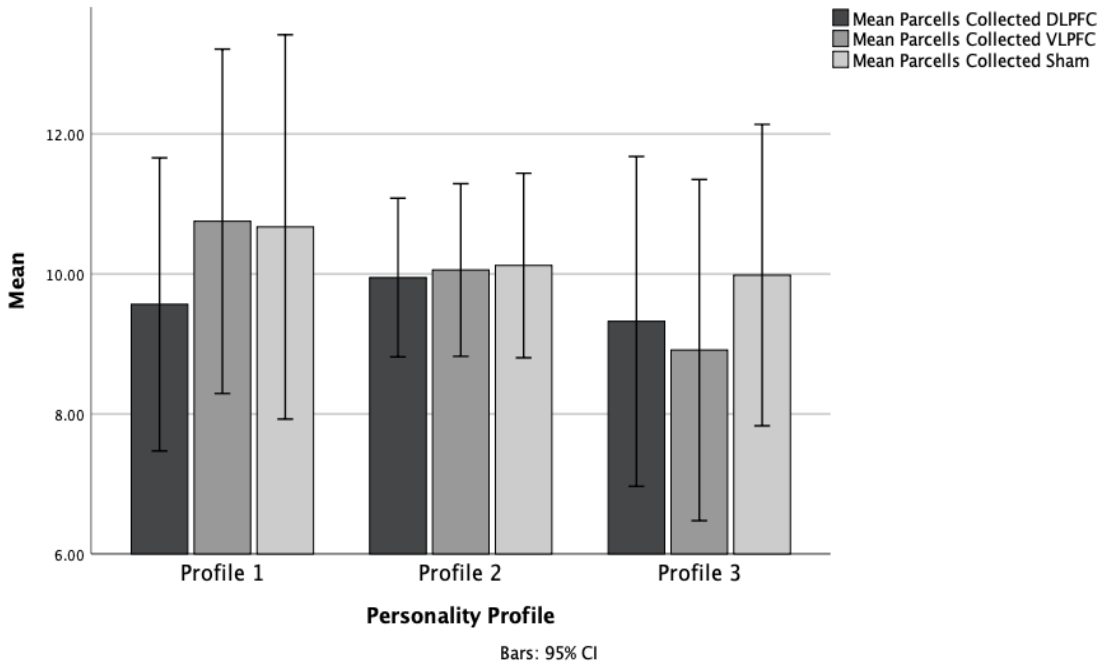


Figure 16 Graphic distribution of mean parcels collected for BRET. Comparison of the means of the independent groups (DLPFC, VLPFC, and Sham) by personality profiles. The figure represents the arithmetic means of each group, plotting the 95% confidence interval (CI) of the mean. Profile 1 showed significant values for MPC in sham compared to DLPFC stimulation. DLPFC: Dorsolateral Prefrontal Cortex, VLPFC: Ventrolateral Prefrontal Cortex. (Source prepared by the author).

Regarding TP, we found no significant differences between the different personality profiles for any of the 3 MtDCS conditions (See results annex Table A10).

7.1.2.2.3 Bayesian analyses

Bayesian comparisons between independent groups (personality and stimulation intensity) for the MtDCS condition (within-subjects factors) and for each of the dependent variables yielded results very similar to those obtained in the frequentist statistical analyses. Overall, the Bayesian analyses reinforced the finding of non-significant effects for the frequentist analyses (i.e., stimulation intensity) and support the null hypothesis.

7.1.2.2.4 Personality

Correlation analyses showed that psychopathy was positively and significantly correlated with AVP for all 3 MtDCS conditions (DLPFC: r=0.47, *p*=0.01; VLPFC: r=0.45, *p*=0.01; sham: r=0.44, *p*=0.01), and that emotionality negatively correlated with all 3 MtDCS conditions (DLPFC: r=-0.41, *p*= 0.05; VLPFC: r=-0.44, *p*=0.01; sham: r=-041, *p*=0.05).

Regarding the BRET, we found that MPC was negatively correlated with narcissism (DLPFC: r=-0.43, *p*=0.05; sham: r=-0.37, *p*=0.05), and positively correlated with agreeableness (sham: r=0.43, *p*=0.05) (see Annex Table A10).

In addition, we included the descriptive analysis of the dependent variables and a pairwise comparison of cathodal DLPFC vs sham, cathodal VLPFC vs sham, and cathodal VLPFC vs cathodal DLPFC under different personality groups (see Annex Table A11 and Table A12).

Table 13 Result Summary Experiment I.

Dependent Variable	**Statistical test**	**Tests of Within-Subjects Effects**		
AVP	GLM	Stimulation type $F(2,56)=3.14$, $p=0.05$	Stimulation type * Intensity $F(2,56)=0.45$, $p=0.64$	Stimulation type * Personality $F(4, 56)=0.78$; $p=0.54$
TE	GLM	Stimulation type $F(2,56)=1.59$, $p=0.21$	Stimulation type * Intensity $F(2,56)=1.63$, $p=0.20$	Stimulation type * Personality $F(4,56)=0.96$, $p=0.43$
WP	GLM	Stimulation type $F(2,56)=1.83$, $p=0.17$	Stimulation type * Intensity $F(2, 56)=0.09$; $p=0.91$	Stimulation type * Personality $F(4,56)=1.14$; $p=0.34$
MPC	GLM	Stimulation type $F(2,56)=3.04$, $p=0.056$	Stimulation type * Intensity $F(2, 56)=0.98$, $p=0.38$	Stimulation type * Personality $F(4,56)=1.60$, $p=0.19$
TP	GLM	Stimulation type $F(2,56)=1.60$, $p=0.21$	Stimulation type * Intensity $F(2, 56)=0.51$, $p=0.60$	Stimulation type * Personality $F(4,56)=0.21$, $p=0.93$

Note. * AVP: adjusted average pumps, TE: Total Earnings, WP: Wanted Pumps, MPC: mean parcels collected, TP: total points. Significant effects are in green.

Dependent Variable	**Statistical test**	**Tests of Within-Subjects Contrasts**		**Tests of Between-Subjects Effects**
AVP	GLM	Linear: Stimulation type $F(1,28)=8.02$, $p=0.01$	Linear: Stimulation type* Personality $F(2, 28)= 1.77$, $p=0.19$	Personality $F(2, 28)=1.06$, $p=0.36$

TE	GLM	Linear: Stimulation type $F(1,28)=1.55$, $p=0.22$	Linear: Stimulation type* Personality $F(2, 28)= .00$, $p=1.00$	Personality $F(2, 28)=6.15$, $p=0.01$
TE	GLM		Quadratic: Stimulation type*Personality $F(2,28)=3.53$, $p=0.04$	
WP	GLM	Linear: Stimulation type $F(1,28)=3.92$, $p=0.057$	Linear: Stimulation type* Personality $F(2, 28)= 2.27$, $p=0.12$	Personality $F(2, 28)=1.04$, $p=0.37$
MPC	GLM	Linear: Stimulation type $F(1,28)=8.50$, $p=0.01$	Linear: Stimulation type* Personality $F(2, 28)= 3.34$, $p=0.05$	Personality $F(2, 28)=0.33$, $p=0.72$
TP	GLM	Linear: Stimulation type $F(1,28)=1.93$, $p=0.18$	Linear: Stimulation type* Personality $F(2, 28)= .30$, $p=0.74$	Personality $F(2, 28)=0.049$, $p=0.95$

Note. * AVP: adjusted average pumps, TE: Total Earnings, WP: Wanted Pumps, MPC: mean parcels collected, TP: total points. Significant effects are in green.

Dependent Variable	Statistical test	Bonferroni Adjustment for Multiple comparisons
AVP	t-test	Stimulation type Sham vs DLPFC $t(27)=2.37$, $p=0.025$
AVP	Multivariate test	Profile 1 $F(2,27)=3.14$, $p=0.059$
AVP	Multivariate test	Profile 2 $F(2,27)=3.75$, $p=0.04$
AVP	t-test	Stimulation type Sham vs DLPFC $t(27)=2.05$, $p=0.050$
TE	t-test	Profile 1 vs Profile 2 $t(28)=2.59$, $p=0.015$
TE	Univariate test	VLPFC Stimulation $F(2,28)=7.70$, $p=0.002$
TE	t-test	VLPFC stimulation profile 1 vs Profile 2 $t(28)=2.56$, $p=0.02$

TE	t-test	VLPFC stimulation profile 2 vs Profile 3 $t(28)=2.62$, p=0.01
WP	Multivariate test	Profile 1 $F(2,27)=3.59$, $p=0.04$
WP	t-test	Profile 1 sham vs DLPFC $t(27)=1.99$, $p=0.056$
MPC	Multivariate test	Profile 1 $F(2,28)=4.55$, $p=0.02$
MPC	t-test	Stimulation type Sham vs DLPFC $t(27)=2.45$, $p=0.02$
MPC	t-test	Profile 1 sham vs DLPFC $t(28)=2.57$, $p=0.02$
TP	Multivariate test	Profile 1 $F(2,27)=0.33$, $p=0.72$
TP	t-test	DLPFC vs sham $t(28)=0.64$, $p=0.52$

Note. * AVP: adjusted average pumps, TE: Total Earnings, WP: Wanted Pumps, MPC: mean parcels collected, TP: total points. Significant effects are in green.

Here we conclude the first experiment. We dedicate a long part of this thesis, at the end, to analyze and discuss the results found in each study in a collected and organized manner. This is done as a means to facilitate the understanding the results of each study.

As stated earlier, because of our interest in cognitive control, and all functions related to it, we have focused the first study on risk decision making. Cognitive processes influence decision making. The second experimental part of this thesis is devoted to the study of one of the processes included in cognitive control, working memory and emotional interference. In addition, we have chosen to explore whether personality could also be a factor to be taken into account.

7.2 Experiment II: WM, emotional interference, rTMS, and personality

In this experiment we explored the contributions of the DLPFC to emotional interference in working memory using a causal approach. Using rTMS, we modulated DLPFC activity in opposite directions (increasing and decreasing its excitability) and assessed working memory performance under the interference of emotionally salient versus neutral and scrambled distractors. We also took personality into account.

7.2.1 Material and methods

7.2.1.1 Participants

Thirty-two female volunteers participated in the study (18-49, mean 24.813±8 years). All of them passed the TMS exclusion criteria and met the internationally established TMS safety criteria (Rossi et al., 2009). None were taking medication or had a history of neurological disorders or psychiatric illness. None had a history of alcohol or drug abuse. We recruited only females because of the extensive literature focusing on sex differences in emotional processing (e.g., Collignon et al., 2010; Gohier et al., 2013; Iordan, Dolcos, Denkova, et al., 2013; Rohrmann, Hopp, Schienle, & Hodapp, 2009; Schienle, Schäfer, Stark, Walter, & Vaitl, 2005)

and how brain activity responds to stimuli that are emotional (J. S. Stevens & Hamann, 2012). Hence, we had to control for possible confounding due to hormones in task performance (e.g., Cobey, Little, & Roberts, 2015; DeBruine, Jones, & Perrett, 2005; Jones et al., 2005; Little, Burriss, Petrie, Jones, & Roberts, 2013; Little, Jones, Burt, & Perrett, 2007; Little et al., 2010; Penton-Voak et al., 1999; Peters, Simmons, & Rhodes, 2009) and in brain activity (Rupp et al., 2009). Thus, we recorded which phase of the menstrual cycle each participant was in at the time of the task. Thirteen were in the luteal phase, six in the preovulatory phase, twelve in the follicular phase and one in the menopausal phase. We separated the participants into three different experimental groups. Each group received a different rTMS protocol: sham, cTBS or iTBS. Ten participants were in the iTBS group, eleven in the cTBS and eleven in the sham group. The allocation of participants was random.

The local Ethics Committee of the Universitat Oberta de Catalunya (UOC) approved this study we and conformed to the declaration of Helsinki. We provided to all participants with written informed consent that they all signed and, in addition, received monetary compensation at the end of the study for their participation.

7.2.1.2 Procedure and brain stimulation

Before starting the experiments, all participants had to fill out the TMS safety guidelines online. Once approved, they also filled out a personality questionnaire (HEXACO and Dirty Dozen).

On the day we conducted the experiment, all participants received an informed consent and performed a practice round of the task. Participants, right after receiving the assigned rTMS stimulation, performed the Delayed Response WM task. The rTMS stimulation over the DLPFC was aimed at increasing (iTBS) or decreasing (cTBS) cortical excitability. In order to localize the target area and thus navigate the position of the TMS coil during stimulation, we obtained a T1 sequence of high-resolution structural magnetic imaging (MRI) for each participant. We used a 1.5 T scanner (Siemens Magnetom Essenza) at Hospital Quirón Salut

in Barcelona. They used the following parameters of the FSPGR-T1 3D: slice thickness = 1 mm; repetition time (TR) = 500 ms; echo time (TE) = 50 ms; matrix = 256×256; field of view (FOV) = 240; 180 sagittal slices.

We used a Magstim Super Rapid^2 stimulator (Magstim Company Ltd., Whitland, U.K.) with a figure eight-coil of 70 mm to apply the rTMS stimulation. Before starting the experimental session, we determined the active motor threshold (aMT) for each participant. The aMT is the minimum intensity of a single TMS pulse that induced a visible muscle spasm in the FDI on 5 of 10 trials when the muscle contracted about 20% of the maximal voluntary contraction. For this procedure, the TMS coil should be placed tangentially over the subject's right M1. In addition, the handgrip should be placed 45° backward. In our sample, the mean aMT was 53.31±7.23 of the maximum stimulator output.

Once the aMT was determined, all participants had to perform a practice block, which included four trials of the task (excluding emotional distractors). The use of this practice round was to familiarize subjects with the task prior to the start of stimulation and to have an understanding of what was being asked of them. Participants could repeat the task as many times as they wanted until they were sure they understood what they had to do during the task. Once they understood the task, each participant received one of the three simulations. The TBS protocols (Y.-Z. Huang, Rothwell, et al., 2009) consist primarily of 600 pulses that are grouped into bursts of three pulses at an intensity of 50 Hz. Every 200 ms the burst repeats (5 Hz). On the one hand, at the time of iTBS, bursts repeat for 2 sec, with an interval of 8 s without stimulation. Blocks of 10 s are made. These 10 s blocks repeat 20 times, making a total of 3 minutes and 12 seconds of stimulation. On the other hand, cTBS consists of bursts that repeat continuously for 40 s, with no intervals without stimulation. Previous studies have shown that when they apply these two protocols to the primary motor cortex, they produce opposite effects on corticospinal excitability. iTBS increases motor cortical excitability and cTBS decreases it

(e.g., Y.-Z. Huang, Rothwell, et al., 2009; Y. Z. Huang et al., 2005; Y. Z. Huang, Rothwell, Chen, Lu, & Chuang, 2011).

We delivered TBS stimulation at an intensity of 80% of their individual aMT. And for sham, using either protocol, we administered it at the same intensity and positioning the coil at the vertex of the scalp, in a 90° inclined perpendicular position, so that it projects the magnetic field away from the scalp.

We administered the stimulation over the left DLPFC. We identified this region anatomically for each participant. For that, we used a frameless stereotaxic system and software (Brainsight, Rogue Research, Montreal, Canada). It was equipped with an infrared tracking system (Polaris Northern Digital, Waterloo, ON, Canada) to identify, in normalized MNI coordinates, the location of the left DLPFC (x=31.06±7.32, y=38.58±6.05, z=34.75±5.57).

Therefore, we were able to accurately localize the coil position during the stimulation protocol for all participants.

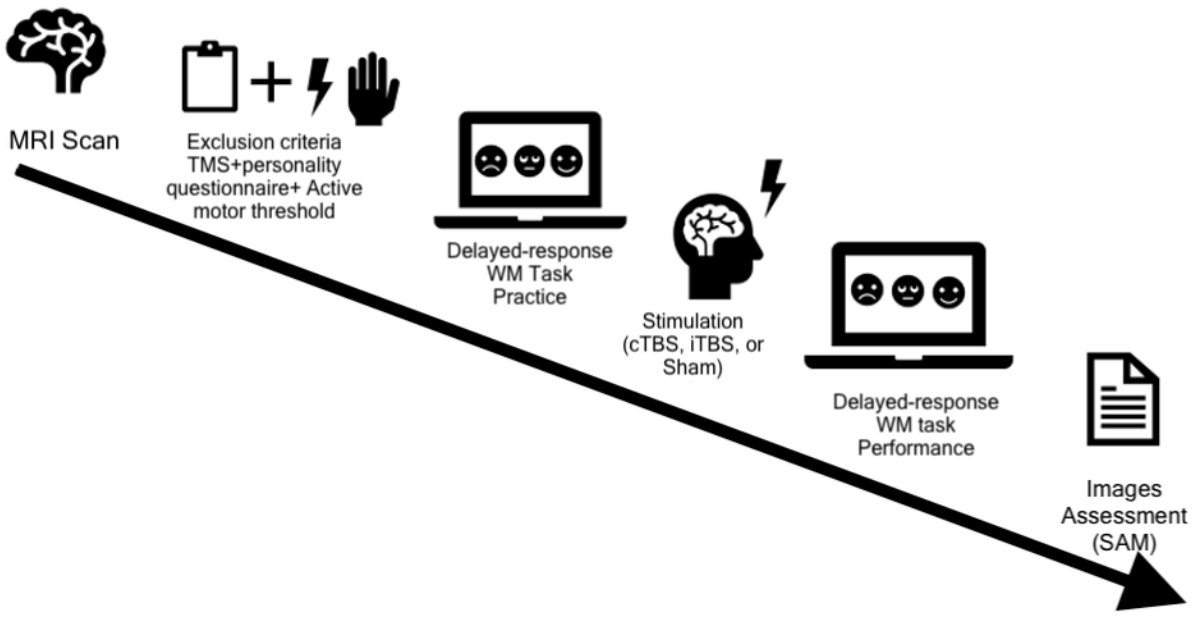


Figure 17 Experimental procedure. Before the experimental session, we acquired a structural MRI to locate the target and guide the stimulation. Before stimulation, we estimated the active motor threshold. Participants practiced the task, and after stimulation, they performed the task. After completing the task,

participants assessed the valence and arousal of the images and received compensation. (Source prepared by the author)

Once they completed the experimental session, we asked all participants to fill out an effective judgment questionnaire about the images presented to them during the task. The questionnaire was the self-Assessment Manikin (SAM) affective rating questionnaire (M. M. Bradley & Lang, 1994). The researchers conducted this questionnaire using a nonverbal pictorial assessment technique. It uses graphic icons representing a series of values along 2 dimensions (arousal and valence) on a rating scale (from 1 to 9). The valence dimensions range from smiling, happy, to hurt and unhappy. The arousal dimension ranged from excited, vigilant to relaxed and drowsy. We asked all participants to indicate their level of arousal and emotional valence for each image (neutral, emotional, stirred). Each response reflected their subjective opinion.

This was done in order to confirm whether the perception of IAPS stimuli reported by our sample corresponded with previous IAPS ratings. Thus, it could possibly identify unlikely effects of rTMS on emotional perceptions based on the subject's post hoc reports.

7.2.1.3 Behavioral task: delayed response WM

Participants performed a computerized task consisting of a delayed-response WM task. In this task, it presented emotional distractors during the delay period (Dolcos & McCarthy, 2006). The WM task consisted of three phases: the first, an encoding phase, the second a delay interval phase, and finally a response phase.

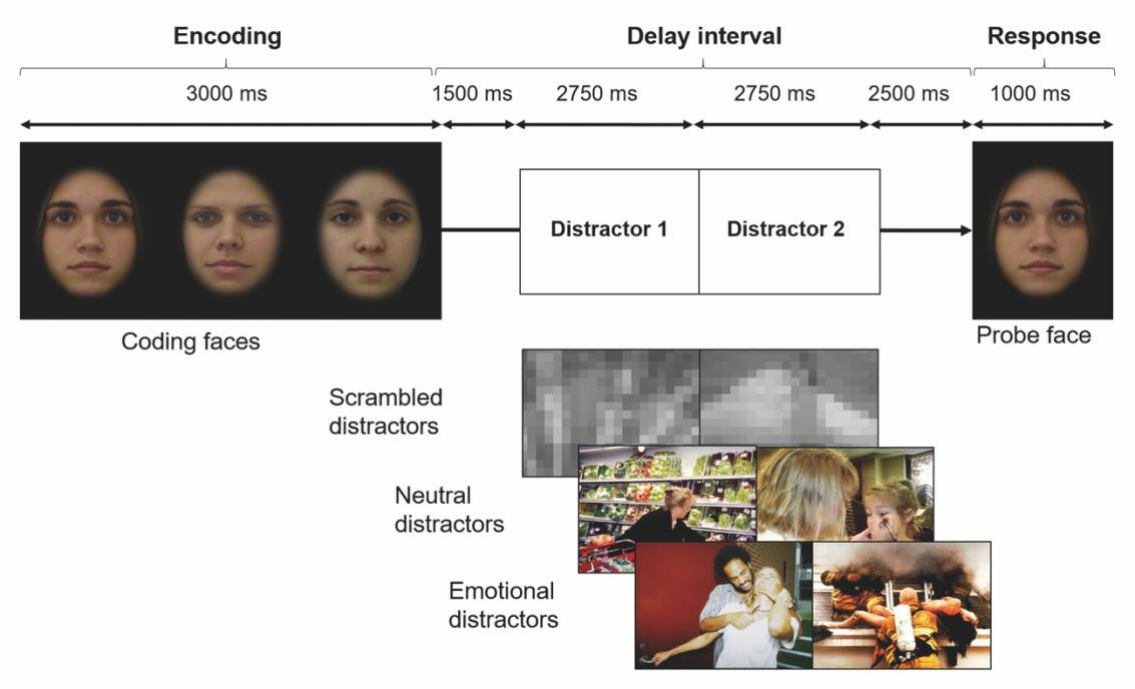


Figure 18 Delayed-response WM paradigm. The encoding phase consisted of three human faces presented simultaneously during 3000 ms. We told participants to memorize these faces. After 11.50 s it showed a probe face on the screen for 1000 ms and subjects had to indicate by pressing either "J" or "K" if they have seen that face previously during the encoding phase. During the task, it presented two distractors of the same kind one after the other (emotional, neutral, or scrambled). Participants had to focus on the task while it presented the distractors. (Source: Viejo-Sobera, R., Marron, E. M., Valero-Cabré, A., & Redolar-Ripoll, D., submitted).

The encoding phase consisted of three neutral faces presented at the same time for 3000 ms. A delay interval phase followed the presentation of these three faces. In this delay interval phase, it shows a black display for 1500 ms and then two distractor images with the same valence (either emotional, neutral or scrambled) are presented one after the other for 2750 ms each. This delay interval phase lasts up to 9.5 s and ends with another black screen lasting up to 2500 ms. Finally, the response phase. In this phase, it presents a test face or 1000 ms. It asks participants to press as fast as they can with their index finger on the computer keyboard "J" or "K". "J" to indicate whether it had previously presented the probe face in the encoding phase,

thus matching. And “K” if it was a new face, therefore, not a match. In general, each trial lasted about 13.5 seconds and the intervals consisting of black screens lasted about 1500 ms. We selected the faces that it displayed during the response phase or the encoding phase from the color FERET database (National Institute of Standards and Technology, USA). And also, from the FEI face database (FEI Artificial Intelligence Laboratory, São Bernardo do Campo, São Paulo, Brazil). The size of the faces within the image was 8 cm wide x 11 cm high. Likewise, the distractor images were 18.5 cm wide x 13.5 cm high. All faces selected were neutral in expression, and we excluded faces that were conspicuous, such as those with piercings, earrings, or glasses. In addition, identifying elements, such as hair and clothing, were covered with a black oval frame.

We obtained distractors, neutral and emotional, from the International Affective Picture System (IAPS) (Lang, P. J., Bradley, M. M., & Cuthbert, 2008). All images depicted a part of the human body. The mean emotional valence of the neutral images was 5.47±1.37 and the mean level of arousal was 3.4±1.96. For images that were emotional, we selected those with the highest arousal and lowest valence. This was done to ensure the salience of the stimuli. Thus, the mean valence of the emotional images was 1.88±1.32 and the mean arousal level was 6.63±2.25 (Lang, P. J., Bradley, M. M., & Cuthbert, 2008). However, coded images, which consisted of a combination of grayscale and pixelated versions of the above images, were used as a control.

During the experiment, participants had to be seated comfortably, about 60 cm away from the screen. The task, as well as the data recording, was performed with e-Prime 2.0 (Psychology Software Tools). It presented the images on a black background on a 17" CRT screen (75 Hz). In total, participants performed 84 trials, 28 with each distractor. Half included all male or all female faces, and one face that it presented a priori or not in the response phase. To lessen the possible impact of the emotional images, and thus minimize the practice effect, the order of

presentation was random across all participants, and they performed the task only once. Between trials, participants took a 1-min break after 50 trials to avoid possible fatigue. In total, it took 22 minutes to complete the task.

7.2.1.4 Data analysis

We performed the main analyses considering the independent variables as categorical variables, and the dependent variables as continuous variables. The categorical variables were rTMS (3 levels: cTBS, iTBS and sham); personality (3 levels, based on LPA scores, see Results). Continuous variables were the three levels of distractors (emotional, neutral and digital), the correct recognition score (CRS), which was calculated based on signal detection theory (Macmillan & Creelman, 1991). It is calculated by: correct responses/(correct responses+incorrect responses). In this equation, correct responses mean those trials in which participants correctly identified the probe face, thus as a hit, and also correctly identified the mismatch. We also used as continuous variables the reaction times of correct and incorrect responses. We also compared the dependent variables with menstrual cycle (luteal, preovulatory, follicular and menopausal), to see if there was any effect on task performance.

Furthermore, we also performed a general linear repeated measures model (GLM) to compare the three groups (iTBS, cTBS and sham; between subject's independent variables), at the three levels of the dependent variable or distractors (emotional, neutral and scrambled), being the within-subjects repeated measures variable. We performed the same analyses using different dependent variables.

We used the Shapiro-Wilk and Levene tests to check that we were working with random samples from normal populations with the same variance, and we used the Mauchly test to check the assumption of sphericity.

To classify participants by personality profile, we performed a latent profile analysis (LPA) of the personality data. LPA, which retrieves latent clusters from the observed data and groups

individuals into clusters with similar characteristics in relation to a set of measured variables (e.g., Flaherty & Kiff, 2012; Oberski, 2016; Steinley & Brusco, 2011) shows additional patterns of relationships over and above regression analyses (Stanley et al., 2017). We determined the number of participants in each class entirely empirically, as there are no a priori assumptions about the number of individuals in each class.

We performed frequentist analyses with SPSS version 27 (IBM Software Group, IL, USA) and STATA version 16 (StataCorp LLC, USA), while we performed Bayesian analyses with JASP computer software, version 0.12.2 (JASP Team, Amsterdam, The Netherlands). Finally, RStudio 1.1.463 and the tidyLPA package (version) (M. Rosenberg et al., 2018) were used to perform LPA of the personality data.

7.2.2 Results

7.2.2.1 Latent profile analysis

We used the LPA scores as independent variables to test whether personality had an effect on emotion and WM. To assess the best-fit profile, we examined 3 models and selected a 3-class model by comparing interpretability and statistical robustness (sample-adjusted Bayesian information criterion (SABIC).

Table 14 Descriptive analysis of personality data

Personality measures	N	Min	Max	Mean	Std. Deviation
Narcissism	32	4.00	15.00	9.31	3.33
Psychopathy	32	4.00	12.00	6.50	2.15
Machiavellianism	32	4.00	14.00	7.91	2.76
Openness to Experience	32	21.00	46.00	36.56	5.54
Conscientiousness	32	23.00	49.00	37.69	6.39
Agreeableness	32	20.00	49.00	31.06	6.64

Extraversion	32	15.00	46.00	31.87	6.56
Emotionality	32	22.00	47.00	35.69	7.02
Honesty/Humility	32	24.00	46.00	37.03	5.23

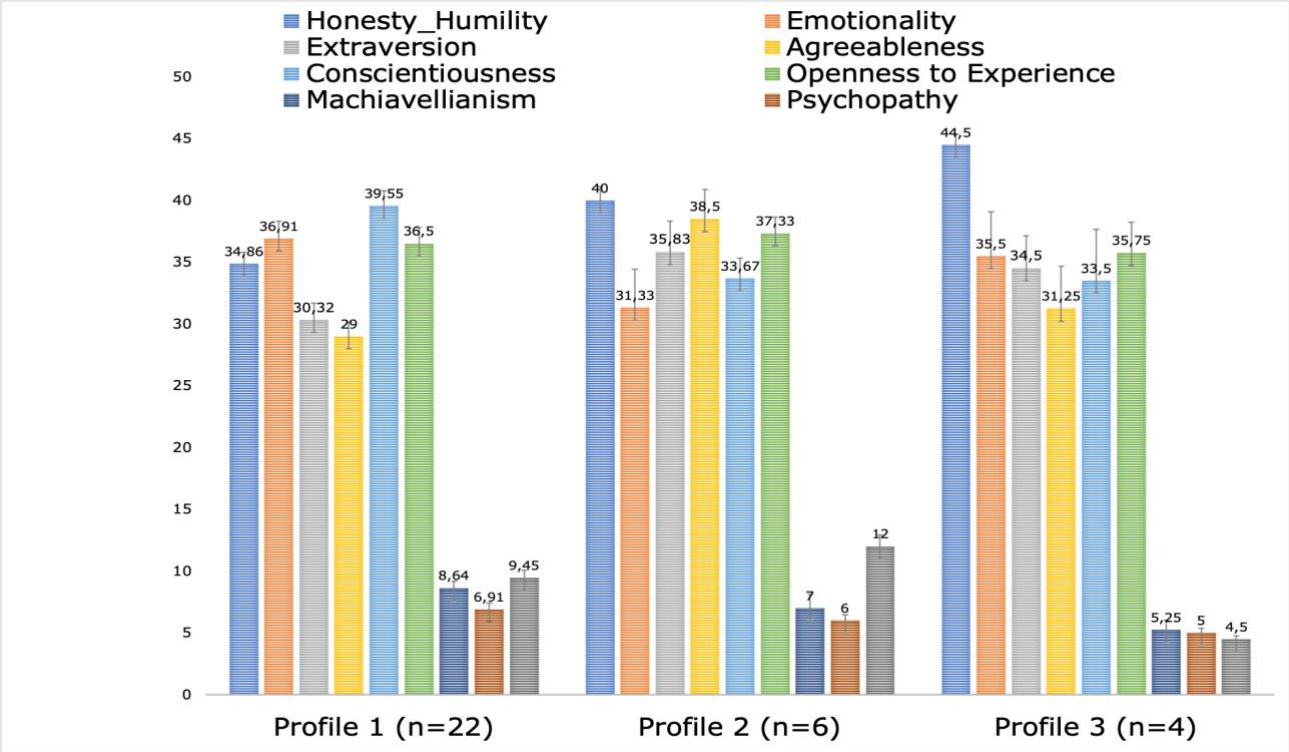
We compared this profile to 1- and 3-profile models with higher Entropy. The latent 3-profile model showed the best balance between SABIC, BIC and Entropy (e.g., Araújo et al., 2019; Criterion, 2015; I Vrieze, 2012; Stanley et al., 2017).

Table 15 Results for competing latent profile analysis models of personality data.

Model	AIC	BIC	SABIC	Entropy
1 (1 profile)	1736.09	1762.47	1706.36	1.00
2 (2 profiles)	1740.85	1781.89	1694.61	.85
3 (3 profiles)	1753.75	1809.44	1690.98	.81

Note. AIC=Akaike's Information criterion; BIC= Bayesian information criterion; SABIC= Sample-size Adjusted Bayesian information criterion.

We also show the means for the dimensions for each personality profile, identifying 3 profiles for interpretation and labeling.



Note. Mean values for this plot are not standard. Error bars indicate standard error.

Figure 19 Personality profile estimation.

As we can see in this graph, the three profiles are very similar, however, there are some minor differences. Profile 3 *(n*=4) is a profile with very high honesty-humility and the lowest measures among the three dark triad dimensions. Therefore, we label this profile as "honest-inhibited". Profile 2 (*n*=6), is the profile with the highest mean in narcissism, and also in openness to experience, so we label this profile as "narcissistic". And profile 1 (*n*=22) is labeled as the normative type. See Annex for graphic representation of personality profiles for both experiments (See Annex Figure A20). In addition, we did a personality profile comparison (see in Annex Table A16 and A17).

7.2.2.2 Working memory-emotional Interference task

Age and motor threshold had significant differences between the three stimulation groups [$F_{(2,31)}$=3.74, p=0.03; observed power=0.63; η^2=.20, 90% CI [0.00-0.35] and [$F_{(2,31)}$=5.49,

p=0.01; observed power=0.81; η^2=.27, 90% CI [0.04-0.41]] (see in Annex Figure A21 and A22).

The planned post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) showed a higher motor threshold for the cTBS stimulation than for the iTBS stimulation and sham respectively ($t_{(29)}$=2.23, p=0.03; Mean difference (Mdiff)=7.55; Cohen's d=.97, 95% CI[0.07-1.85] and $t_{(29)}$=2.53, p=0.02; Mean difference (Mdiff)=8.09; Cohen's d=1.07, 95% CI[0.19-1.95) (see Table 18)

Table 18 Results age and motor threshold.

Dependent Variable	**Statistical test**	**Bonferroni Adjustment for Multiple comparisons**
Age	t-test	iTBS vs sham t(29)=0.45, p=0.65
Motor Threshold	t-test	cTBS vs iTBS t(29)=2.23, p=0.03
Motor Threshold	t-test	cTBS vs sham t(29)=2.53, p=0.02
Dependent Variable	**Statistical test**	**Tests of Between-Subjects Effects**
Age	GLM	Stimulation type F(2,31)=3.74, p=0.03
Motor Threshold	GLM	Stimulation type F(2,31)=5.49, p=0.01

Note. Significant effects are in green.

We divided the results into six different analyses:

1. The effect of stimulation on WM taking into account the distractors (neutral, emotional and digital). For corrected recognition scores (CRS), we found no significant differences for the

main effect of group, distractor, or their interaction. We found no significant differences in post hoc tests.

For correct reaction times, there was no significant effect for the stimulus group or for the group-distractor interaction. However, there was a significant effect for the distractors.

[$F_{(2,58)}$=5.48, p=0.01; observed power=0.83; η^2=.15, 90% CI [0.02-0.28]].

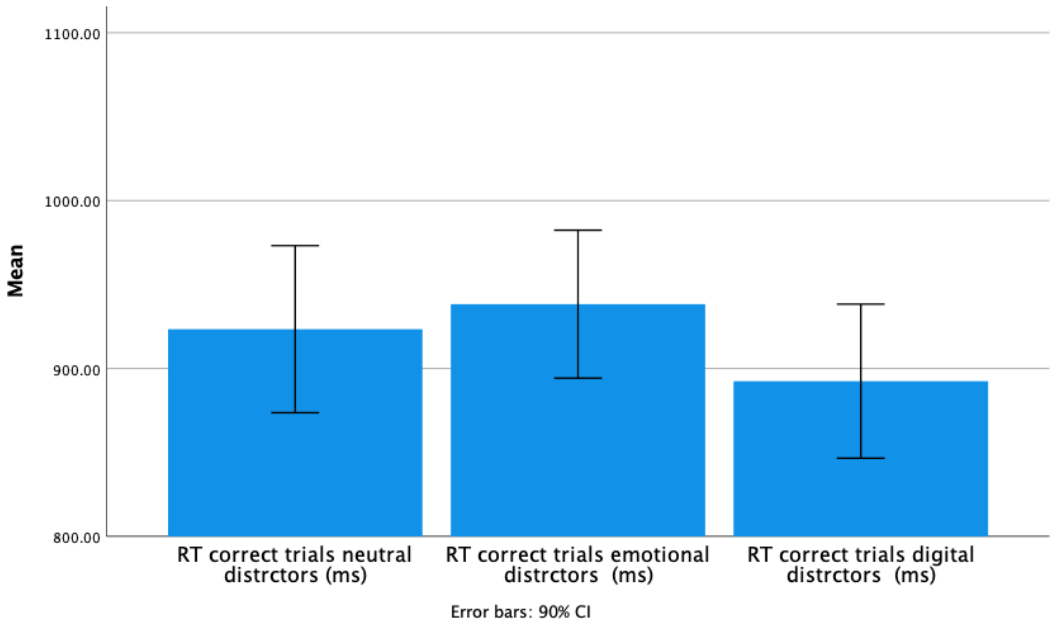


Figure 23 Mean reaction times for each distractor (neutral, emotional, and digital). (Source prepared by author)

Specifically, the post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) revealed a lower reaction time for correct trials for digital distractors compared to emotional distractors ($t_{(29)}$=2.42, p=0.02; Mean difference (Mdiff)=45.62; Cohen's d=.61, 95% CI[0.08-1.11]).

The reaction time for incorrect trials was not significant, neither for the group, the distractor nor the interaction. We found no significant differences between reaction times and the stimulation group. Therefore, it seems to point to the fact that stimulation did not modify processing speed during the working memory task (Table 19).

Table 19 Reaction times (RT) for the three stimulation groups and the three stimuli. Correct Responses are the data from the trials in which participants correctly identified the face from the encoding phase as being presented before, or not being presented before. Incorrect response means participants did not identify it correctly.

Response	Distractor	TMS	Mean	SD	95% CI
Correct	Neutral	iTBS	835.76	120.78	749.36-922.16
		cTBS	928.95	161.66	820.34-1037-5642
		Sham	997.71	179.81	876.91-1118.52
	Emotional	iTBS	865.15	142.67	763.09-967.21
		cTBS	942.20	134.30	851.97-1032.43
		Sham	1001.08	144.68	903.88-1098.28
	Digital	iTBS	828.32	125.36	748.64-918.00
		cTBS	893.98	113.05	818.03-969.94
		Sham	949.25	195.07	818.20-1080.31
Incorrect	Neutral	iTBS	931.01	160.25	816.37-1045.65
		cTBS	1035.13	204.56	897.70-1172.56
		Sham	1114.42	328.11	893.98-1334.85
	Emotional	iTBS	987.85	185.03	855.48-1120.22
		cTBS	1026.31	270.68	844.46-1208.16
		Sham	1099.02	159.12	992.12-1205.92
	Digital	iTBS	993.15	183.54	861.85-1124.45
		cTBS	978.89	230.79	823.84-1133.95
		Sham	1112.58	263.03	935.87-1289.29

As we can see in the table, even though the results were not significant, there is a tendency to decrease reaction times for TMS stimulation compared to sham for both trials, correct and incorrect (see Table 20).

Table 20 Results of the effect of the stimulation considering distractors.

Dependent Variable	Statistical test	Tests of Within-Subjects Effects		Tests of Within-Subjects Contrasts		Tests of Between-Subjects Effects
CRS	GLM	Distractor $F(2,58)=0.88$, $p=0.42$	Distractor*Stimulation type $F(4,58)=0.16$, $p=0.96$	Linear: Distractor $F(1,29)=0.61$, $p=0.44$	Linear: Distractor*Stimulation type $F(2,29)=0.11$, $p=0.89$	Stimulation type $F(2,29)=0.23$, $p=0.79$
RTcor	GLM	Distractor $F(2,58)=5.48$, $p=0.01$	Distractor*Stimulation type $F(4,58)=0.37$, $p=0.83$	Linear: Distractor $F(1,29)=4.80$, $p=0.04$	Linear: Distractor*Stimulation type $F(2,29)=0.74$, $p=0.48$	Stimulation type $F(2,29)=2.53$, $p=0.097$
RTer	GLM	Distractor $F(2,58)=0.05$, $p=0.95$	Distractor*Stimulation type $F(4,58)=0.56$, $p=0.69$	Linear: Distractor $F(1,29)=0.00$, $p=0.96$	Linear: Distractor*Stimulation type $F(2,29)=1.03$, $p=0.37$	Stimulation type $F(2,29)=1.34$, $p=0.28$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

Dependent Variable	Statistical test	Bonferroni Adjustment for Multiple comparisons
CRS	t-test	cTBS emotional distractor vs neutral distractor $t(29)=0.35$, $p=0.73$
RTcor	t-test	emotional vs digital distractors $t(29)=2.42$, $p=0.02$
RTcor	Pairwise Comparisons	Neutral distractor iTBS vs Sham $t(28)=1.84$, $p=0.08$
RTer	Pairwise Comparisons	iTBS vs sham $t(29)=0.91$, $p=0.37$
RTer	Pairwise Comparisons	Neutral distractor iTBS vs Sham $t(28)=1.08$, $p=0.29$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

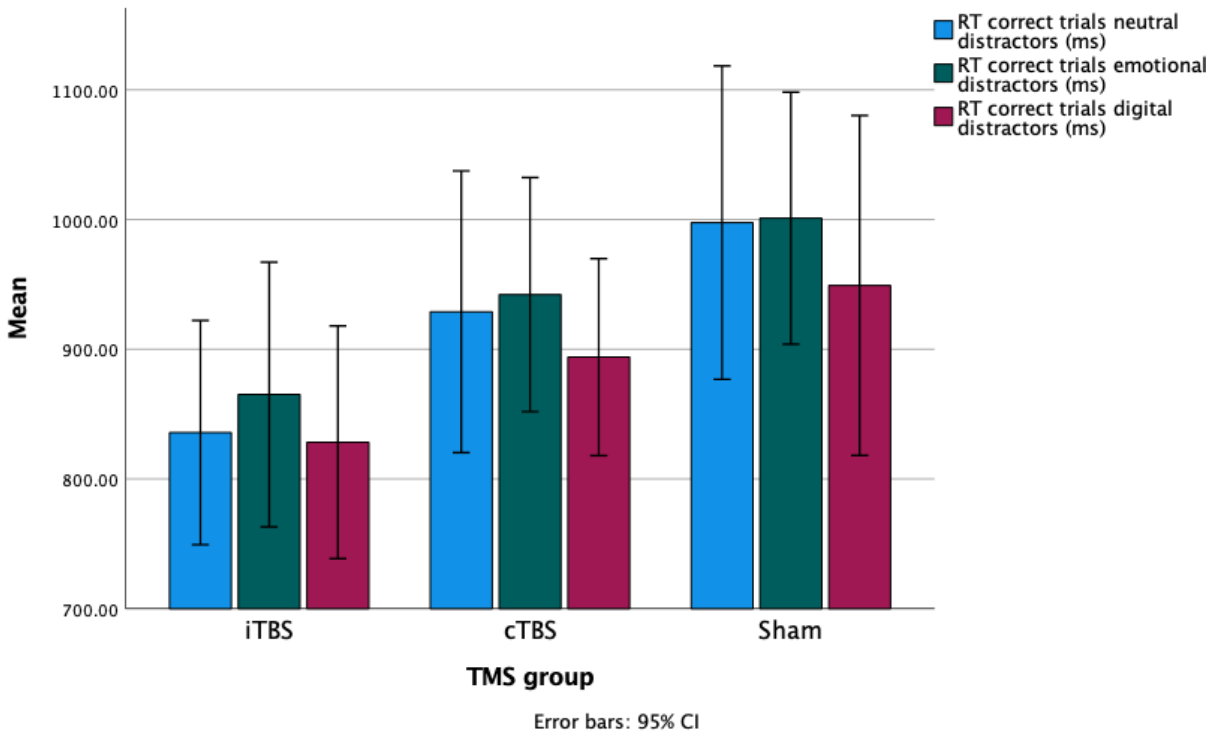


Figure 24 Reaction time distribution for correct trials by stimulation group and distractor type. (Source prepared by author)

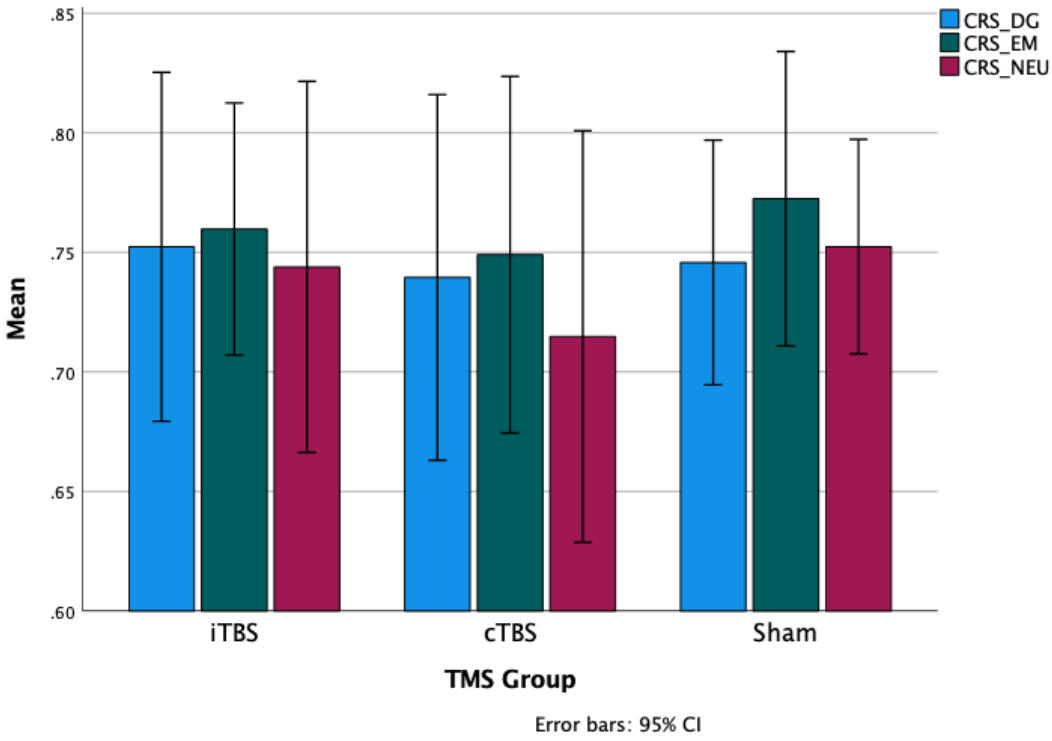


Figure 25 Corrected recognition scores distributed by stimulation group and distractor type. (Source prepared by author)

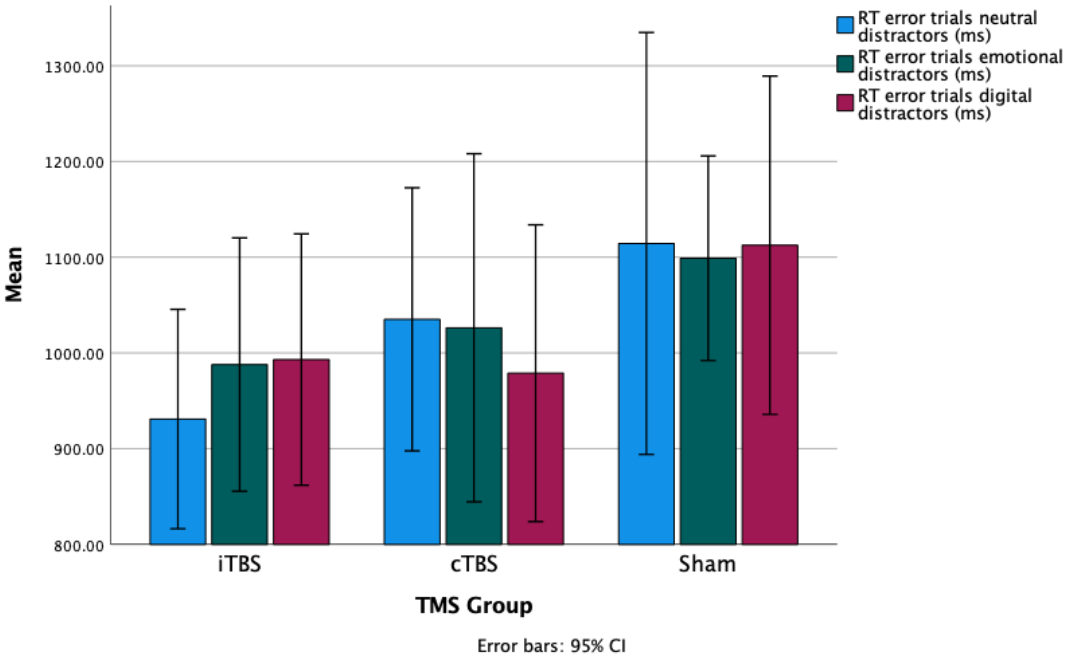


Figure 26 Reaction time for error trials by stimulation group and distractor type. (Source prepared by author)

2. The effect of stimulation on the WM task without taking into consideration the distractors. However, we found no significant effect. We saw a certain tendency, that with a bigger sample might give significant results (see Table 21)

Table 21 Effects of stimulation type on working memory without taking into consideration the distractors.

Dependent Variable	**Statistical test**	**Tests of Between-Subjects Effects**
CRS	GLM	Stimulation type $F(2,29)=0.21$, $p=0.81$
RTcor	GLM	Stimulation type $F(2,29)=2.53$, $p=0.097$
RTer	GLM	Stimulation type $F(2,29)=1.34$, $p=0.28$
Dependent Variable	**Statistical test**	**Bonferroni Adjustment for Multiple comparisons**
CRS	Univariate tests	$F(2,29)=0.21$, $p=0.81$

RTcor	Pairwise Comparisons	iTBS vs Sham $t(29)=1.71$, $p=0.097$
RTer	Pairwise Comparisons	iTBS vs Sham $t(29)=0.91$, $p=0.37$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

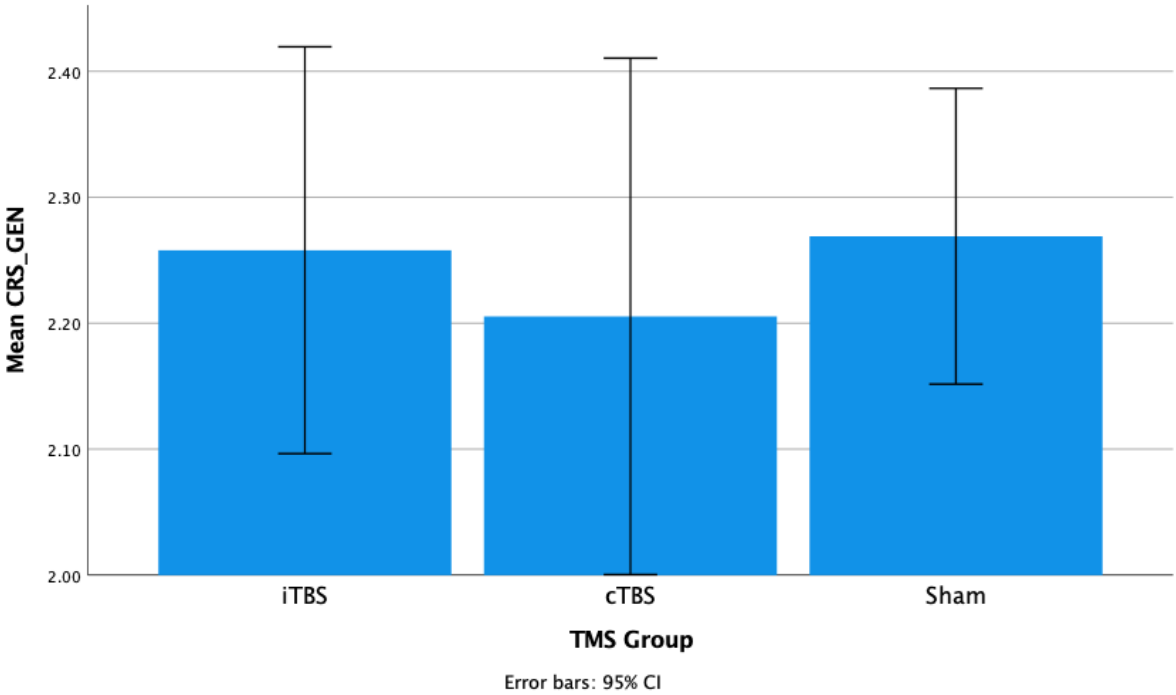


Figure 27 General corrected recognition scores by stimulation group (Source prepared by author)

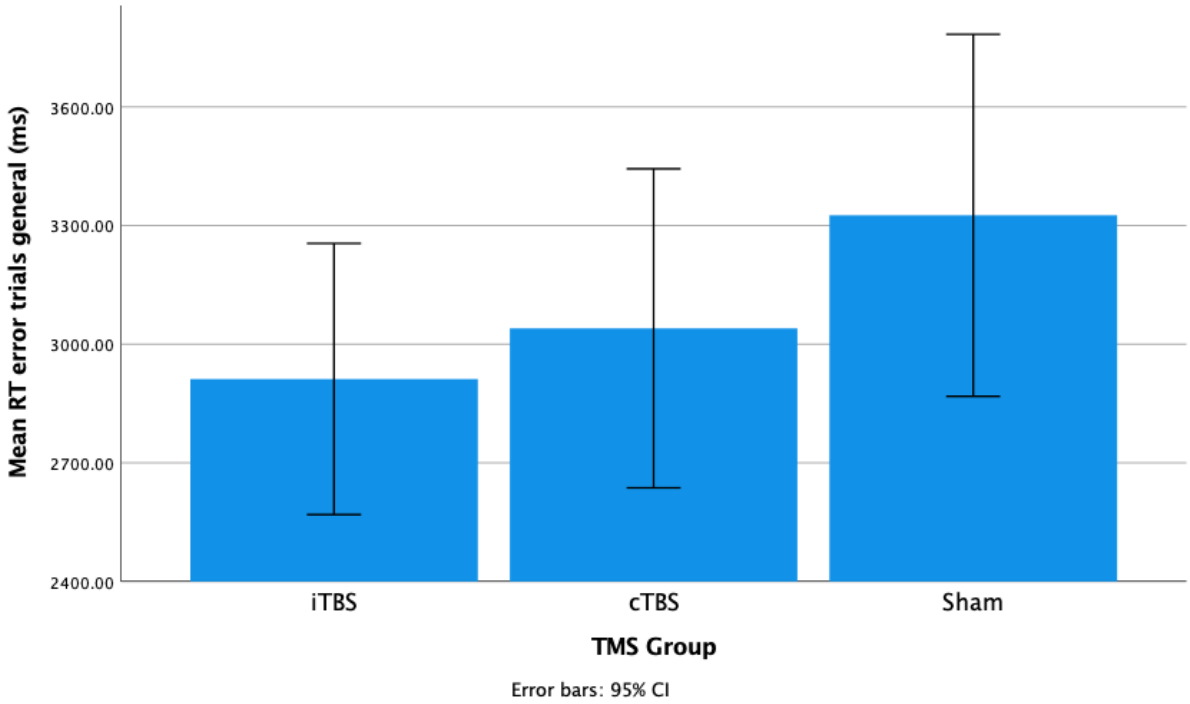


Figure 28 General reaction time for error trials by stimulation group (Source prepared by author)

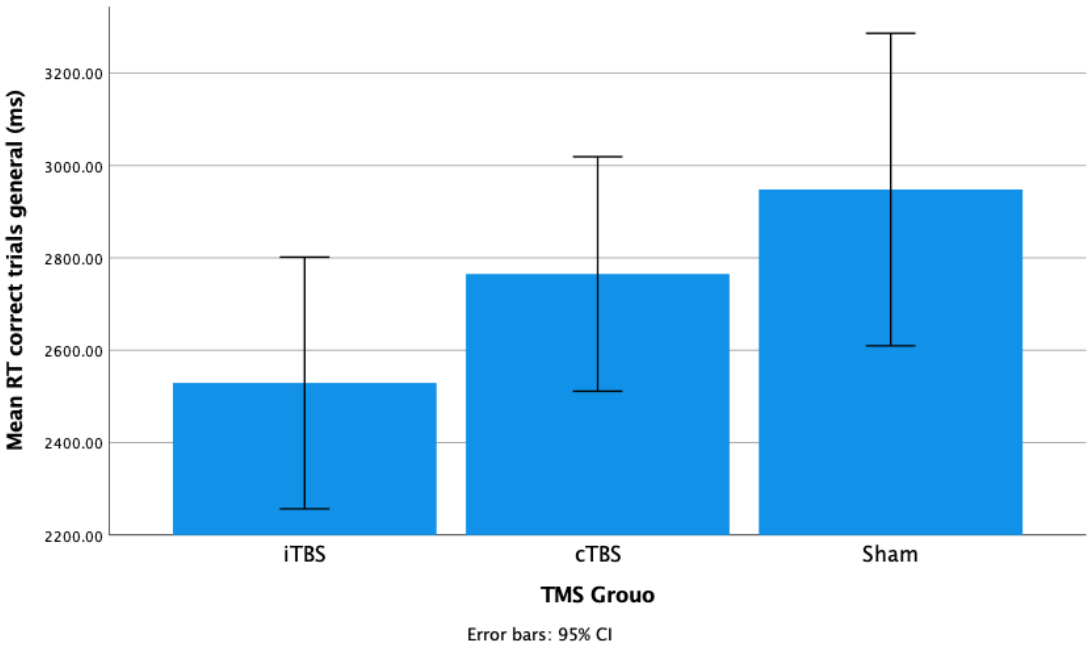


Figure 29 General reaction time for correct trials by stimulation group (Source prepared by author)

3. The effect of personality on the WM task, taking distractors into account. We found a significant within-subject contrast for distractors and distractor and personality interference, respectively, for the corrected recognition scores [$F_{(1,29)}$=5.47, p=0.03; observed power=0.61; η^2=.15, 90% CI [0.01-0.34] and [$F_{(2,29)}$=3.47, p=0.04; observed power=0.60; η^2=.19, 90% CI [0.00-0.35]].

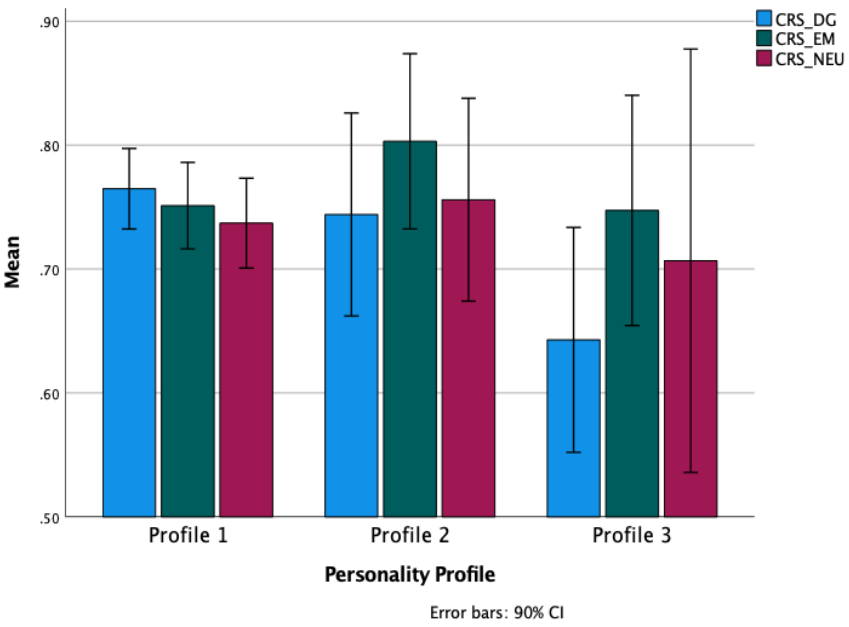


Figure 30 Corrected recognition scores distribution by profile and distractor. (Source prepared by author)

The post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) revealed an almost significant effect showing that profile 1 has a higher CRS for digital distractors compared to profile 3 ($t_{(29)}$ =2.01, p=0.05; Mdiff=0.12; Cohen's d= 1.09 95%, CI[0.01-2.18]).

The reaction time for corrected trials shows also a significant effect for distractors and a tendency for significance for the interaction between distractors and personality [$F_{(2,58)}$=6.68, p=0.002; observed power=0.90; η^2=.18, 90% CI [0.04-0.31] and [$F_{(4,58)}$=2.35, p=0.06; observed power=0.64; η^2=.13, 90% CI [0.00-0.23]].

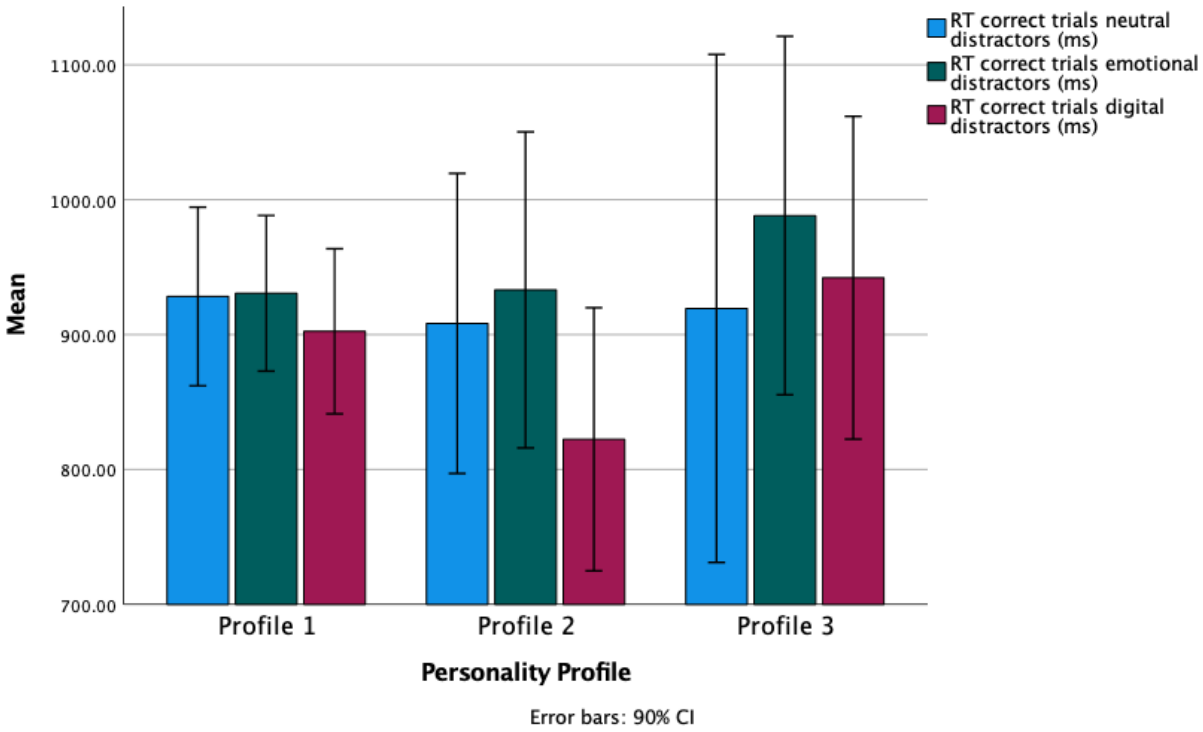


Figure 31 Reaction times (ms) of correct trials distributed by profile and distractors. (Source prepared by author)

Specifically, the post-hoc paired *t*-test (Bonferroni adjustment for multiple comparisons) revealed that participants from profile 2 took longer to react when dealing with neutral distractors than digital distractors. And took longer with emotional distractors than with digital

distractors ($t_{(29)}$ =2.40, p=0.02; Mdiff=85.88; Cohen's d=1.38 95%, CI[0.18-2.56] and $t_{(29)}$ =2.79, p=0.01; Mdiff=110.76; Cohen's d=1.61 95%, CI[0.39-2.80]).

The reaction time for incorrect trials did not have significant effects, however, the interaction between distractors and personality tended towards significance (see Table 22).

Table 22 Effects of personality on working memory taking into account the distractors.

Dependent Variable	**Statistical test**	**Tests of Within-Subjects Effects**		**Tests of Within-Subjects Contrasts**		**Tests of Between-Subjects Effects**
CRS	GLM	Distractor $F(2,58)=2.82$, $p=0.07$	Distractor*Personality $F(4,58)=1.85$, $p=0.13$	Linear: Distractor $F(1,29)=5.47$, $p=0.03$	Linear: Distractor*Personality $F(2,29)=3.47$, $p=0.04$	Personality $F(2,29)=0.98$, $p=0.39$
RTcor	GLM	Distractor $F(2,58)=6.68$, $p=0.0025$	Distractor*Personality $F(4,58)=2.35$, $p=0.06$	Linear: Distractor $F(1,29)=3.18$, $p=0.08$	Linear: Distractor*Personality $F(2,29)=2.81$, $p=0.08$	Personality $F(2,29)=0.20$, $p=0.82$

RTer	GLM	Distractor $F(2,58)=1.69$, $p=0.19$	Distractor*Personality $F(4,58)=2.24$, $p=0.08$	Linear: Distractor $F(1,29)=0.51$, $p=0.48$	Linear: Distractor*Personality $F(2,29)=0.78$, $p=0.47$	Personality $F(2,29)=0.47$, $p=0.63$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

Dependent Variable	**Statistical test**	**Bonferroni Adjustment for Multiple comparisons**
CRS	Pairwise Comparisons	Digital distractors profile 1 vs profile 3 $t(29)=2.01$, $p=0.05$
RTcor	Pairwise Comparisons	Profile 2 neutral vs digital distractors $t(29)=2.40$, $p=0.02$
RTcor	Pairwise Comparisons	Profile 2 emotional vs digital distractors $t(29)=2.79$, $p=0.01$
RTer	Pairwise Comparisons	Profile 2 neutral vs emotional distractors $t(29)=1.82$, $p=0.08$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

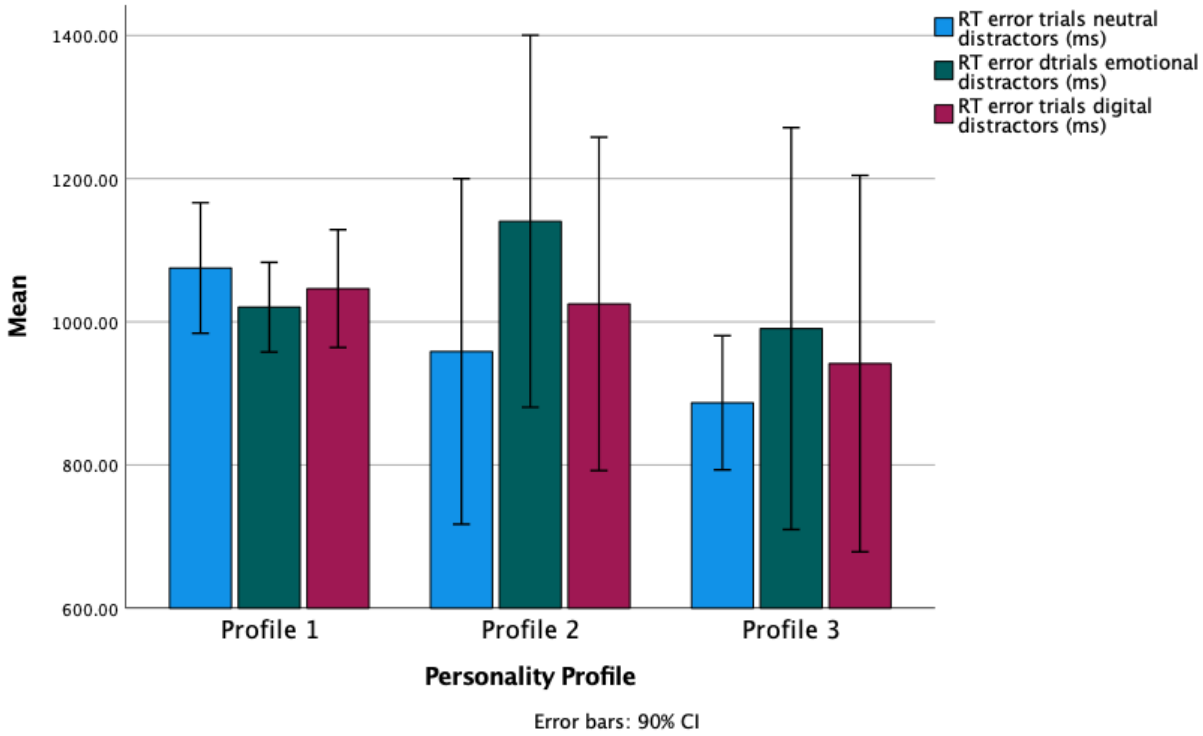


Figure 32 Reaction times (ms) of error trials distributed by profile and distractors. (Source prepared by author)

4. The effect of personality on the WM task overall, regardless of distractors.

There were no significant effects on the task for personality alone (see Table 23).

Table 23 Effect of personality on working memory without considering the distractors.

Dependent Variable	**Statistical test**	**Tests of Between-Subjects Effects**
CRS	GLM	Personality $F(2,29)=0.99$, $p=0.38$
TRcor	GLM	Personality $F(2,29)=0.20$, $p=0.82$
TRer	GLM	Personality $F(2,29)=0.47$, $p=0.63$

Dependent Variable	Statistical test	Bonferroni Adjustment for Multiple comparisons
CRS	Pairwise Comparisons	Profile 1 vs Profile 3 $t(29)=0.39$, $p=0.70$
RTcor	Univariate Tests	$F(2,29)=0.20$, $p=0.82$
RTer	Univariate Tests	$F(2,29)=0.47$, $p=0.63$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

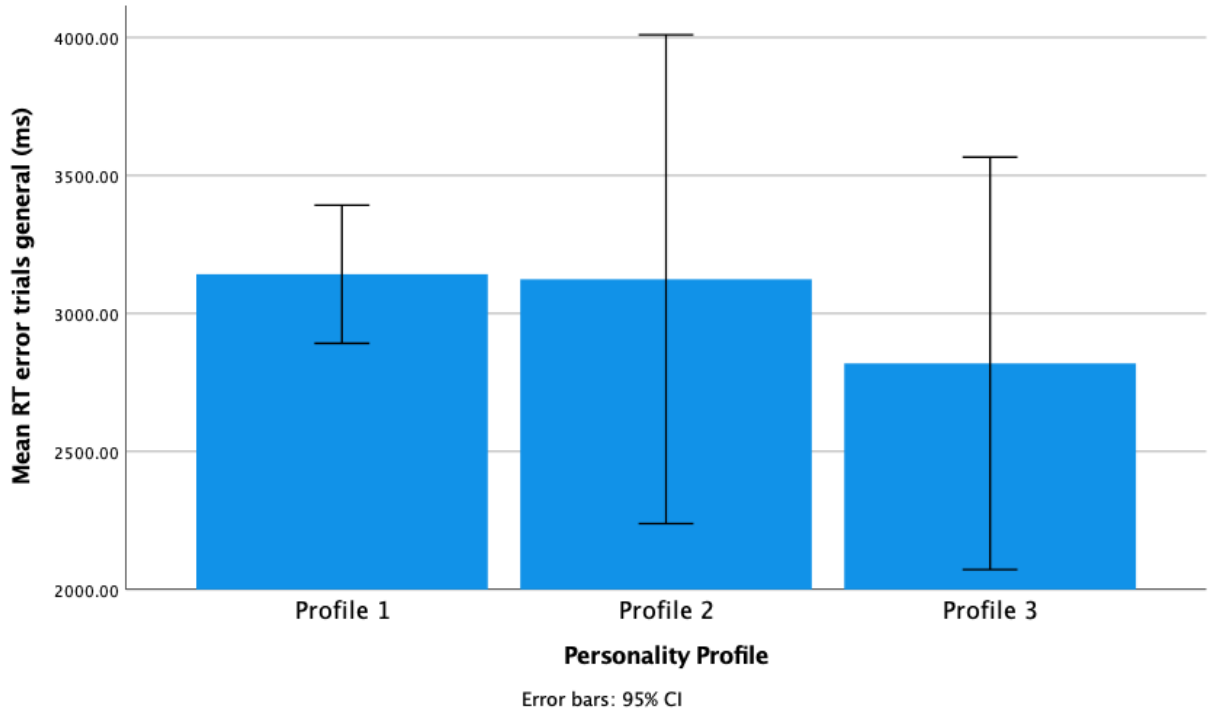


Figure 33 General reaction times (ms) of error trials distributed by profile. (Source prepared by author)

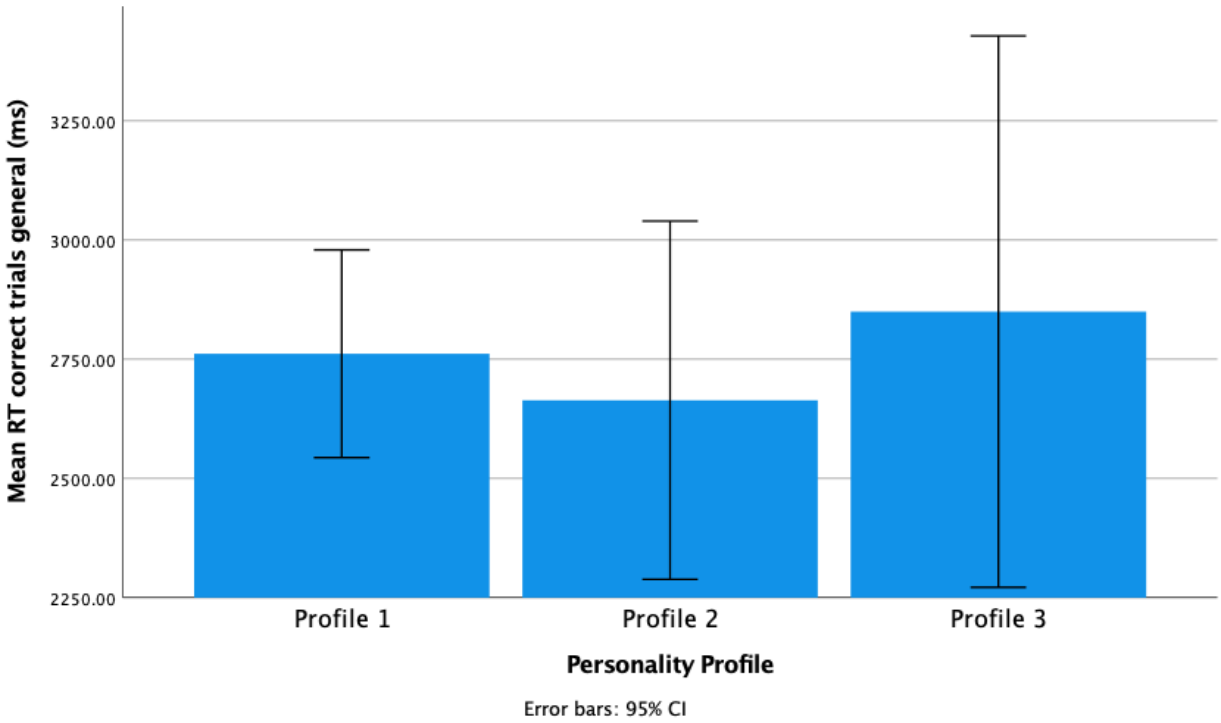


Figure 34 General reaction times (ms) of correct trials distributed by profile. (Source prepared by author)

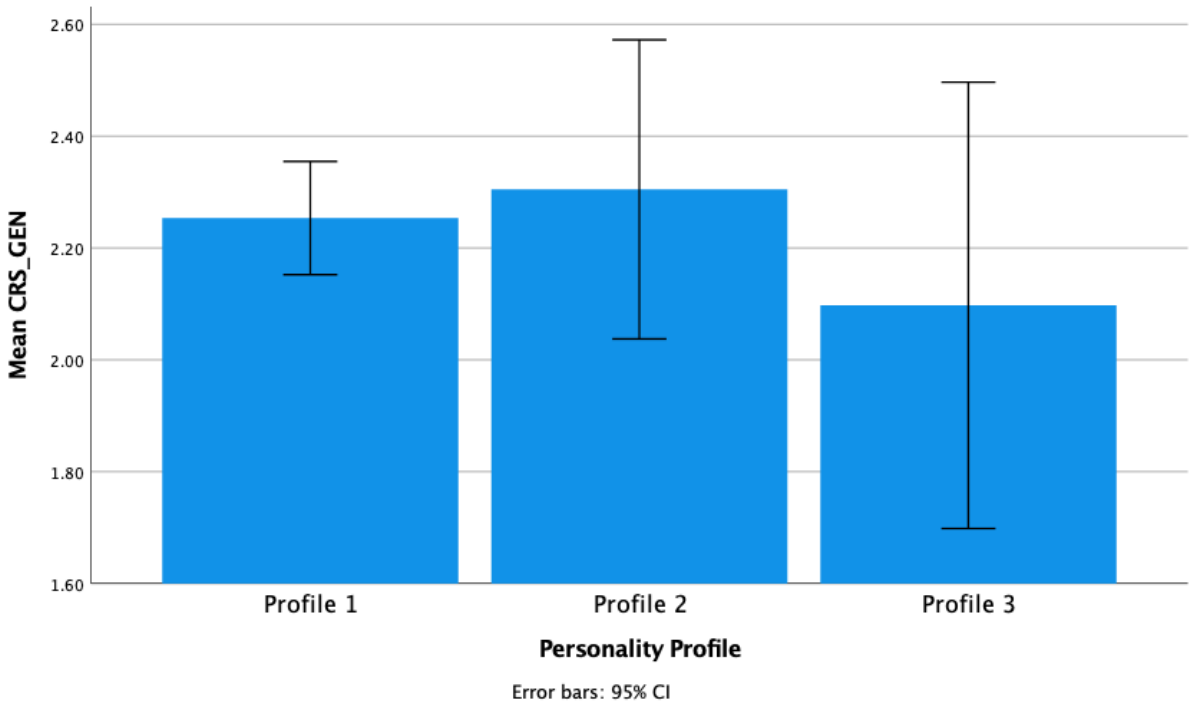


Figure 35 General corrected recognition scores distributed by profile. (Source prepared by author)

5. The effect of both stimulation group and personality on the working memory task also taking into account distractors.

Corrected recognition scores showed no significant effects and reaction time for correct trials. But it did show significant effects for the interaction of personality, group and distractor for reaction time of incorrect trials [$F_{(4,50)}$=3.27, p=0.02; observed power=0.80; η^2=.20, 90% CI [0.02-0.31]]. In addition, the post-hoc paired t-test (Bonferroni adjustment for multiple comparisons) revealed that profile 1 had a higher reaction time for neutral distractors than emotional distractors ($t_{(25)}$ =2.42, p=0.02; Mdiff=90.46; Cohen's d=0.72 95%, CI[0.09-1.34]) and profile 2 had a higher reaction time for emotional distractors than neutral distractors ($t_{(25)}$ =2.94, p=0.01; Mdiff=208.26; Cohen's d=2.90 95%, CI[0.45-2.90]) (see Table 24).

Table 24 Effect of personality and stimulation on working memory, taking into consideration the distractors.

Dependent Variable	**Statistical test**	**Tests of Within-Subjects Effects**	**Tests of Within-Subjects Contrasts**	**Tests of Between-Subjects Effects**
CRS	GLM	Distractor*Personality*Stimulation type F(4,50)=0.83, p=0.51	Linear: Distractor*Personality*Stimulation type F(2,25)=0.51, p=0.60	Personality*Stimulation type F(2,25)=1.38, p=0.27
RTcor	GLM	Distractor*Personality*Stimulation type F(4,50)=1.18, p=0.33	Linear: Distractor*Personality*Stimulation type F(2,25)=1.96, p=0.16	Personality*Stimulation type F(2,25)=1.63, p=0.22

RTer	GLM	Distractor*Personality*Stimulation type $F(4,50)=3.27$, $p=0.02$	Linear: Distractor*Personality*Stimulation type $F(2,25)=1.61$, $p=0.22$	Personality*Stimulation type $F(2,25)=2.85$, $p=0.08$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

Dependent Variable	**Statistical test**	**Bonferroni Adjustment for Multiple comparisons**
CRS	Pairwise Comparisons	Profile 1 vs Profile 3 $t(25)=0.31$, $p=0.76$
CRS	Pairwise Comparisons	Digital distractor Profile 1 vs Profile 3 $t(24)=1.88$, $p=0.07$
RTcor	Pairwise Comparisons	iTBS vs sham $t(25)=1.50$, $p=0.14$
RTer	Pairwise Comparisons	Profile 1 neutral vs emotional distractors $t(25)=2.42$, $p=0.02$
RTer	Pairwise Comparisons	Profile 2 emotional vs neutral distractors $t(25)=2.94$, $p=0.01$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

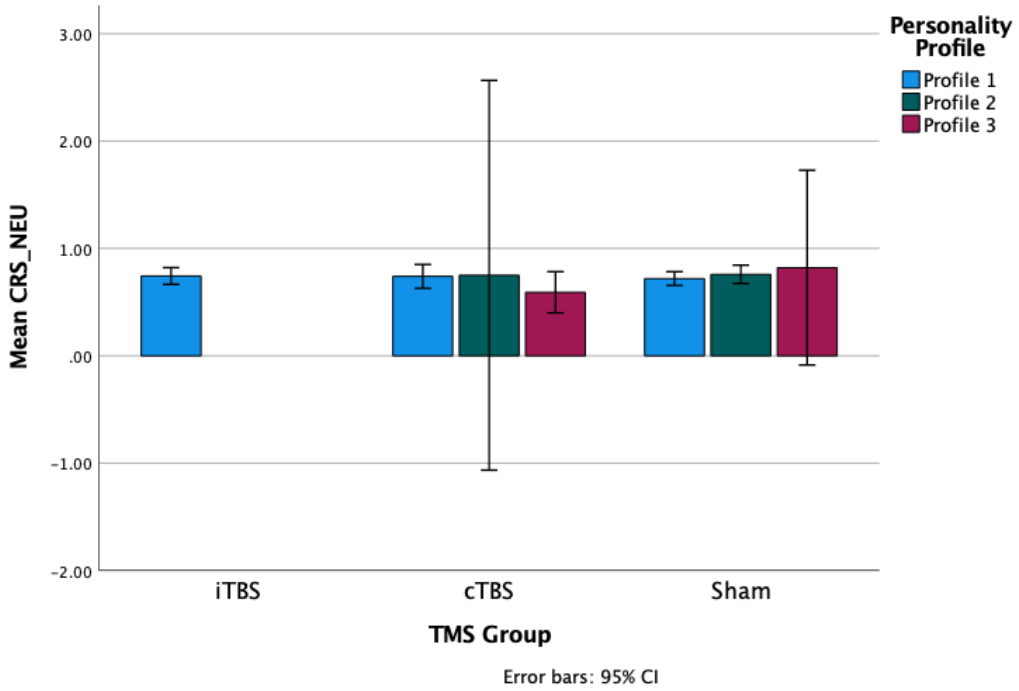


Figure 36 Corrected recognition scores for neutral distractors distributed by profile and stimulation. (Source prepared by author)

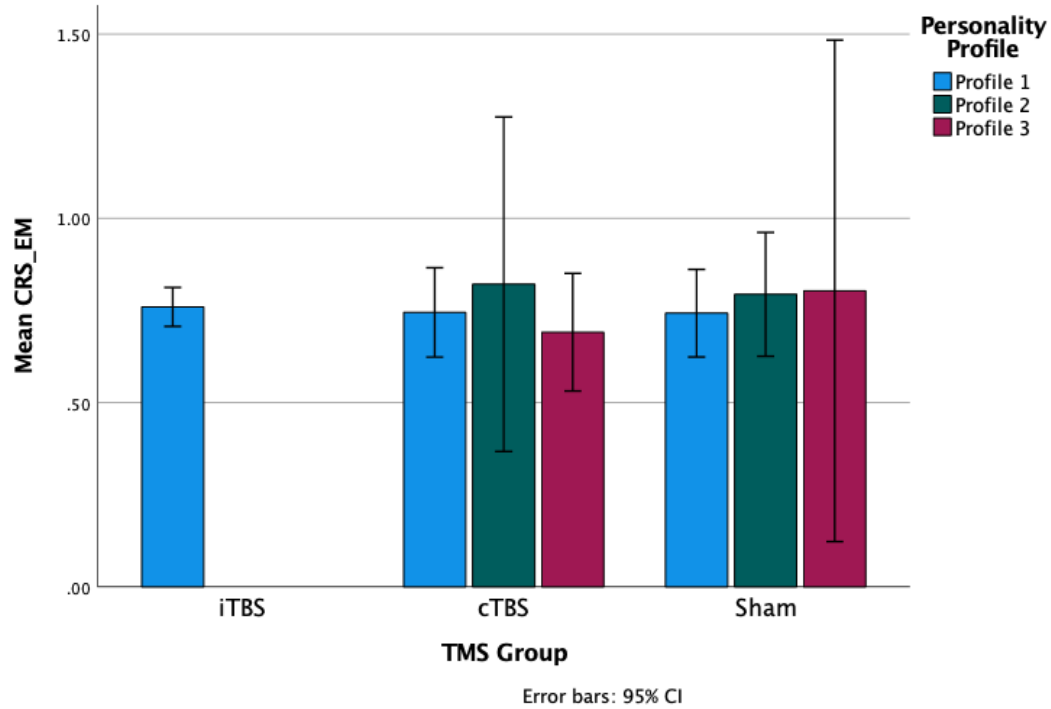


Figure 37 Corrected recognition scores for emotional distractors distributed by profile and stimulation.

(Source prepared by author)

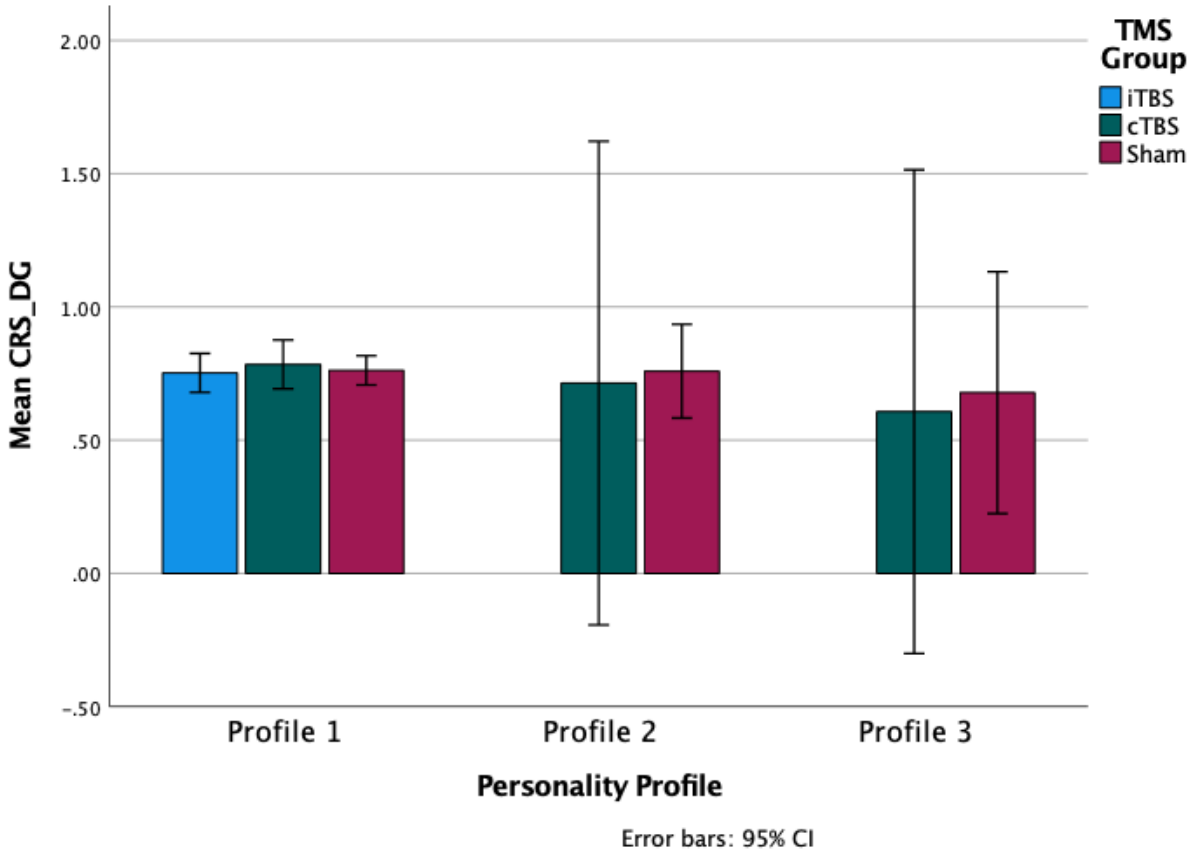


Figure 38 Corrected recognition scores for digital distractors distributed by profile and stimulation.

(Source prepared by author)

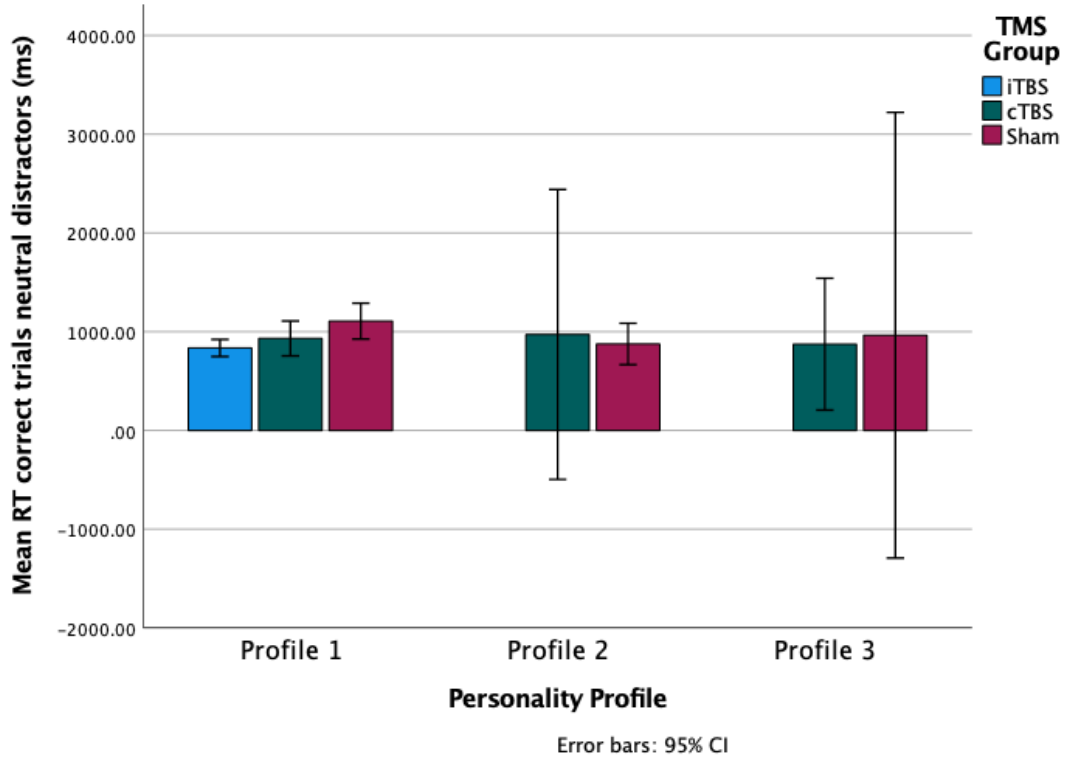


Figure 39 Reaction time for correct trials for neutral distractors distributed by profile and stimulation. (Source prepared by author)

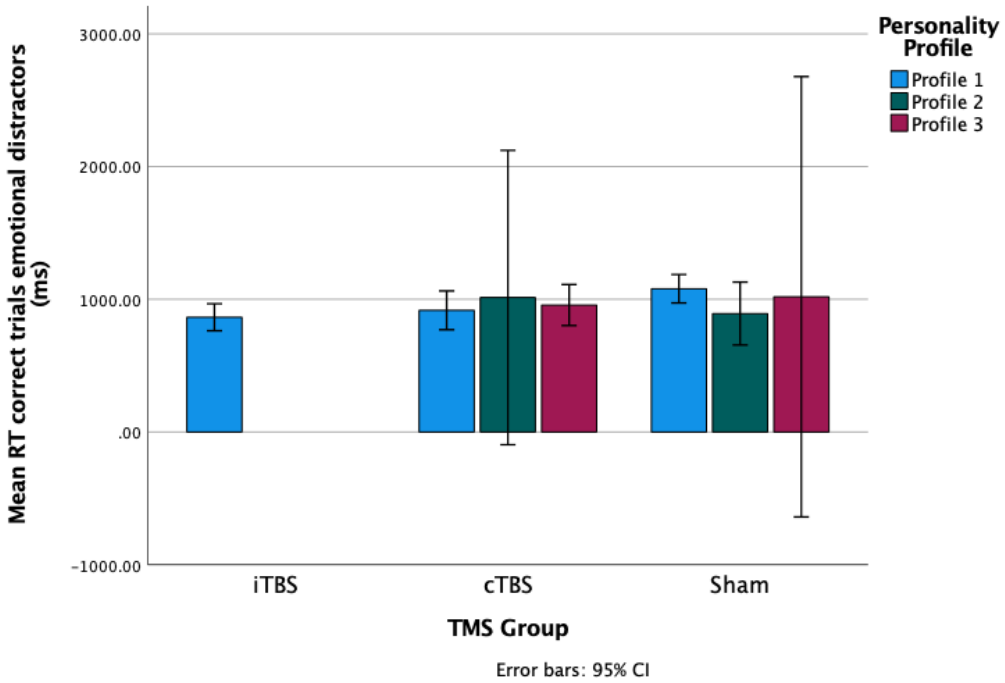


Figure 40 Reaction time for correct trials for emotional distractors distributed by profile and stimulation. (Source prepared by author)

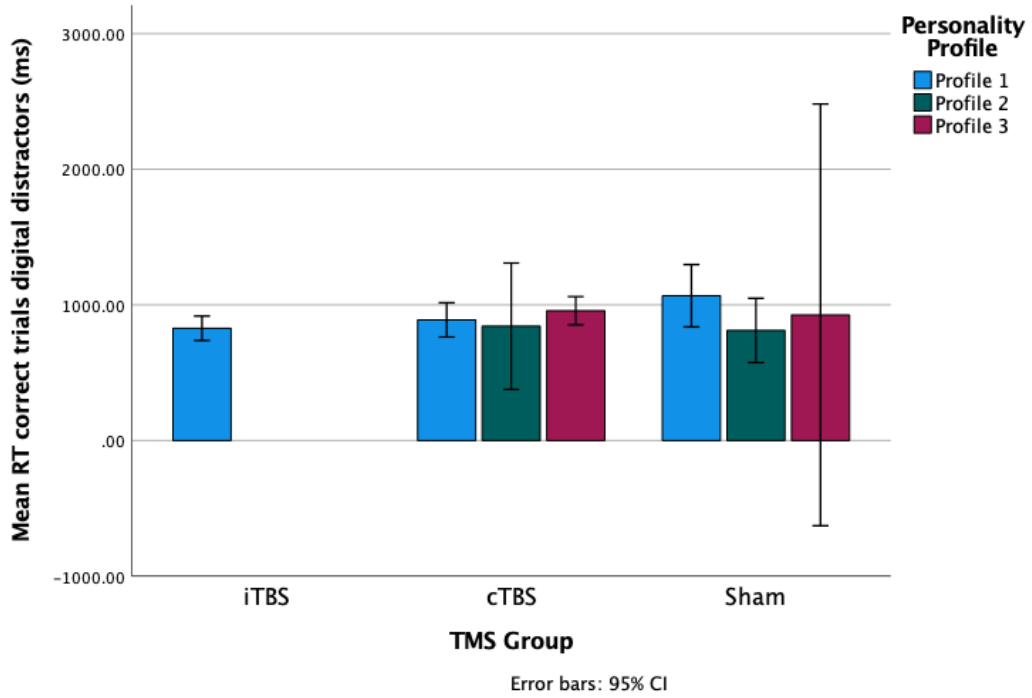


Figure 41 Reaction time for correct trials for digital distractors distributed by profile and stimulation.

(Source prepared by author)

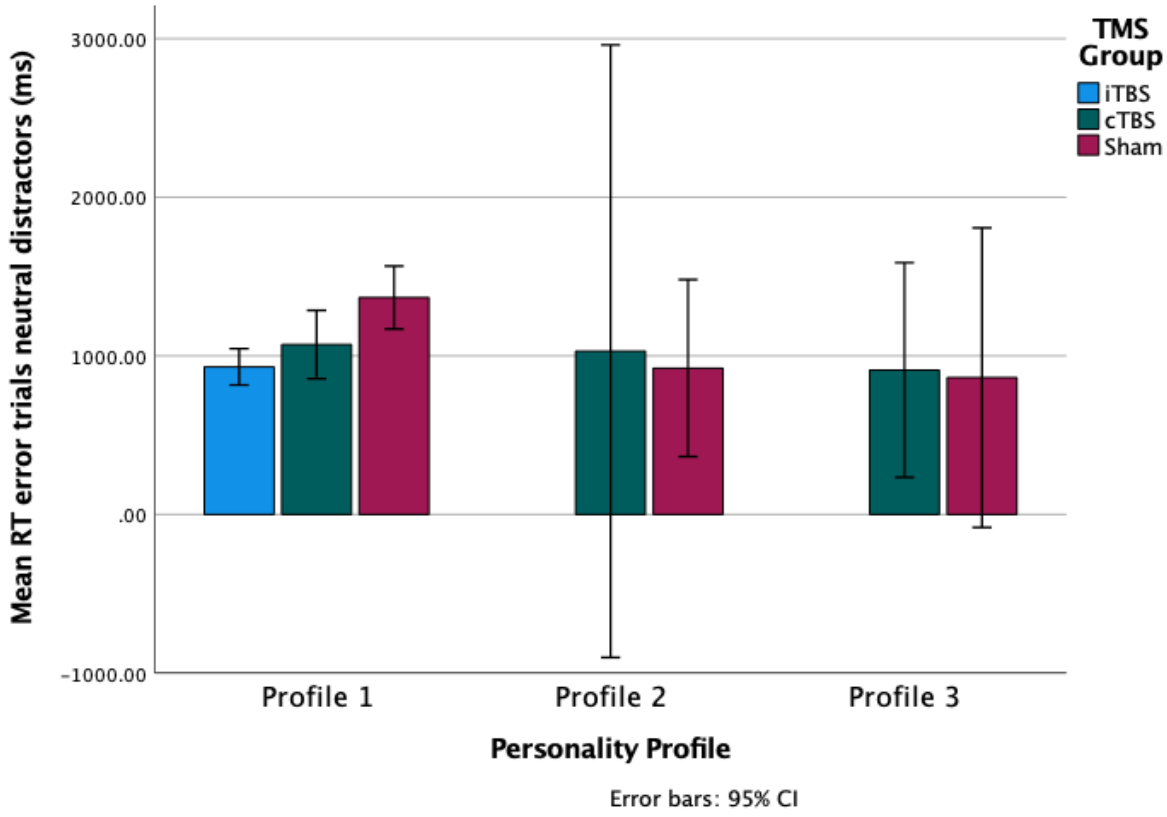


Figure 42 Reaction time for error trials for neutral distractors distributed by profile and stimulation.

(Source prepared by author)

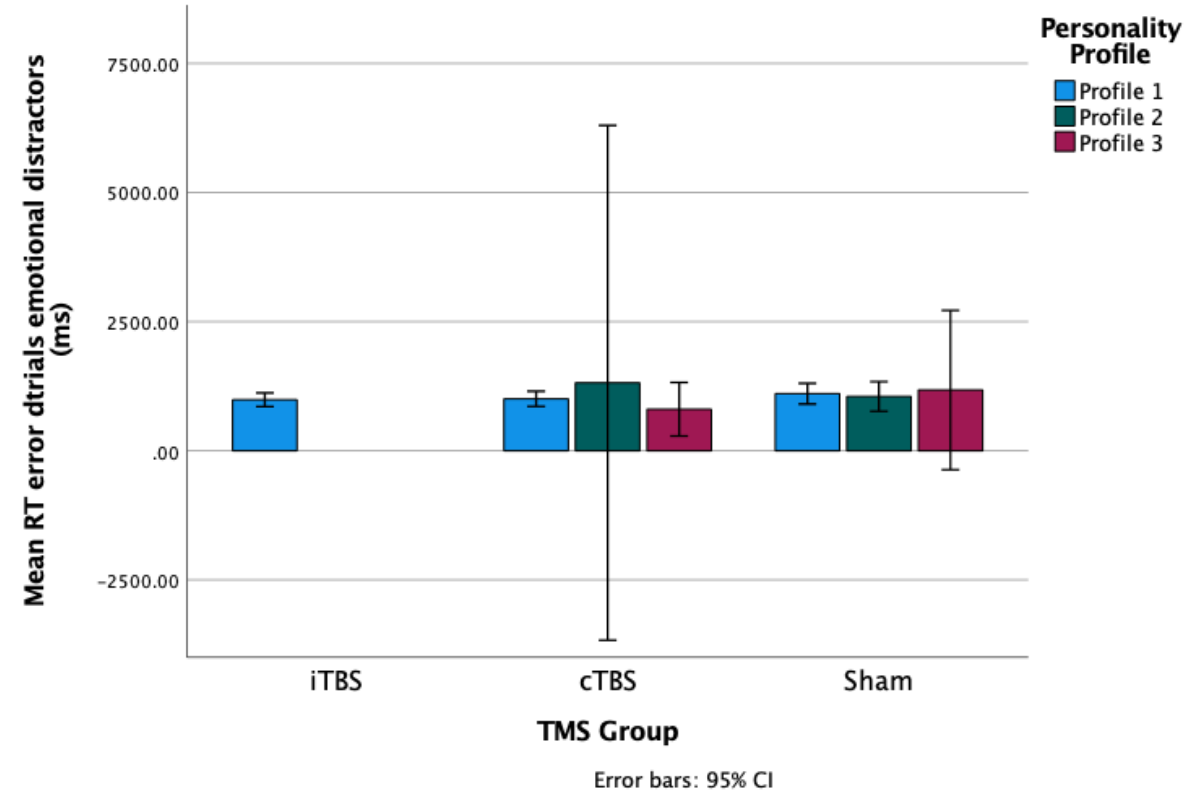


Figure 43 Reaction time for error trials for emotional distractors distributed by profile and stimulation.

(Source prepared by author)

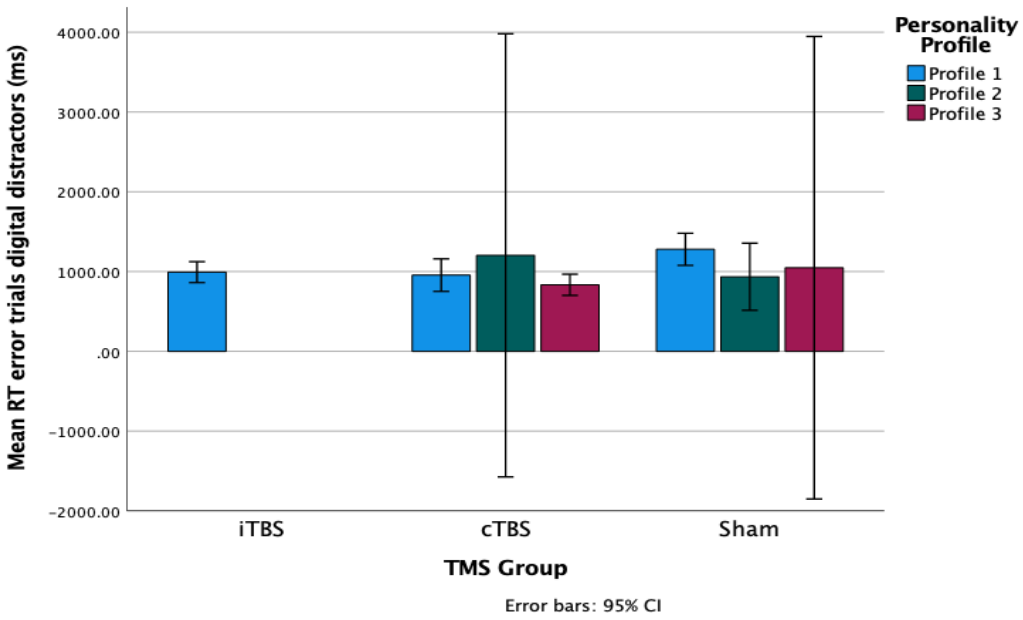


Figure 44 Reaction time for error trials for digital distractors distributed by profile and stimulation. (Source prepared by author)

6. The effect of personality and stimulation group on the WM task without accounting for distractors.

There was no significant effect on corrected recognition scores. However, the between-subjects effect of reaction time for correct trials showed a significant effect for the stimulation group [$F_{(2,25)}$=3.63, p=0.04; observed power=0.61; η^2=.22, 90% CI [0.00-0.39]].

However, there was no significant effect on the reaction time of incorrect trials (see Table 25).

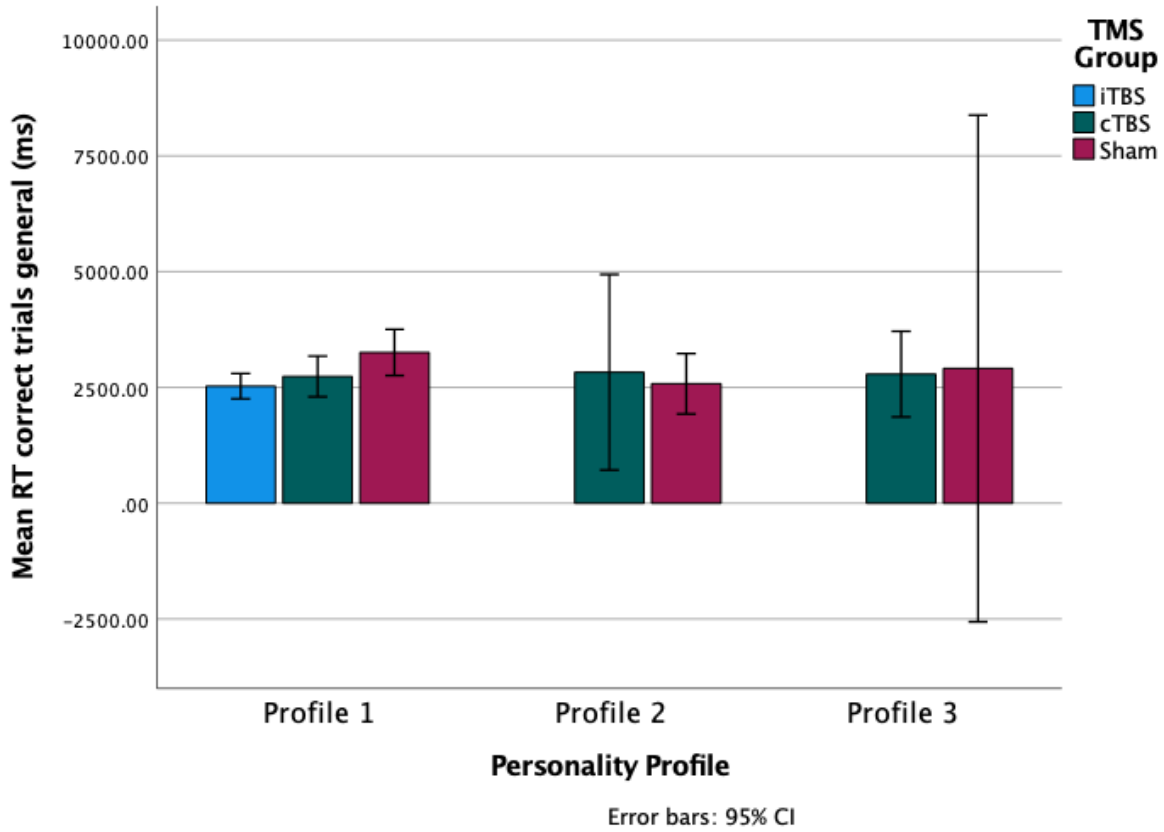


Figure 45 General reaction time for correct trials distributed by profile and stimulation. (Source prepared by author)

Table 25 Effect of stimulation type and personality on working memory without taking into consideration the distractors.

Dependent Variable	**Statistical test**	**Tests of Between-Subjects Effects**
CRS	GLM	Personality*Stimulation type $F(2,25)=1.34$, $p=0.28$
RTcor	GLM	Stimulation type $F(2,25)=3.63$, $p=0.04$
RTcor	GLM	Personality*Stimulation type $F(2,25)=1.63$, $p=0.22$
RTer	GLM	Personality*Stimulation type $F(2,25)=2.85$, $p=0.08$
Dependent Variable	**Statistical test**	**Bonferroni Adjustment for Multiple comparisons**
CRS	Pairwise Comparisons	Profile 1 vs Profile 3 $t(25)=0.29$, $p=0.77$
RTcor	Pairwise Comparisons	iTBS vs Sham $t(25)=1.50$, $p=0.14$
RTcor	Multiple Comparisons	iTBS vs Sham $t(25)=1.79$, $p=0.08$

RTer	Pairwise Comparisons	iTBS vs Sham $t(25)=0.58$, $p=0.56$

Note* CRS: correct recognition scores, RTcor: Reaction time for correct trials, RTer: Reaction time for incorrect trials. Significant effects are in green.

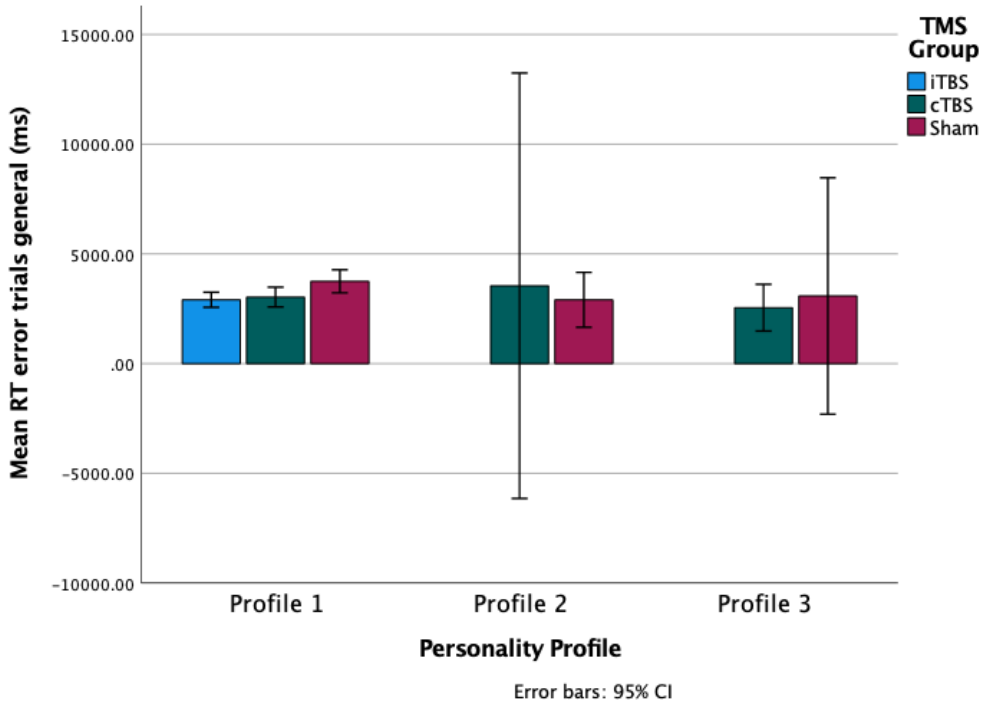


Figure 46 General reaction time for error trials distributed by profile and stimulation. (Source prepared by author)

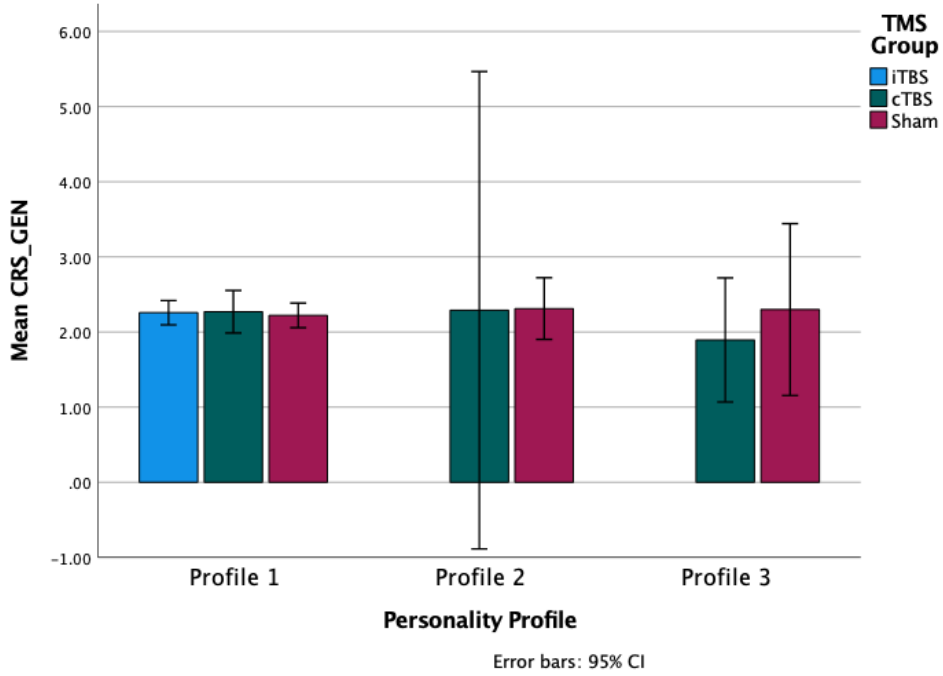


Figure 47 General corrected recognition scores distributed by profile and stimulation. (Source prepared by author)

DISCUSSION

The aim of this section is to explore the results obtained and detailed above in the experimental section. As well as to delve into possible explanations, and to point out how and if it coincides with the hypothesis proposed in this thesis.

We directed the key points in how the independent variables modulated cognition, either risky decision-making or emotional interference in WM. Consequently, and in order to provide a more complete detailed explanation of the results obtained, we set out the discussion by the cognitive domains explored, as well as by the experiments. In this thesis, we have aimed to study the dissociation of VLPFC and DLPFC in cognition, particularly in risk taking and WM. For this purpose, we carried out two experimental procedures. During the first experiment, we stimulated with NIBS both regions while performing a risk-taking task. For the second experiment, we only stimulated the left DLPFC, as this experimental procedure followed the same premises as a previous study performed at the Cognitive NeuroLab. In addition, we considered personality to explore whether it could modify the effect of NIBS on cognition.

8.1 Differential contributions of DLPFC and VLPFC to risk decision-making considering personality

To provide causal evidence of the role of DLPFC and VLPFC in risky decision-making, we conducted a MtDCS study based on a comparison of three pathways of active stimulation (DLPFC and VLPFC) and sham stimulation. Our aim was to explore whether the effect on risk decision-making of reducing excitability in those brain areas could be modulated by personality factors. Despite the lack of evidence on risky decision-making from models, MtDCS setups can stimulate distributed brain networks in a target area, resulting in a further increase in excitability over time (e.g., D. B. Fischer et al., 2017; Ruffini et al., 2014).

Our results show that, compared to sham stimulation, DLPFC inhibition led to a more conservative response: in BART in terms of fewer pumps and fewer desired pumps (AVP and WP), and in BRET in terms of a lower number of parcels collected (MPC). When analyzed by personality profile, we observed this effect exclusively in impulsive-disinhibited participants (profile 1 individuals).

As expected, in BART, normative participants (profile 2) compared to impulsive-disinhibited (profile 1) tended to be more conservative and, therefore, to earn less money (TE). However, the effect was dependent on the stimulation received, with participants in the normative group showing a tendency to respond more conservatively when VLPFC was inhibited.

We demonstrated that the MtDCS-induced effect on risk decision-making was not dependent on the intensity of stimulation. Previous studies have shown that 2 mA intensity of tDCS does not produce effects greater than 1.5 mA in healthy participants (e.g., Ho et al., 2016; Jamil et al., 2017). However, we were unable to find studies that explored those differences, as postulated by some authors, in risky decision-making task outcomes when the stimulation intensity increased or decreased (H. Guo et al., 2018b).

Our results support the hypothesis of a differential role of DLPFC and VLPFC in risky decision-making that depends on personality characteristics. Specifically, left VLPFC activity could increase risk propensity in normative individuals, whereas left DLPFC activity would only increase risk propensity in impulsive-disinhibited individuals.

8.1.1 DLPFC

Our findings support the argument that tDCS consisting of bilateral stimulation of the DLPFC (e.g., Boggio, Campanhã, et al., 2010; Cheng & Lee, 2016; S. Fecteau et al., 2007; Fecteau, Pascual-Leone, et al., 2007; D. Huang et al., 2017; Minati et al., 2012; Ota et al., 2019; Ye et al., 2016b) and focalized unilateral stimulation of the left DLPFC (e.g., H. Guo et al., 2018b; Sela et al., 2012a) may promote lower risk propensity and higher risk aversion following

inhibition of the left DLPFC, and higher risk propensity and lower risk aversion following activation of the left DLPFC. Excessive risk propensity in decision-making could be due to inadequate excitability in the DLPFC and/or unbalanced interhemispheric interaction (Gorini et al., 2014).

The fundamental difference between our results and those of the aforementioned papers is that the effect on risky decision-making of left DLPFC inhibition is personality-dependent. Previous results reported that a right anodal/left cathodal tDCS montage in the DLPFC reduced risk-taking behavior, correlating with state and trait impulsivity (Cheng & Lee, 2016). The effect of tDCS was greater in more impulsive individuals. Whereas tDCS with the anode over the right DLPFC and the cathode over the left DLPFC reduced risk taking in smokers with higher impulsivity and sensation-seeking drives than nonsmokers. Likely by increasing cognitive control over affective drives, which, in turn, would lead to a reduction in risky decision-making (Pripfl et al., 2013a).

Our findings provide evidence for a personality-dependent effect of tDCS on risky decision-making patterns, suggesting that individual differences need to be taken into account. The greater effect of tDCS for impulsive-disinhibited individuals would point to the potential of using this neuromodulation technique to decrease pathological risk-taking behaviors.

8.1.2 VLPFC

To our knowledge, this is the first study that has explored the possible causal role of VLPFC in 2 decision-making tasks, BART, and BRET. Previous studies of BART have found that the right DLPFC whole-brain connectivity negatively correlated with the number of pumps, suggesting that tDCS may affect activation and connectivity in brain regions distal to stimulated sites. Including regions involved in valuation and choice choice (Weber et al., 2014). It is plausible that the neural bases underlying risk decision-making include different portions of the cortex, located on a continuum that includes lateral and medial prefrontal areas.

Thus, tDCS reduced risk-taking behavior during BART. Either with the anode over the left DLPFC and the cathode over the right orbitofrontal cortex or with the anode over the right orbitofrontal cortex and the cathode over the left DLPFC (Nejati et al., 2018). For those reasons, it is possible that other prefrontal regions, such as the VLPFC (e.g., Camus et al., 2009; Fellows & Farah, 2007; Mohr, Biele, Krugel, et al., 2010) or orbitofrontal regions play a differential role in risky decision-making (Nejati et al., 2018). This idea fits with the existence of 2 dissociable neural systems (dorsal, which includes the DLPFC, and ventral, which includes the VLPFC) in the prefrontal cortex. This idea underlies the effects of emotion and cognitive regulation on risk decision-making (e.g., Morawetz, Mohr, Heekeren, & Bode, 2020; Yamasaki & Labar, 2002).

The role of the left VLPFC in risk propensity in decision-making could be explained by the dual role of the left VLPFC in the regulation of emotional processes and in ambiguity resolution. The regulation of emotional processes could play a key role in value calculation, whereas changes in emotional states may correlate with changes in decision outcomes, even when emotions not directly connected with any choice characteristics (Morawetz et al., 2020). For ambiguity, the left VLPFC could play a role in resolving that ambiguity or in attempting to make sense of an ambiguous situation (e.g., Bach, Hulme, Penny, & Dolan, 2011; Huettel et al., 2006), reflecting individual attitudes of uncertainty of activation patterns in that region (Levy, 2016).

8.1.3 Personality

Previous studies have suggested that emotions, sensation-seeking, psychopathy, and impulsivity influence risk-taking behavior (e.g., Humphreys, Lee, & Tottenham, 2013; Hunt et al., 2005b; Lauriola, Panno, Levin, & Lejuez, 2013; Suhr & Tsanadis, 2007). Our results show that certain personality traits, specifically narcissism and psychopathy, correlate with risky decision-making, especially in the external non-manipulation sham condition. This is not

surprising, as there is a large body of research linking risk-taking with narcissism and psychopathy (Malesza & Ostaszewski, 2016). Thus, our results align fairly well with the existing literature (e.g., Camchong, Goodie, McDowell, Gilmore, & Clementz, 2007; Campbell, Goodie, & Foster, 2004; Klayman, Soll, González-Vallejo, & Barlas, 1999). Indeed, the dark triad is a good predictor of overconfidence (Wissing & Reinhard, 2017), which may ultimately explain why high-scoring dark triad individuals tend to take more behavioral risks.

Our research showing that individual personality differences modify the impact of MtDCS on risky decision-making, which provides insights into the brain regions involved in dark triad personality. Previous research has shown that the DLPFC plays an important role in emotional regulation and risk-taking behaviors (Kaiser et al., 2018). But also, in aggression (Buckholtz & Meyer-Lindenberg, 2008) through threat assessment mediated by static amygdala-DLPFC antagonism in resting-state connectivity (Kaiser et al., 2018). Thus, individual differences in behavior or personality under sham conditions may reflect individual differences in resting-state connectivity (Nostro et al., 2018). Thus, modulation of DLPFC activity may have an impact only on those whose functional networks are not functioning properly. The story is quite similar for the VLPFC. Recent research has found that VLPFC stimulation modulates frustration-induced aggression (Gallucci, Riva, Romero Lauro, & Bushman, 2020). Again, the VLPFC is crucial for the down-regulation of aggression.

Researchers consider interindividual differences and deviations from the mean to be a matter of noise and a source of error; however, very few studies to date have highlighted the role of interindividual differences in explaining such error, which is actually unexplained variability (e.g., Baeken et al., 2019; Qi et al., 2019; Zimerman & Hummel, 2010). Existing studies offer explanations focused on age and plasticity (Zimerman & Hummel, 2010) and also on neuroanatomy or inherent variability in brains (L. M. Li et al., 2015). Explaining unidentified sources of variability should be the path to more effective personalized interventions.

Interindividual phenotypic differences reveal underlying interindividual differences in brain structure (DeYoung et al., 2011) or brain functioning (Corr, 2004), although this is not widely recognized in the field of cognitive neuroscience. Thus, different sensitivities to NIBS might offer insights into the role of specific brain areas in normal and abnormal personality functioning, or (conversely) explain which personality traits explain why some interventions do not work for some people. For these reasons, we strongly recommend that we include routine personality assessments of patients before conducting NIBS.

8.2 Dorsolateral prefrontal contributions to the modulation of emotional interference on working memory

Animal and human research has extensively explored the mechanisms by which emotionally salient stimuli, processed largely by the amygdala and posterior orbitofrontal cortex (pOFC), enhance or impair cognitive performance, processed primarily by prefrontal and parietal brain regions (Dolcos, Wang, & Mather, 2015). This has established that arousing experiences can activate endogenous processes and facilitate memory (e.g., Redolar-Ripoll et al., 2003; Segura-Torres, Aldavert-Vera, Gatell-Segura, Redolar-Ripoll, & Morgado-Bernal, 2010) and that the strength of such facilitation reflects its emotional salience (McGaugh, 2015). On the other hand, increased arousal caused by emotionally negative distractors can also result in declines in cognitive performance (e.g., Iordan, Dolcos, & Dolcos, 2013; Stout, Shackman, Pedersen, Miskovich, & Larson, 2017), induced by the reallocation of neural resources to the encoding of salient emotional information with greater adaptive value (Levine & Edelstein, 2009).

Recent human fMRI studies by Dolcos et al. have explored the anatomical basis underlying the interaction between emotion and cognition by assessing WM and episodic memory in the presence of negative emotional distractors (e.g., Dolcos et al., 2008, 2013; Dolcos & McCarthy, 2006; Iordan, Dolcos, & Dolcos, 2019). These studies suggest an opposite impact of emotional

salience, showing improved episodic memory and impaired WM. The observed emotional effects on memory correlate with increases in activity in a *ventral affective system (VAS)*, including the amygdala. And decreases in activity in a *dorsal executive system (DES)*, including regions of the DLPFC and lateral parietal cortex (Dolcos et al., 2013). On this correlational basis, the authors hypothesized that the VAS exerts an influence on the DES, disrupting ongoing cognitive processes to better respond to emotional stimuli of high adaptive value (Iordan & Dolcos, 2017). In addition, the DES would also interact with the VAS allowing inhibition of emotional interference on cognitive processing (Dolcos, Iordan, & Dolcos, 2011). The DLPFC is a key area in mediating the interaction between the DES and VAS, but its role in this interaction remains to be clarified. On the other hand, research considers the VLPFC part of the VAS given its activation coupling with the amygdala, its contributions to emotional processing, and its major role in the production of affective states (e.g., Dolcos et al., 2006; Iordan et al., 2019; Phillips, Drevets, Rauch, & Lane, 2003). However, research also associates the VLPFC with DES, given its increases in activity, as shown in fMRI studies, associated with successful inhibition of emotional distractors and reappraisal (e.g., Clarke & Johnstone, 2013; Dolcos et al., 2013; Ochsner et al., 2004). As part of the DES, the VLPFC, would control the activity of VAS areas (such as the amygdala) to enable optimal cognitive performance when effectively coping with emotional distractors. However, research considers such an influence, likely mediated by direct connectivity between the amygdala and DLPFC (Iordan, Dolcos, & Dolcos, 2013), weak and anatomically indirect (e.g., Barbas, Wang, Joyce, & García-Cabezas, 2018; Ray & Zald, 2012). Unfortunately, the pioneering fMRI approaches used so far to explore this controversial question failed to establish the causal nature of behavior-structure relationships (Ray & Zald, 2012) and may be prone to confounding epiphenomenal activations. Ultimately, the topic would benefit from more causal evidence, thus it requires NIBS approaches to study such contributions.

We aimed to clarify the role of the DLPFC in mediating interactions between the DES and VAS during emotional interference in cognitive processing using a NIBS approach. To this end, we studied the effects of two active TBS protocols to increase (iTBS) or decrease (cTBS) right DLPFC activity compared to sham stimulation. We assessed the impact of offline rTMS interventions on WM performance with an adapted version of a previously published delayed response paradigm using emotionally charged distractors presented during the delay-interval phase compared to neutral distractors or coded imagery (e.g., Dolcos et al., 2013; Dolcos & McCarthy, 2006). We hypothesized that increases in DLPFC activity would have led to preservation, or even enhancement, of WM capacity in the face of an emotionally interfering situation. However, decreases in excitability in this area would transiently impair performance on the WM task. In essence, we aimed to provide causal evidence for the role of DLPFC in mediating interactions between the DES, linked to cognitive processing, and the VAS, linked to emotional processing, during a WM task.

Contrary to the starting hypothesis, our results have shown that neither increased nor decreased cortex excitability modifies the effect of emotional interference on WM task performance. Also, the effect of arousal on both emotional interference and WM task performance does not depend on the personality profiles of the participants.

How might we explain these results? First, it is of vital importance to consider the neural and functional bases underlying the **interaction between the DES and VAS.** In our laboratory we conducted a previous experiment with the only difference to the present work being that the region of the prefrontal cortex modulated by TBS was the ventrolateral one. The results of this previous experiment showed that, in the presence of emotional distractors, increases in VLPFC activity after iTBS impaired performance on the WM task. But decreases in activity in this same area after cTBS improved WM scores, in both cases, compared to sham stimulation. Importantly, these effects did not occur in trials involving neutral or scrambled distractors.

These results can be interpreted in the framework of an existing influential anatomical model of the interaction between DES and VAS: *the structural model* (e.g., Barbas, 2015; Barbas & Rempel-Clower, 1997; García-Cabezas, Zikopoulos, & Barbas, 2019). The structural model predicts the direction of information flow (f*eedback or feedforward*) between connected cortical regions based on their laminar structure (Barbas, 2000). It proposes that *feedback* connections start from the less laminated cortices and project to the progressively more differentiated ones, while the reverse applies to *feedforward* projections (Barbas, 2015). This assumption allows very precise inferences to be made about the direction in which information is most likely to flow between two cortical areas (either feedback or feedforward) based on their cytoarchitectonic characteristics. Within this framework, the results of these previous experiments support the idea that the less laminated VLPFC would be a gateway for emotional information coming from the amygdala to reach the more laminated DLPFC *via* feedback connections. Specifically, activation of the amygdala, triggered by the perception of emotionally charged distractors, influences activity in lateral prefrontal regions via the pOFC (Barbas et al., 2018) (Figure 31). The pOFC receives information from the amygdala via feedforward projections and plays a key role in the integration of emotional and sensory inputs and in the attribution of affective meaning (e.g., Barbas, 2000; García-Cabezas & Barbas, 2016; John, Bullock, Zikopoulos, & Barbas, 2013; Ray & Zald, 2012). In our previous experiment, increased activity in the VLPFC following iTBS would have facilitated feedback flow from the less laminated pOFC to the more laminated DLPFC. Enhancing the transmission of emotional information that is known to interfere with and worsen WM outcomes (e.g., Iordan, Dolcos, & Dolcos, 2013; Stout et al., 2017). Conversely, inhibition of VLPFC activity following cTBS would have disrupted the flow of emotional information (again from the pOFC to the DLPFC via feedback projections), preventing it from affecting WM performance. This model clearly explains the role of the ventrolateral cortex in emotional interference on WM,

but it is insufficient to explain the results of the present dissertation. In this sense, the ventrolateral cortex could also send its projections to other prefrontal, parietal and temporal regions (Gerbella, Belmalih, Borra, Rozzi, & Luppino, 2010), conveying the influence of emotional information on different cognitive functions. This would explain why increasing or decreasing DLPFC excitability did not have such a marked effect on emotional inference in WM. Through its *feedforward* projections to the ventrolateral region, given that the other prefrontal, parietal, and temporal projection pathways are available.

Importantly, for this previous study (VLPFC) and for the present dissertation (DLPFC), offline rTMS modulations of VLPFC and DLPFC activity following iTBS or cTBS had no impact on the subjectively perceived emotional value and arousal level of imagery. Participants reported these values. Therefore, the differential results in each modality of rTMS cannot be attributed to changes in the perceived impact of the distractors.

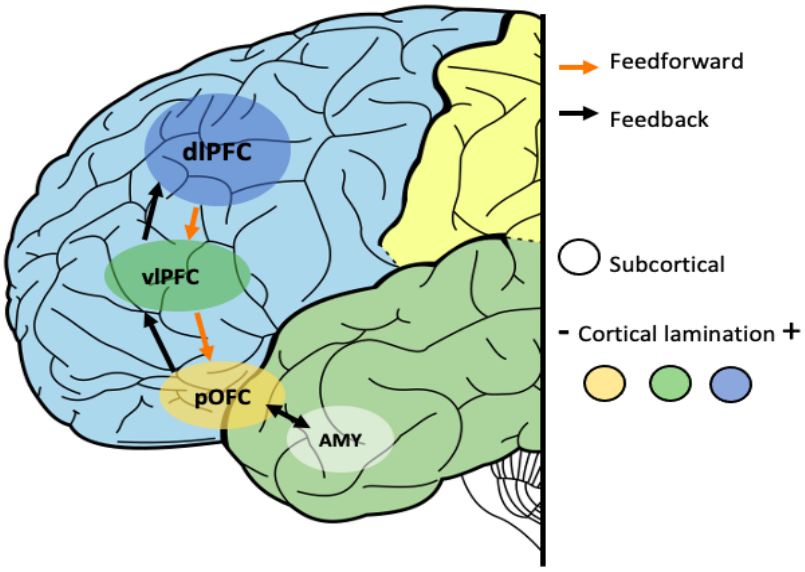


Figure 48 Graphic representation of the information flow between the amygdala and the dorsolateral prefrontal cortex. According to the structural model (Barbas & Rempel-Clower, 1997), the pOFC receives emotional information from the amygdala (AMY), and is heavily connected to it. Then, sends feedback projections to more laminated cortices involved in WM processing such as the VLPFC and

the *DLPFC* successively (Barbas et al., 2018). (Adapted from Viejo-Sobera, R., Marron, E. M., Valero-Cabré, A., & Redolar-Ripoll, D., submitted)

Previous studies using rTMS to disrupt DLPC and DLPFC activity have shown similar results regarding impaired transmission of emotional information in different tasks, which supports our own results and interpretation. Weintraub-Brevda & Chua (R. Weintraub-Brevda & Chua, 2018) applied cTBS on the left and right VLPFC, as well as the vertex as a control condition, and tested emotional enhancement of memory. The authors found that, after decreasing the excitability of the right VLPFC, there was no memory enhancement for negative excitatory words compared to stimulation over the left VLPFC and the vertex. On the other hand, Chick et al., (Rolle, Chick, Trivedi, Monuszko, & Etkin, 2019) used online rTMS to disrupt the VLPFC during a facial emotion perception task. They found that active compared to sham stimulation prevented perceptual gains on happy face trials and worsened performance on angry face trials. In our study, we found no changes in emotional perception of distractors. Probably due to differences in the nature of the task (perception vs. WM) and the stimulation protocol (online vs. offline). But these results may also indicate that the role of the VLPFC is related to the transmission of information from the amygdala to the cortices involved in cognitive processing. And its disruption also disrupts such transmission.

Given the opposite activation patterns of the VLPFC and DLPFC observed in fMRI studies (Dolcos et al., 2013), we could reach an alternative explanation for the findings of this thesis. It could be that modulation of the DLPFC could have modified the activation of its ventral counterpart (VLPFC). Enhancing or impairing global WM capacity, independent of the presence of emotional distractors. However, our data show that WM performance on trials in which the distractors consisted of *neutral* or *digital* images (hence, with low emotional valence and arousal) was not affected by stimulation.

These results reinforce the idea that DLPFC does not seem to be involved in emotional interference on WM. However, as demonstrated in the previous experiment conducted in our laboratory, VLPFC would be causally involved in modulating the impact of emotional information on cognitive processing.

However, studies showed that potentiation of right DLPFC activity with tDCS decreases perceived arousal to negative emotional stimuli (Rêgo et al., 2015). And previous reports showed that increasing WM load reduces amygdala activation to threatening stimuli (e.g., Clarke & Johnstone, 2013; Van Dillen, Heslenfeld, & Koole, 2009b) and decrease anxiety (Vytal, Cornwell, Arkin, & Grillon, 2012). The interpretation of our results, in the context of the structural model, suggests that the DLPFC might indeed be able to influence emotional processing to some extent through *feedforward* projections directed to the ventral and medial prefrontal cortices (Barbas, 2015). But, on the other hand, the DLPFC would not be directly implicated in the interference that emotional stimuli may have on ongoing WM capacity through projections to cortical regions such as the pOFC or subcortical structures such as the amygdala.

In this regard, the following question is of particular importance: how can it be that in our experiment, rTMS administered to the DLPFC may have a differential effect on the two types of projections (*feedback* and *feedforward*)? One possible explanation is related to the influence of off-line rTMS on the intrinsic dynamics and activity flow of these two pathways. We distinctively characterize *feedback* projections (those from limbic cortices such as the pOFC to lateral prefrontal cortices) as a "tonic influence" that actively contributes to the construction of our perception of the world (e.g., Barbas, 2000; Chanes & Barrett, 2016; Hutchinson & Barrett, 2019). Furthermore, computational modeling of the structural model (John et al., 2013) suggests that tonic (i.e., constant) activation of the pOFC turns on the so-called "cautious mode", increasing processing of threatening stimuli and preventing extinction of a response.

On the other hand, decreasing pOFC activity after cTBS would further facilitate the "rapid switch mode", decreasing the influence of emotionally negative distractors on the task. Finally, neuroimaging studies using a face WM task also show that irrelevant threatening distractors produce WM resource reallocation of the DLPFC induced by increased amygdala activation. But this reallocation does not take place when threat-related information is task-relevant (e.g., Stout, Shackman, & Larson, 2013; Stout et al., 2017).

Instead, interpretations within the framework of the anatomical structural model (Barbas & Rempel-Clower, 1997) support the notion that the VLPFC is a region that transmits relevant emotional information to the DLPFC *via* feedback projections from the pOFC. The well-established pattern of rich structural feedback and feedforward connectivity argues for the importance and sophistication of systems that integrate emotion and cognition in the human prefrontal cortex. And appropriately regulating individual and joint regional contributions (e.g., J. R. Gray, Braver, & Raichle, 2002a; Pessoa, 2008a; Phelps, 2006; Schweizer et al., 2019).

Alternatively, the observed lack of effect of TMS on both WM and emotional interference on this cognitive ability could have other alternative explanations. We will describe some of these explanations that complement the structural model discussed above. To do so, in the following paragraphs, we will explore different arguments and considerations previously documented in the literature to understand our results.

First, we must consider whether the stimulation protocol (TBS) and the target brain region (the DLPFC) were best suited for the specific objectives of this research. Although research focused on cognitive enhancement is not widely use, yet, TBS protocols, they were chosen for their ability to induce longer-lasting effects on the cerebral cortex with shorter stimulation times compared to rTMS (e.g., Goldsworthy et al., 2012; Suppa et al., 2016b). A recent systematic review and meta-analysis evaluating the reliability and efficacy of TBS protocols applied to

the prefrontal cortex in healthy participants (Lowe, Manocchio, Safati, & Hall, 2018), has shown variability of effects. TBS can somewhat modulate cognitive control, but its efficacy appears to be task-dependent, being greater for WM paradigms. However, only 8 studies have used this paradigm to improve executive functions, so the results should be interpreted with caution.

We should also consider that research potentially explains the effect of TMS in healthy samples by inter- and intraindividual variables (e.g., Hinder et al., 2014; Jannati, Block, Oberman, Rotenberg, & Pascual-Leone, 2017; López-Alonso et al., 2014; Suppa et al., 2016b). These variables include genetic factors (e.g., Cheeran et al., 2008; N. J. Lee et al., 2014; Li Voti et al., 2011; Mori et al., 2011), cortical network organization (e.g., Nettekoven et al., 2014, 2015), and age and motor threshold (Müller-Dahlhaus, Orekhov, Liu, & Ziemann, 2008), among other factors.

As shown in our results, there were significant differences in our stimulation groups for age and motor threshold. The mean motor threshold was higher in the cTBS group than in the iTBS and sham groups. Regarding MT, previous studies have found a negative correlation between WM and resting motor threshold. Specifically, lower rMT meant better performance during a WM task (Schicktanz et al., 2014). Following these findings, we could hypothesize that since one of our groups (cTBS) had a higher mean MT, this might have influenced their performance during the WM task. Thus, perhaps explaining our lack of significant results. In terms of age, there were also significant differences. The sham group was older than the iTBS and cTBS groups. In addition, previous studies have pointed to the fact that brain excitability decreases in older individuals, especially compared to younger ones (Tang et al., 2019). Furthermore, in studies dealing with Lf-rTMS and depression, only younger patients benefited from stimulation (Aguirre et al., 2011). However, given that our older sample is the sham sample, this might not

have caused any setbacks. This is important to note since both variables could explain the lack of significant results.

As for the stimulation target, the right DLPFC is a relatively large area; however, the figure-of-eight coil and navigated stimulation increase the focus and accuracy of target localization. Furthermore, the broad connectivity of the DLPFC (Sepulcre, Sabuncu, Yeo, Liu, & Johnson, 2012) and the involvement of different regions of this area could offer another explanation. This explanation is that because of the previously mentioned, it is possible that the highly specific target was not directly responsible for the neural processes underlying the cognitive abilities assessed by our WM task. We selected our target based on structural coordinates and their involvement in executive functions and WM (Kühn et al., 2014). But it is possible that our stimulation protocol (cTBS or iTBS) and/or the target did not affect the functional circuits involved in emotional interference in WM (e.g., Richlan, Schubert, Mayer, Hutzler, & Kronbichler, 2018; Strenziok et al., 2014).

Brain state dependence deserves special interest, as "any induced neural activity occurs in the context of a baseline neural activity" (Silvanto & Pascual-Leone, 2008). Research shows that TMS effects could be qualitatively modulated by manipulation of the pre-stimulation brain state (e.g., Silvanto, Bona, & Cattaneo, 2017; Silvanto & Cattaneo, 2017). In our study, we administered stimulation to take advantage of the state-dependence phenomenon, and all participants received stimulation immediately prior to the WM task. However, we did not implement any specific control of participants' ongoing mental state immediately before or during stimulation. Therefore, neural activity could certainly have differed across participants, resulting in uncontrolled or no effects of the stimulation.

As discussed above, we observed no clear effect of stimulation on cognitive performance in the WM task in our study. In this regard, we should reflect on the ceiling effect of TMS on cognitive performance in healthy subjects. In neuropsychology, patients with neurological

diseases or psychiatric patients usually have some room for improvement, but in healthy individuals already performing at or near their potential, cognitive improvement is difficult to achieve. The effects of TMS are related to participants' baseline performance, with lower baseline scores associated with greater cognitive facilitation (Silvanto, Bona, Marelli, & Cattaneo, 2018). In the same meta-analysis mentioned above (Lowe et al., 2018), the authors note that they observed the largest effect size for an older adult population. Hence, supporting the idea that TBS may be more effective in addressing cognitive decline or deterioration in clinical or vulnerable populations than in improving cognition in healthy ones. In the same vein, Looi et al. (Looi et al., 2016) reported better outcomes for subjects who performed worse at baseline. In our study, the participants were healthy, young, and highly educated, which would leave little room for cognitive improvement. Overall, these and previous results underscore the importance of reconsidering whether efforts in NIBS research should be directed at improving cognitive performance in healthy individuals, and raise some ethical concerns given the possible greater potential of these techniques for clinical populations. However, it should not be forgotten that the aim of this study, and many others involving healthy individuals, is to apply the knowledge gained in these samples to the clinic. Rather than to try to benefit healthy individuals without the need for these technologies. In any case, the ethical debate should always be present in neuroscientific research and especially in the field of noninvasive stimulation.

As for personality, we found no significant effect on either WM or emotional interference. There is previous evidence that some personality traits, such as anxiety (i.e., negative emotionality) could moderate emotional interference (Holtmann et al., 2013), at least in patients with borderline personality disorder. The failure to find any effect in this regard could be due to a lack of relationship in healthy patients, a lack of statistical power, or a combination of both. In the Holtmann et al. study, the authors found a large effect size, which should have

replicated with our sample size. Furthermore, as we can see in our results, we observed significant differences between the profiles for certain personality dimensions. Profile 1 and 2 showed significant differences for Honesty/Humility, as did profile 1 and 3. Profile 1 and 2 also showed significant differences in agreeableness. And profiles 1 and 3 showed significant differences for Narcissism, as well as profiles 2 and 3. However, with a larger sample, we believe we could have found more prominent differences between the profiles. Thus, the results of the latent profile analysis should be taken with caution, given the low number of participants in two of the latent profiles.

In addition, some research has related personality traits to WM, providing evidence that this relationship occurs at the brain level (J. R. Gray & Braver, 2002). However, we have not been able to provide evidence in this regard for the reasons mentioned above. Following this, previous work has also related WM to extraversion. The higher the extraversion, the better the WM performance (e.g., M D Lieberman & Rosenthal, 2001; Matthew D Lieberman, 2000). However, our profiles showed no significant differences for extraversion. We found significant differences for narcissism, though.

Research observes that in subjects with personality disorders, such as borderline, narcissistic, etc., there are significant deficits in cognitive skills, such as WM, suggesting an alteration of PFC (Garcia-Villamisar, Dattilo, & Garcia-Martinez, 2017). Therefore, with a larger sample, or a clinical sample, we could have obtained significant results. Another study for older adults assessed personality traits from the five-factor model and different cognitive functions, including delayed memory. Another personality dimension that was associated with better performance across domains was agreeableness (Sutin, Stephan, Luchetti, & Terracciano, 2019). Which is another personality dimension that was significant for our profiles. Given this, and based on our sample, we believed that with a larger sample we could have found significant effects.

8.3 General Discussion

This thesis has focused on the study of cognition by NIBS, considering personality. Both experimental procedures have targeted the DLPFC. Experimental procedure I also targeted the VLPFC, but because experimental procedure II was a continuation of a previous study focusing on the VLPFC, we chose to stimulate only the DLPFC. In addition, we focused on two cognitive functions where emotion could be an influencing factor, WM and risk-taking.

For both experiments, we pre-screened personality profiles and used well-established tasks to measure WM and risk-taking. We also used two well-known NIBS techniques. However, only one of the studies yielded overall significant results. Experiment I showed that narcissism and psychopathy correlate with risk-taking. Thus, personality modified MtDCS stimulation of risky decision-making. Overall, experiment I showed that when compared to sham stimulation the inhibition of the DLPFC caused a conservative response, during both risk-taking tasks. This followed previous literature which showed that inhibition of the DLPFC might lead to higher aversion to risk. In addition, our study showed that the effects of DLPFC inhibition on risk-taking could be dependent on personality. As well as VLPFC stimulation, since only participants from the normative profile showed an inclination to be more conservative after VLPFC inhibition.

However, Experiment II was not so straightforward. We also found three profiles; however, the differences were not as significant. Although we could see some trend towards how NIBS modified WM and the influence of distractors on WM, this was not significant. This experiment showed that the group receiving cTBS stimulation had a higher MT than the iTBS which as mentioned above could offer an explanation for our lack of results. As well, it showed a lower reaction time for digital distractors compared to emotional distractors, but not for stimulation group. However, as shown in Table 19 we could observe a tendency towards a lower reaction

time when there was TMS stimulation compared to sham. The same could be said about the effect of TMS on WM without taking into consideration the distractors.

When considering the effects of personality on the WM taking into account distractors, we saw a tendency towards being significant for participants from profile 1 that shows a higher corrected recognition score for distractors that were digital. In addition, it also showed that participants from profile 2 had a bigger reaction time with emotional distractors or neutral. Hence, experiment II did show a certain tendency, but overall, the results were either non-significant or inconclusive. This could be a result of different factors that have already been highlighted previously in the discussion.

In conclusion, this thesis has shed some light on the variability found in NIBS studies. Focusing not on age and plasticity, but on personality. Pointing towards more personalized inclusion criteria when approaching NIBS protocols for research or clinical treatments. In addition, the different sensitivities to NIBS could offer insight into the role that certain brain areas play in explaining certain personality traits and how these interventions do not have the expected results in certain individuals. At the same time, both experiments have also offered insight into the limitations of stimulating brains considered healthy. Although NIBS are very promising techniques, especially Experiment II has shown limitations when we localize stimulation to a highly connected area.

8.4 Main limitations and future directions

Future directions of these studies might be for experiment I, the creation of more precise interventions as treatments for individuals highly prone to risk, or even as a treatment to reduce psychopathy. In addition, it continues an already open conversation regarding the variability found in NIBS and the need to develop more precise interventions that consider personality as well as other individual differences.

In Experiment II, our results were not significant, so modifying DLPFC excitability did not have an effect on WM task performance or how emotional interference affected WM. However, future directions for this study would be to increase the sample and be able to reach a meaningful conclusion whether DLPFC is in fact not involved in WM emotional interference. Or if there are other factors that need consideration. Also, and based on the significant results obtained in the VLPFC study, it would be interesting to apply this technique to enhance the dysfunction of neural circuits regulating emotion in clinical samples.

Furthermore, to talk about our limitations is also to talk about future directions and how we can improve the present research. Our main limitation for both experimental procedures is the small sample size relative to the personality profile. In this sense, both studies are merely exploratory, and the results should be interpreted with caution.

However, we have some reason to believe that some findings of the present research would replicate with larger samples, especially regarding to the classification of personality profiles. For Experiment I, using the SABIC, we had an observed power of 0.98 to correctly identify the number of profiles, using 8 indicators and a mean effect size across profiles of 0.53. We are confident that larger samples would yield similar results. In fact, a larger sample with more non-normative profiles could help predict how the effects of stimulation on risk decision-making might vary by personality and could open a window to new interventions aimed at reducing psychopathy.

Furthermore, a possible explanation for the lack of functional dissociation between these cortical regions could lie in the degree of electric field overlap produced by the electrode montage used (Yu Huang, Datta, Bikson, & Parra, 2019). It would be interesting to replicate this experiment using a technique with higher special resolution, such as TMS.

As for Experiment II, the major limitation has been time. Our sample for Experiment II is very small, (n=32), especially considering the personality profile groups, and due to COVID-19, we

could not add the additional participants who had already performed an fMRI scan to participate in the second study. This is because the laboratory remains to this day closed due to COVID-19 precautions. Hence, we cannot access the rTMS needed for the experiment. With a larger sample, we could have reached more conclusive results and even identified the possible variability that made our results non-significant.

Possible explanations may be the poor reliability and efficacy of TBS protocols, highly localized stimulation in a broad and widely connected brain area, inter- and intra-individual variability. Also, the phenomenon of brain state dependence, the ceiling effect of cognitive enhancement in healthy subjects, or a combination of some or all of these factors. Within this framework, despite not achieving the desired effects of stimulation, our results, although exploratory, provide valuable information on the limitations of stimulating healthy brains. Furthermore, our findings also highlight the importance of reconciling brain stimulation and neuroimaging data with neuroanatomical models. Cautioning against using correlational neuroimaging approaches to draw relevant conclusions about the communication dynamics of highly integrative processes such as those linking emotion and cognition.

It is worth considering future applications of our results to potentially ameliorate dysfunctions of neural circuits regulating emotions and their impact on cognitive processing that are common to different psychiatric conditions (e.g., Price & Drevets, 2010; R. Blair, 2013). For example, rTMS-mediated activation of DLPFC could help patients with post-traumatic stress disorder by modulating the avoidance of intrusive negative affective information and its impact on cognitive processing (Hayes, VanElzakker, & Shin, 2012). Conversely, increased DLPFC activity may enhance dysfunctional communication between emotional and prefrontal areas in individuals with psychopathy (Craig et al., 2009), modulating the impulsivity, blunted emotional responses, and increased goal-directed behavior that characterizes these patients (e.g., R. Blair, 2013; Volman et al., 2016).

There is a need for further research to elucidate whether personality moderates' emotional interference in healthy individuals.

9. Conclusions

In the first exploratory experiment, we found that tDCS modified risk-taking behavior depending on personality traits. Specifically, left DLPFC related to risk propensity in impulsive-disinhibited individuals, whereas left VLPFC related to risk propensity in normative individuals. Thus, it provided evidence for a personality-dependent tDCS effect in models of risk decision-making. This suggests that the already growing notion that individual differences in personality need consideration. Furthermore, we could use these protocols as a method to decrease risk-taking behavior in individuals with impulsive tendencies.

In addition, we showed that the effect of MtDCS was not dependent on the stimulation's intensity. This falls in line with previous studies showing that there were no differences in healthy samples. However, we lacked a clear dissociation between VLPFC and DLPFC which could be achieve in the future with a different montage use, or by using TMS or different NIBS. Our findings for experiment I are promising and it showed the effect that personality has on risk-taking and how it can influence NIBS protocols. Hence it would be interesting to replicate those findings in bigger samples as well as clinical samples.

But experiment II did not show direct significant results. Overall, the results were inconclusive. With a bigger sample we might have achieve a more solid conclusion, as well as significant results. Overall, this thesis focused on cognition and personality and the interaction of the two. Specially we focused in risk-taking and Working memory as cognitive functions and by means of NIBS we tried to see the implications of the DLPFC on both functions. And if personality could also be a factor to have in consideration, especially when applying NIBS techniques. Hence, we can conclude that regarding risk-taking we saw the role of the DLPFC on risk-taking, and in a smaller portion the VLPFC. As well, we showed how NIBS techniques are influenced by personality and therefore it could create a need to provide specialized protocols

that take into consideration individual differences as a whole. However, regarding Working Memory, we did not reach any concrete conclusion. There were certain factors to be taken into consideration as a reason to why we did not reach them such as: COVID-19, small sample, MT....Hence, this lack of results does show certain areas regarding the use of NIBS which to this day still need to be taken into consideration when doing research or applying protocols in the clinical field.

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Annex

Table A7 Descriptive analysis of personality dimensions by profile.

Profile	Dimensions	*N*	Mean	SD	95% CI
Profile 1	Narcissism	10	12.70	4.72	9.33-16.07
	Psychopathy	10	10.20	3.19	7.92-12.48
	Machiavellianism	10	13.60	1.78	12.33-14.87
	Openness to experience	10	34.50	6.20	30.06-38.94
	Conscientiousness	10	35.70	3.77	33.00-38.39
	Agreeableness	10	30.50	6.95	25.53-35.47
	Extraversion	10	37.20	3.49	34.70-39.69
	Emotionality	10	29.80	6.37	25.24-34.35
	Honesty/humility	10	24.70	3.46	22.22-27.18
Profile 2	Narcissism	18	8.22	2.62	6.92-9.53
	Psychopathy	18	6.55	2.25	5.43-7.68
	Machiavellianism	18	7.22	2.67	5.89-8.55
	Openness to experience	18	38.39	4.32	36.23-40.54
	Conscientiousness	18	39.50	5.93	36.54-42.45
	Agreeableness	18	34.22	7.28	30.60-37.84
	Extraversion	18	33.72	6.18	30.64-36.79
	Emotionality	18	31.88	6.03	28.89-34.89
	Honesty/humility	18	38.67	4.52	36.42-40.92
Profile 3	Narcissism	6	9.33	1.63	7.62-11.05
	Psychopathy	6	9.17	1.94	7.13-11.20
	Machiavellianism	6	12.83	1.94	10.79-14.87

Openness to experience	6	37.83	4.91	32.67-42.99
Conscientiousness	6	33.67	3.93	29.54-37.79
Agreeableness	6	24.83	5.64	18.91-30.74
Extraversion	6	22.16	5.95	15.92-28.40
Emotionality	6	36.16	8.47	27.28-45.06
Honesty/humility	6	34.17	2.56	31.48-36.85

Note. The minimum and maximum possible values for the dark-triad/dirty-dozen dimensions (psychopathy, Machiavellianism, narcissism) were 4 and 20, and for HEXACO (emotionality, extraversion, agreeableness, conscientiousness, openness to experience, honesty-humility) were 10 and 50.

Table A8 Personality profiles comparisons. Between subject effects. The significant results show significant effects for those dependent variables between subjects.

Dependent Variable	**Statistical test**	**Tests of Between-Subjects Effects**
Honesty_Humility	GLM	Personality $F(2, 31)=39.79$, $p<.01$
Emotionality	GLM	Personality $F(2, 31)=1.76$, $p=0.19$
Extraversion	GLM	Personality $F(2,31)=14.688$, $p<.01$
Agreeableness	GLM	Personality $F(2, 31)=4.25$; $p=0.02$
Conscientiousness	GLM	Personality $F(2, 31)=3.69$; $p=0.03$
Openness to Experience	GLM	Personality $F(2, 31)=1.99$; $p=0.15$
Machiavellianism	GLM	Personality $F(2, 31)=29.13$; $p<.01$
Psychopathy	GLM	Personality $F(2, 31)=7.39$; $p<.01$
Narcissism	GLM	Personality $F(2, 31)=6.09$; $p<.01$

Note * Significant effects are in green.

Table A9 Multiple comparisons between profiles for personality dimensions. Significant effects show a significant difference between profiles for different personality dimensions.

Dependent Variable	Statistical test	Bonferroni Adjustment for Multiple comparisons
Honesty_Humility	Multiple Comparisons	Profile 1 vs Profile 2 $t(31)=3.63$, $p<.01$ Profile 1 vs Profile 3 $t(31)=3.63$, $p<.01$
Emotionality	Multiple Comparisons	Profile 1 vs Profile 3 $t(31)=1.28$, $p=0.21$ Profile 2 vs Profile 3 $t(31)=0.63$, $p=0.53$
Extraversion	Multiple Comparisons	Profile 2 vs Profile 3 $t(31)=3.63$, $p<.01$ Profile 1 vs Profile 3 $t(31)=3.63$, $p<.01$
Agreeableness	Multiple Comparisons	Profile 2 vs Profile 3 $t(31)=2.41$, $p=0.02$
Conscientiousness	Multiple Comparisons	Profile 2 vs Profile 3 $t(31)=1.92$, $p=0.06$
Openness to Experience	Multiple Comparisons	Profile 1 vs Profile 2 $t(31)=1.37$, $p=0.18$ Profile 1 vs Profile 3 $t(31)=0.48$, $p=0.63$
Machiavellianism	Multiple Comparisons	Profile 1 vs Profile 2 $t(31)=3.63$, $p<.01$ Profile 2 vs Profile 3 $t(31)=3.63$, $p<.01$
Psychopathy	Multiple Comparisons	Profile 1 vs Profile 2 $t(31)=3.22$, $p<.01$
Narcissism	Multiple Comparisons	Profile 1 vs Profile 2 $t(31)=3.02$, $p<.01$

Note * Significant effects are in green.

Table A10 Correlations between personality and dependent variables. HEXACO and dark-triad correlations with BRET and BART dependent variables, respectively.

Variables	1	2	3	4	5	6	7	8	9
1. Mean parcels collected DLPFC	-	.64	.78	-.2	.27	.31	.02	-.34	.05
2. Mean parcels collected VLPFC	.64	-	.72	-.16	.16	.21	.30	-.24	-.08
3. Mean parcels collected Sham	.78	.72	-	-.07	.17	.43	.06	-.34	-0.4
4. Openness to Experience	-.021	-.16	-.07	-	.48	-.07	-.19	-.10	.31
5. Conscientiousness	.27	.16	.17	.48	-	.04	.09	-.26	.35
6. Agreeableness	.31	.21	.43	-.07	.04	-	.12	-.24	-.19

7. Extraversion	.03	.30	.06	-.19	.09	.12	-	-.36	-.22
8. Emotionality	-.34	-.24	-.34	-.10	-.26	-.24	-.36	-	0.8
9. Honesty/Humility	.04	-.08	-.04	.31	.35	.19	-.22	.08	-
M	9.72	10.06	10.25	37.15	37.35	31.47	32.70	32.03	33.76
SD	2.42	2.75	2.89	5.18	5.49	7.59	7.43	6.73	7.27

Note. Light green $p < .05$. Dark green $p < .01$. Significant effects are in green.

Variables	1	2	3	4	5	6
1. Mean parcels collected DLPFC	-	.64	.78	-.07	.87	-.43
2. Mean parcels collected VLPFC	.63	-	.72	-.03	.25	-.27

3. Mean parcels collected Sham	.78	.72	-	-.09	.25	-.37
4. Machiavellianism	-.07	-.03	-.09	-	.49	.49
5. Psychopathy	.08	.24	.25	.49	-	.14
6. Narcissism	-.43	-.27	-.37	.49	.14	-
M	9.72	10.06	10.25	10.09	8.09	9.73
SD	2.42	2.75	2.89	3.83	2.97	3.74

Note. Light green $p < .05$. Dark green $p < .01$. Significant effects are in green.

Variables	1	2	3	4	5	6	7	8	9
1. Total Points DLPFC	-	.31	.15	.03	.27	.14	-.04	.08	-.02

2. Total Points VLPFC	.31	-	.22	-.28	-.21	-.08	.13	-.06	-.22
3. Total Points Sham	.15	.22	-	-.16	.17	.07	-.04	-.42	.05
4. Openness to Experience	.03	-.28	-.16	-	.48	-.07	-.19	-.10	.30
5. Conscientiousness	.27	-.21	.17	.48	-	.04	.09	-.25	.35
6. Agreeableness	.14	-.08	.07	-.07	.04	-	.11	-.24	.19
7. Extraversion	-.04	.13	-.04	-.19	.09	.11	-	-.36	-.21
8. Emotionality	.08	-.06	-.42	-.10	-.25	-.24	-.36	-	.08
9. Honesty/Humility	-.02	-.22	.05	.30	.35	.19	-.21	.08	-

M	613.53	615.76	656.59	37.15	37.35	31.47	32.70	32.03	33.76
SD	117.50	129.63	167.76	5.18	5.49	7.59	7.43	6.73	7.27

Note. Light green p < .05. Dark green p < .01. Significant effects are in green.

Variables	1	2	3	4	5	6
1. Total Points DLPFC	-	.30	.15	-.24	-.11	-.08
2. Total Points VLPFC	.30	-	.22	.04	.12	.09
3. Total Points Sham	.15	.22	-	-.28	.26	-.08
4. Machiavellianism	-.08	.09	-.08	-	.49	.49
5. Psychopathy	-.11	.12	.25	.49	-	.14

6. Narcissism	-.24	.04	-.28	.49	.14	-
M	613.53	615.76	656.59	10.09	8.09	9.73
SD	117.50	129.63	167.76	3.83	2.97	3.74

Note. Light green p < .05. Dark green p < .01. Significant effects are in green.

Variables	1	2	3	4	5	6	7	8	9
1. Average adjusted pumps DLPFC	-	.85	.90	-.16	-.08	.33	-.03	-.40	-.12
2. Average adjusted pumps VLPFC	.85	-	.88	-.31	-.15	.23	.11	-.43	-.23
3. Average adjusted pumps Sham	.90	.88	-	-.13	.01	.23	.05	-.41	-.06

4. Openness to Experience	-.16	-.31	-.13	-	.48	-.07	-.19	-.10	.30
5. Conscientiousness	-.08	-.15	.01	.48	-	.04	.09	-.25	.35
6. Agreeableness	.33	.23	.23	-.07	.04	-	.11	-.24	.19
7. Extraversion	-.03	.11	.05	-.19	.09	.11	-	-.36	-.21
8. Emotionality	-.40	-.43	-.41	-.10	-.25	-.24	-.36	-	.08
9. Honesty/Humility	-.12	-.23	-.06	.30	.35	.19	-.21	.08	-
M	50.69	51.37	54.04	37.15	37.35	31.47	32.70	32.03	33.76
SD	13.26	16.43	16.39	5.18	5.49	7.59	7.43	6.73	7.27

Note. Light green $p < .05$. Dark green $p < .01$. Significant effects are in green.

Variables	1	2	3	4	5	6
1. Average adjusted pumps DLPFC	-	.85	.90	.13	.47	-.10
2. Average adjusted pumps VLPFC	.85	-	.88	.14	.44	-.06
3. Average adjusted pumps Sham	.90	.88	-	.02	.44	-.07
4. Machiavellianism	.13	.14	.02	-	.49	.49
5. Psychopathy	.47	.44	.44	.49	-	.14
6. Narcissism	-.10	-.06	-.07	.49	.14	-
M	50.69	51.37	54.04	10.09	8.09	9.73

SD		13.26	16.43	16.39	3.83	2.97	3.74		

Note. Light green p < .05. Dark green p < .01. Significant effects are in green.

Variables	1	2	3	4	5	6	7	8	9
1. Total Earnings DLPFC	-	.25	-.21	-.13	-.25	.22	.16	-.22	-.35
2. Total Earnings VLPFC	.25	-	.32	-.37	-.50	-.01	-.26	.05	-.38
3. Total Earnings Sham	-.21	.32	-	-.04	.14	-.26	-.12	.08	-.16
4. Openness to Experience	-.13	-.37	-.04	-	.48	-.07	-.19	-.10	.30
5. Conscientiousness	-.25	-.50	.14	.48	-	.04	.09	-.25	.35

6. Agreeableness	.22	-.01	-.26	-.07	.04	-	.11	-.24	.19
7. Extraversion	.16	-.26	-.12	-.19	.09	.11	-	-.36	-.21
8. Emotionality	-.22	.05	.08	-.10	-.25	-.24	-.36	-	.08
9. Honesty/Humility	-.35	-.38	-.16	.30	.35	.19	-.21	.08	-
M	792.47	796.24	826.38	37.15	37.35	31.47	32.70	32.03	33.76
SD	190.30	176.80	171.01	5.18	5.49	7.59	7.43	6.73	7.27

Note. Light green $p < .05$. Dark green $p < .01$. Significant effects are in green.

Variables	1	2	3	4	5	6

1. Total Earnings DLPFC	-	.25	-.21	.32	.39	-.01
2. Total Earnings VLPFC	.25	-	.32	.35	.32	.03
3. Total Earnings Sham	-.21	.32	-	.01	.19	.18
4. Machiavellianism	.32	.35	.01	-	.49	.49
5. Psychopathy	.39	.32	.19	.49	-	.14
6. Narcissism	-.01	.03	.18	.49	.14	-
M	792.47	796.24	826.38	10.09	8.09	9.73
SD	190.30	176.80	171.01	3.83	2.97	3.74

Note. Light green $p < .05$. Dark green $p < .01$. Significant effects are in green.

Variables	1	2	3	4	5	6	7	8	9
1. Total Wanted pumps DLPFC	-	.84	.91	-.04	.00	.30	-.03	-.36	-.03
2. Total Wanted pumps VLPFC	.84	-	.83	-.28	-.07	.21	.13	-.42	-.14
3. Total Wanted pumps Sham	.91	.83	-	-.01	.02	.24	.12	-.38	-.01
4. Openness to Experience	-.04	-.28	-.01	-	.48	-.07	-.19	-.10	.30
5. Conscientiousness	.00	-.07	.02	.48	-	.04	.09	-.25	.35
6. Agreeableness	.30	.21	.24	-.07	.04	-	.11	-.24	.19
7. Extraversion	-.03	.13	.12	-.19	.09	.11	-	-.36	-.21

8. Emotionality	-.36	-.42	-.38	-.10	-.25	-.24	-.36	-	.08
9. /Humility	-.03	-.14	-.01	.30	.35	.19	-.21	.08	-
M	1733.94	1705.18	1820.65	37.15	37.35	31.47	32.70	32.03	33.76
SD	412.47	474.27	571.66	5.18	5.49	7.59	7.43	6.73	7.27

Note. Light green p < .05. Dark green p < .01. Significant effects are in green.

Variables	1	2	3	4	5	6
1. Total Wanted pumps DLPFC	-	.84	.91	.01	.39	-.09
2. Total Wanted pumps VLPFC	.84	-	.83	.10	.38	-.05
3. Total Wanted pumps Sham	.91	.83	-	.01	.37	-.06

4. Machiavellianism	.01	.10	.01	-	.49	.49
5. Psychopathy	.39	.38	.37	.49	-	.14
6. Narcissism	-.09	-.05	-.06	.49	.14	-
M	1733.94	1705.18	1820.65	10.09	8.09	9.73
SD	412.47	474.27	571.66	3.83	2.97	3.74

Note. Light green $p < .05$. Dark green $p < .01$. * Significant effects are in green.

Table A11 Descriptive analyses of dependent variables.

			DLPFC			VLPFC			Sham		
			Mean	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**
Average adjusted pumps	**Profile 1**	**1.5 mA (*n*=9)**	55.81	12.61	46.49-65.12	58.53	15.88	47.04-70.03	58.79	12.91	47.16-70.43
		2 mA (*n*=1)	57.23	.	29.28-85.18	63.76	.	29.28-98.24	72.85	.	37.95-107.76
	Profile 2	**1.5 mA(*n*=10)**	49.35	8.40	40.52-58.19	47.30	11.20	36.40-58.21	51.38	12.47	40.35-62.43
		2 mA (*n*=8)	44.95	15.39	35.07-54.83	46.64	18.90	34.45-58.83	50.92	20.61	38.58-63.27
	Profile 3	**1.5 mA (*n*=3)**	49.74	25.70	33.60-65.87	53.50	27.94	33.59-73.41	54.03	29.21	33.88-74.18
		2 mA (*n*=3)	53.84	12.77	37.70-69.98	49.77	19.00	29.86-69.68	50.72	18.87	30.57-70.87
Wanted Pumps	**Profile 1**	**1.5 mA (*n*=9)**	1864.33	326.03	1569.20-2159.45	1889.44	387.33	1557.77-2221.12	2024.89	598.89	1621.15-2428.63
		2 mA (*n*=1)	1927.00	.	1041.62-2812.37	2254.00	.	1258.99-3249.00	2411.00	.	1199.79-3622.21
	Profile 2	**1.5 mA (*n*=10)**	1657.20	278.62	1377.21-1937.18	1604.50	314.30	1289.85-1919.14	1702.50	439.38	1319.48-2085.52
		2 mA (*n*=8)	1649.50	538.92	1336.47-1962.53	1604.00	618.68	1252.21-1955.78	1764.38	668.49	1336.15-2129.60
	Profile 3	**1.5 mA (*n*=3)**	1634.00	816.52	1122.82-2145.17	1628.00	847.26	1053.53-2202.46	1687.00	838.43	987.71-2386.29
		2 mA (*n*=3)	1859.33	397.12	1348.16-2370.50	1652.00	606.42	1077.53-2226.46	1688.67	569.47	989.37-2387.96

			DLPFC			VLPFC			Sham		
			Mean	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**
Total Earnings BART	**Profile 1**	**1.5 mA (*n*=9)**	933.67	224.83	821.740-1045.59	849.33	113.08	747.05-951.60	834.89	277.77	712.53-957.24
		2 mA (*n*=1)	744.00	.	408.22-1079.78	1084.00	.	777.18-1390.82	1020.00	.	652.93-1387.06
	Profile 2	**1.5 mA (*n*=10)**	819.10	220.30	712.92-925.28	763.20	110.74	666.17-860.22	803.20	114.66	687.12-919.27
		2 mA (*n*=8)	619.13	190.85	500.40-737.84	647.00	144.86	538.52-755.48	805.00	87.16	675.22-934.77
	Profile 3	**1.5 mA (*n*=3)**	731.33	101.44	537.47-925.19	964.00	269.02	786.85-1141.14	797.00	111.01	585.07-1008.92
		2 mA (*n*=3)	819.67	73.38	625.80-1013.53	881.33	248.88	704.19-1058.47	900.00	206.96	688.07-1111.92
Total Points BRET	**Profile 1**	**1.5 mA (*n*=9)**	603.56	137.10	521.53-685.57	617.78	163.87	524.98-710.57	622.67	144.01	499.56-745.77
		2 mA (*n*=1)	620.00	.	373.63-866.07	548.00	.	269.62-826.38	716.00	.	346.68-1085.31
	Profile 2	**1.5 mA (*n*=10)**	642.00	121.35	564.18-719.81	653.20	122.58	565.17-741.23	659.20	126.43	542.42-775.98
		2 mA (*n*=8)	615.50	118.92	528.501-702.49	579.50	145.61	481.07-677.92	664.00	197.87	533.43-794.57
	Profile 3	**1.5 mA (*n*=3)**	653.33	68.15	511.26-795.40	573.33	14.05	412.611-734.05	684.00	346.57	470.78-897.22
		2 mA (*n*=3)	501.33	80.13	359.26-643.40	646.67	95.44	485.94-807.39	682.67	207.43	469.44-895.88
	Profile 1	**1.5 mA (*n*=9)**	9.66	3.08	7.88-11.44	10.60	3.61	8.64-12.56	10.34	3.92	8.25-12.44

		2 mA (*n*=1)	8.66	.	3.33-13.99	12.03	.	6.15-17.91	13.56	.	7.28-19.85
Mean Parcels Collected	**Profile 2**	**1.5 mA (*n*=10)**	10.00	1.83	8.32-11.69	10.54	2.58	8.68-12.40	10.21	2.84	8.22-12.19
		2 mA (*n*=8)	9.86	2.87	7.98-11.75	9.44	2.35	7.36-11.52	10.00	2.57	7.78-12.22
	Profile 3	**1.5 mA (*n*=3)**	9.29	3.54	6.22-12.37	8.98	3.11	5.58-12.37	10.02	3.09	6.39-13.64
		2 mA (*n*=3)	9.34	.21	6.26-12.42	8.84	1.93	5.45-12.23	9.94	.97	6.31-13.57

Note. * First column, dependent variables; second and third columns, independent variables (personality profiles and stimulation intensity). DLPFC: Dorsolateral Prefrontal Cortex, VLPFC: Ventrolateral Prefrontal Cortex

Table A12 Pairwise comparison of cathodal DLPFC vs sham, cathodal VLPFC vs sham, and cathodal VLPFC vs cathodal DLPFC under different personality groups.

				t	**Mean Difference**	**Std. Error**	**Sig.[a]**	**95% CI**
	DLPFC		**VLPFC**	-.03	-4.62	4.60	.97	-16.35-7.09
			Sham	-2.05	-9.30	3.65	.05	-18.61-.00
Profile 1			**DLPFC**	.03	4.62	4.60	.97	-7.09-16.35
(*n*=10)	**VLPFC**		**Sham**	-.15	-4.67	6.36	.87	-15.78-6.43

				t	Mean Difference	Std. Error	Sig.[a]	95% CI
			DLPFC	2.05	9.30	3.65	.05	-.00-18.61
		Sham	**VLPFC**	.15	4.67	4.36	.87	6.43-15.78
			VLPFC	-	.18	2.07	1.00	-5.09-5.45
		DLPFC	**Sham**	-1.9	-4.00	1.64	.06	-8.19-.18
			DLPFC	-	.18	2.07	1.00	-5.45-5.09
	Profile 2	**VLPFC**	**Sham**	-1.57	-4.18	1.96	.12	-9.18-.81
Average	**(*n*=18)**		**DLPFC**	1.92	4.00	1.64	.06	-.18-8.19
adjusted		**Sham**	**VLPFC**	1.57	4.18	1.96	.12	-.81-9.18
Pumps			**VLPFC**	-	.15	3.56	1.00	-8.93-9.23
		DLPFC	**Sham**	-	-.59	2.83	1.00	-7.80-6.61
			DLPFC	-	-.15	3.56	1.00	-9.23-8.93
	Profile 3	**VLPFC**	**Sham**	-	-.74	3.37	1.00	-9.34-7.86
	(*n*=6)		**DLPFC**	-	.59	2.83	1.00	-6.61-7.80

	Sham	**VLPFC**	-	.74	3.37	1.00	-7.86-9.34
			t	**Mean Difference**	**Std. Error**	**Sig.[a]**	**95% CI**
Profile 1 (*n*=10)	**DLPFC**	**VLPFC**	-.051	-176.05	135.22	.61	-520.40-168.29
		Sham	-1.99	-322.27	129.17	.05	-651.21-6.66
	VLPFC	**DLPFC**	.051	176.05	135.22	.61	-168.29-520.40
		Sham	-	-146.22	179.65	1.00	-603.69-311.25
	Sham	**DLPFC**	1.99	322.27	129.17	.05	-6.66-651.21
		VLPFC	-	146.22	179.65	1.00	-311.25-603.69
Profile 2 (*n*=18)	**DLPFC**	**VLPFC**	-	49.10	60.85	1.00	-105.85-204.05
		Sham	-.62	-80.08	58.12	.53	-228.11-67.93
	VLPFC	**DLPFC**	-	-49.10	60.85	1.00	-204.05-105.85
		Sham	-.09	-129.18	80.84	.36	-335.05-76.67
	Sham	**DLPFC**	.62	80.08	58.12	.53	-67.93-228.11
		VLPFC	.09	129.18	80.84	.36	-76.67-335.05

					Mean			
Wanted				***t***	**Difference**	**Std. Error**	**Sig.[a]**	**95% CI**
Pumps			**VLPFC**	.06	106.66	104.74	.95	-160.06-373.40
		DLPFC	**Sham**	-	58.83	100.05	1.00	-195.96-313.62
			DLPFC	-0.06	-106.66	104.74	.95	-373.40-160.06
	Profile 3	**VLPFC**	**Sham**	-	-47.83	139.15	1.00	-402.19-306.52
	(*n*=6)		**DLPFC**	-	-58.83	100.05	1.00	-313.62-195.96
		Sham	**VLPFC**	-	47.83	139.15	1.00	-306.52-402.19
			VLPFC	-.27	-127.83	111.82	.78	-412.57-156.91
		DLPFC	**Sham**	-	-88.61	147.52	1.00	-464.28-287.06
			DLPFC	.27	127.83	111.82	.78	-156.91-412.57
		VLPFC	**Sham**	-	39.22	103.05	1.00	-223.19-301.63
	Profile 1		**DLPFC**	-	88.61	147.52	1.00	-287.06-464.28
	(*n*=10)	**Sham**	**VLPFC**	-	-39.22	103.05	1.00	-301.63-223.19
			VLPFC	-	14.01	50.31	1.00	-114.12-142.14

		DLPFC	**Sham**	-.48	-84.98	66.38	.63	-254.04-84.06
			DLPFC	-	-14.01	50.31	1.00	-142.14-114.12
	Profile 2	**VLPFC**	**Sham**	-1.58	-99.00	46.37	.12	-217.08-19.08
	(*n*=18)		**DLPFC**	.48	84.98	66.38	.63	-84.06-254.04
		Sham	**VLPFC**	1.58	99.00	46.37	.12	-19.08-217.08
Total Earnings BART				***t***	**Mean Difference**	**Std. Error**	**Sig.[a]**	**95% CI**
			VLPFC	-1.05	-147.16	86.61	.30	-367.72-73.39
		DLPFC	**Sham**	-	-73.00	114.27	1.00	-363.99-217.99
			DLPFC	1.05	147.16	86.61	.30	-73.39-367.72
	Profile 3	**VLPFC**	**Sham**	-	74.16	79.82	1.00	-129.09-277.43
	(*n*=6)	**Sham**	**DLPFC**	-	73.00	114.27	1.00	-217.99-363.99
			VLPFC	-	-74.16	79.82	1.00	-277.43-129.09
			VLPFC	-	28.88	77.10	1.00	-167.46-225.23
		DLPFC	**Sham**	-	-57.55	105.20	1.00	-325.45-210.34

			DLPFC	-	-28.88	77.10	1.00	-225.23-167.46
		VLPFC	**Sham**	-	-86.44	104.07	1.00	-351.46-178.57
	Profile 1		**DLPFC**	-	57.55	105.20	1.00	-210.34-325.45
	(*n*=10)	**Sham**	**VLPFC**	-	86.44	104.07	1.00	-178.57-351.46
				t	**Mean Difference**	**Std. Error**	**Sig.[a]**	**95% CI**
			VLPFC	-	12.40	34.69	1.00	-75.95-100.75
		DLPFC	**Sham**	-	-32.85	47.34	1.00	-153.40-87.70
			DLPFC	-	-12.40	34.69	1.00	-100.75-75.95
Total Points BRET	**Profile 2**	**VLPFC**	**Sham**	-	-45.25	46.83	1.00	-164.50-74.00
	(*n*=18)		**DLPFC**	-	32.85	47.34	1.00	-87.70-153.40
		Sham	**VLPFC**	-	45.25	46.83	1.00	-74.00-164.50
			VLPFC	-	-32.66	59.72	1.00	-184.75-119.42
		DLPFC	**Sham**	-.51	-106.00	81.49	.61	-313.51-101.51
			DLPFC	-	32.66	59.72	1.00	-119.42-184.75

	Profile 3 (*n*=6)	**VLPFC**	**Sham**	-	-73.33	80.61	1.00	-278.61-131.95
		Sham	**DLPFC**	.51	106.00	81.49	.61	-101.51-313.51
			VLPFC	-	73.33	80.61	1.00	-131.95-278.61
				t	**Mean Difference**	**Std. Error**	**Sig.[a]**	**95% CI**
	Profile 1 (*n*=10)	**DLPFC**	**VLPFC**	-1.20	-2.15	1.18	.23	-5.17-.86
			Sham	-2.57	-2.79	.92	.01	-5.14- -.43
		VLPFC	**DLPFC**	1.20	2.15	1.18	.23	-.86-5.17
			Sham	-	-.63	1.15	1.00	-3.57-2.29
		Sham	**DLPFC**	2.57	2.79	.92	.01	.43-5.149
			VLPFC	-	.63	1.15	1.00	-2.29-3.57
Mean Parcels Collected	**Profile 2 (*n*=18)**	**DLPFC**	**VLPFC**	-	-.05	.53	1.00	-1.41-1.30
			Sham	-	-.16	.41	1.00	-1.23-.89
		VLPFC	**DLPFC**	-	.05	.53	1.00	-1.30-1.41
			Sham	-	-.11	.51	1.00	-1.43-1.20

		DLPFC	-	.16	.41	1.00	-.89-1.23
	Sham	**VLPFC**	-	.11	.51	1.00	-1.20-1.43
		VLPFC	-	.40	.91	1.00	-1.92-2.74
	DLPFC	**Sham**	-	-.66	.71	1.00	-2.48-1.16
		DLPFC	-	-.40	.91	1.00	-2.74-1.92
Profile 3	**VLPFC**	**Sham**	-.13	-1.07	.89	.72	-3.34-1.20
(*n*=6)		**DLPFC**	-	.66	.71	1.00	-1.16-2.48
	Sham	**VLPFC**	.13	1.07	.89	.72	-1.20-3.34

Note. * First column, dependent variables; second, independent variables (personality profiles). a. Adjustment for multiple comparison: Bonferroni. DLPFC: Dorsolateral Prefrontal Cortex, VLPFC: Ventrolateral Prefrontal Cortex. The shaded rows are where statistically significant differences have been found

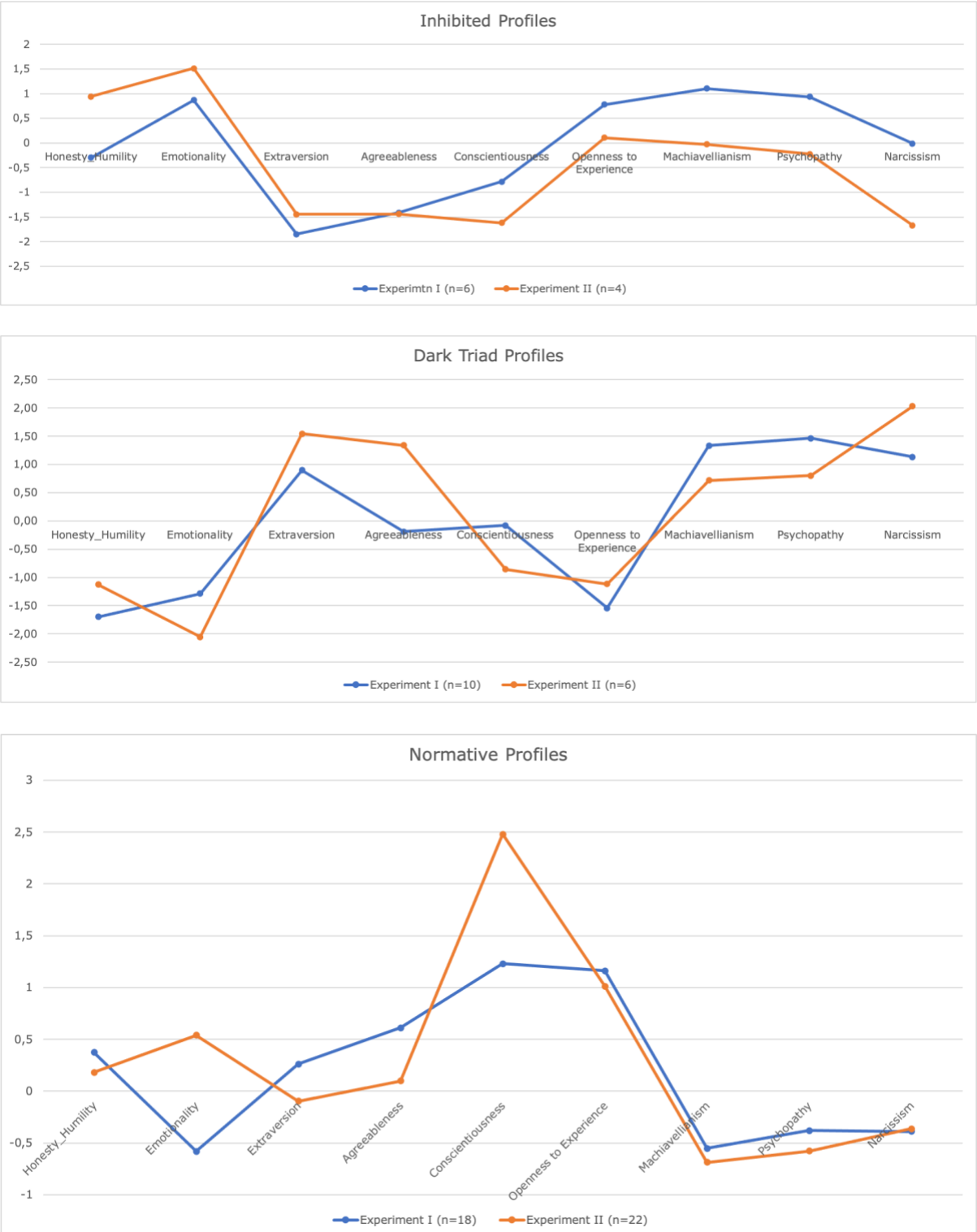

Figure A20 Graphic representation of personality profiles of both experimental procedures with standardized values.

Table A16 Personality profiles comparisons. Between subject effects.

Dependent Variable	Statistical test	Tests of Between-Subjects Effects
Honesty_Humility	GLM	Personality $F(2, 29)=11.71$, $p<.01$
Emotionality	GLM	Personality $F(2, 29)=1.53$, $p=0.23$
Extraversion	GLM	Personality $F(2,29)=2.18$, $p=0.13$
Agreeableness	GLM	Personality $F(2, 29)=6.55$, $p<.01$
Conscientiousness	GLM	Personality $F(2, 29)=3.43$, $p=0.046$
Openness to Experience	GLM	Personality $F(2, 29)=0.09$, $p=0.91$
Machiavellianism	GLM	Personality $F(2, 29)=3.39$, $p=0.047$
Psychopathy	GLM	Personality $F(2, 29)=1.58$, $p=0.22$
Narcissism	GLM	Personality $F(2, 29)=9.48$, $p<.01$

Note * Significant effects are in green.

Table A17 Multiple comparisons between profiles for personality dimensions.

Dependent Variable	Statistical test	Bonferroni Adjustment for Multiple comparisons

Honesty_Humility	Multiple Comparisons	Profile 1 vs Profile 2 $t(29)=2.29$, $p=0.03$ Profile 1 vs Profile 3 $t(29)=3.63$, $p<.01$
Emotionality	Multiple Comparisons	Profile 1 vs Profile 2 $t(29)=1.12$, $p=0.27$
Extraversion	Multiple Comparisons	Profile 1 vs Profile 3 $t(29)=0.38$, $p=0.70$ Profile 1 vs Profile 2 $t(29)=1.31$, $p=0.20$
Agreeableness	Multiple Comparisons	Profile 1 vs Profile 3 $t(29)=3.23$, $p<.01$
Conscientiousness	Multiple Comparisons	Profile 1 vs Profile 2 $t(29)=1.60$, $p=0.12$
Openness to Experience	Multiple Comparisons	Profile 1 vs Profile 2 $t(29)=-$, $p=1.00$
Machiavellianism	Multiple Comparisons	Profile 1 vs Profile 2 $t(29)=0.62$, $p=0.54$ Profile 1 vs Profile 3 $t(29)=1.95$, $p=0.06$
Psychopathy	Multiple Comparisons	Profile 1 vs Profile 3 $t(29)=1.01$, $p=0.32$
Narcissism	Multiple Comparisons	Profile 1 vs Profile 3 $t(29)=2.96$, $p<.01$ Profile 2 vs Profile 3 $t(29)=3.63$, $p<.01$

Note * Significant effects are in green.

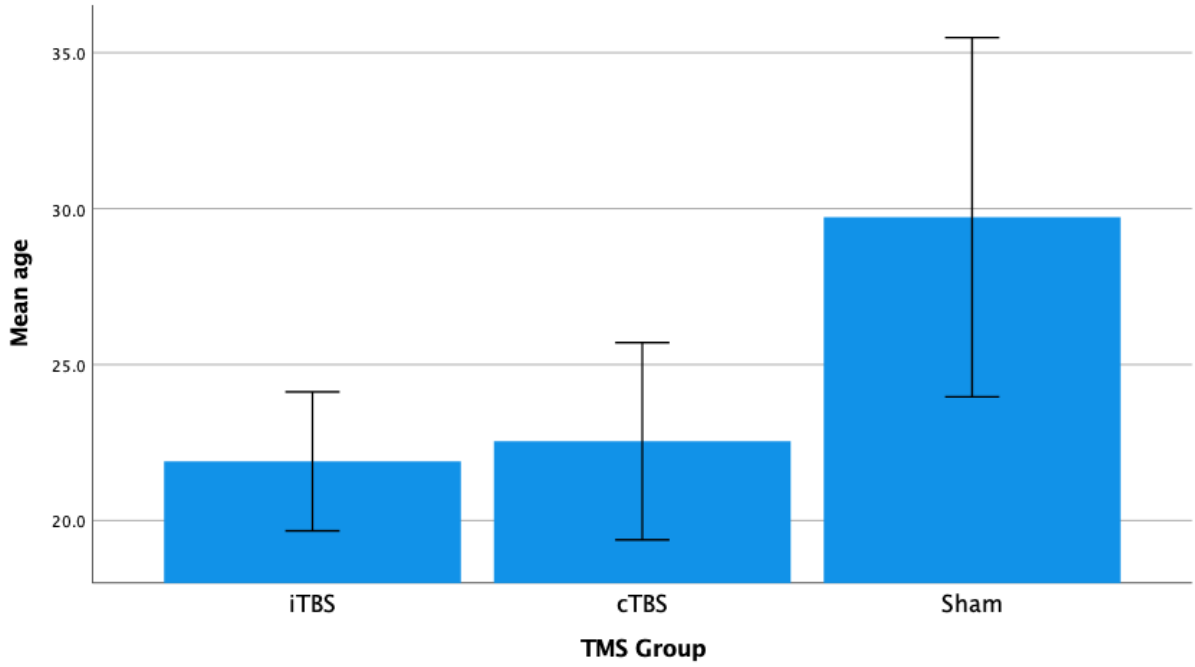

Figure A21 Mean age of participants for each stimulation group.

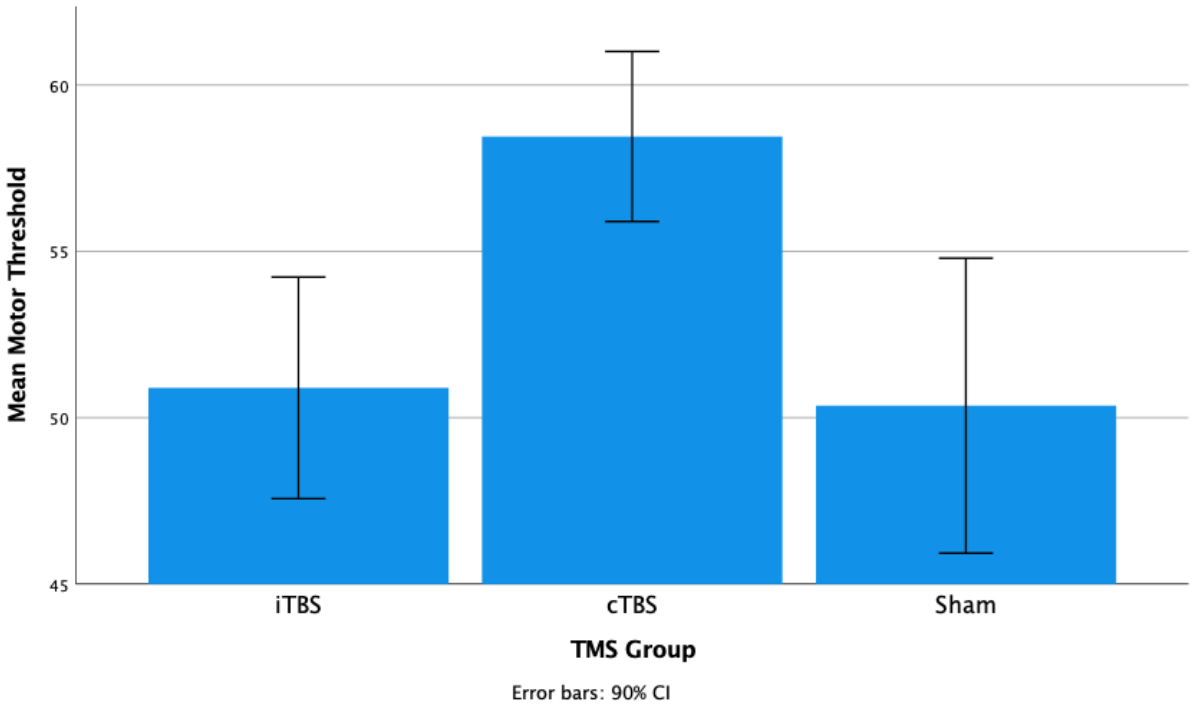

Figure A22 Mean motor threshold by stimulation group. (Source prepared by author)

Table A26 Descriptive analysis of personality dimensions by profile Experiment II

Profile	Dimensions	N	Mean	SD	95% CI
Profile 1	Narcissism	22	9.45	2.94	4-14
	Psychopathy	22	6.91	2.38	4-12
	Machiavellianism	22	8.64	2.62	4-14
	Openness to experience	22	36.50	6.23	21-46
	Conscientiousness	22	39.55	5.89	29-49
	Agreeableness	22	29.00	5.47	20-40
	Extraversion	22	30.32	6.49	15-46
	Emotionality	22	36.91	6.66	22-47
	Honesty/humility	22	34.86	4.47	24-43
Profile 2	Narcissism	6	12.00	2.28	9-15
	Psychopathy	6	6.00	1.26	4-7
	Machiavellianism	6	7.00	2.82	4-11
	Openness to experience	6	37.33	3.26	33-41
	Conscientiousness	6	33.67	4.17	27-39
	Agreeableness	6	38.50	5.85	33-49
	Extraversion	6	35.83	6.14	26-42
	Emotionality	6	31.33	7.65	24-45
	Honesty/humility	6	40.00	2.82	36-44
Profile 3	Narcissism	4	4.50	.57	4-5
	Psychopathy	4	5.00	.81	4-6
	Machiavellianism	4	5.25	1.50	4-7
	Openness to experience	4	35.75	4.99	29-41
	Conscientiousness	4	33.50	8.34	23-42

Agreeableness	4	31.25	6.85	23-39
Extraversion	4	34.50	5.32	29-40
Emotionality	4	35.50	7.18	29-45
Honesty/humility	4	44.50	1.73	42-46

Note. The minimum and maximum possible values for the dark-triad/dirty-dozen dimensions (psychopathy, Machiavellianism, narcissism) were 4 and 20, and for HEXACO (emotionality, extraversion, agreeableness, conscientiousness, openness to experience, honesty-humility) were 10 and 50.

Abbreviation list

DLPFC: dorsolateral prefrontal cortex; MtDCS: Multifocal transcranial direct current stimulation; VLPFC: ventrolateral prefrontal cortex; tDCS: transcranial direct current stimulation; TMS: transcranial Magnetic stimulation; tACS: transcranial altering current stimulation; HD-tDCS: Hight definition transcranial direct current stimulation; BART: Balloon analogue risk task; BERT: Bomb risk elicitation task; NIBS: non-invasive brain stimulation; LPFC: the left lateral prefrontal cortex; VMF: ventromedial prefrontal cortex; LPA: Latent profile analysis; AVP: Adjusted Average pumps; TE: Total Earning; WP: Wanted Pumps; MPC: mean parcels collected; TP: Total points; right orbifrontal cortex: rOFC; orbitofrontal cortex: OFC; rostral anterior cingulate cortex: rACC; posterior cingulate cortex: PCC; angular gyrus: AG; working memory: WM; motor threshold: MT; resting motor threshold: rMT; intraparietal sulcus: IS; inferior frontal junction: IFJ; dorsomedial prefrontal cortex: DMPFC; CRS: corrected recognition score; RTcor: rection time correct trials; RTer: reaction time error trials; posterior orbitofrontal cortex: pOFC

Figure and table index

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