Doctoral Dissertation

Neurocognitive Mechanisms of Mindfulness and Grit Traits: An Individual Differences Approach to Cognitive Control

(Mecanismos neurocognitivos de los rasgos de mindfulness y grit: una aproximación al control cognitivo desde las diferencias individuales)

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A mi madre, que me demostró que querer es poder.

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Introductory Note

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The content of this doctoral dissertation has been drawn up according to the regulations of the University of Granada to obtain the International Doctorate Mention in the Psychology Doctoral Program. According to this, the majority of the thesis has been written in English. Specifically, the preface is written in English and Spanish. Following, in Chapters I to IV a theoretical introduction to the subject of the investigation is presented in English. Next, the empirical chapters (from V to IX) also proceeds in English. Then, the general discussion and concluding remarks are written in English (Chapter X). Finally, a chapter including summary and conclusion of the thesis is written in Spanish (Chapter XI).

Contents

Preface

“May your choices reflect your hopes, not your fears.”
Nelson Mandela

As time goes by our choices and circunstances lead us to a certain path. When observed, this path will make some people happy with their own life, while others will not feel this way. Two factors are responsible for this distinction: the reality around them and the interpretation they do of this reality. From the positive psychology field there is an increasing amount of research studying the elements that harbor both an objective and subjective successful life. As part of these elements two traits have been shown to predict success and well-being: mindfulness and grit. Mindfulness is defined as the ability to focus attention towards the present moment with a non-judgmental attitude, while grit refers to the tendency to get engaged in long term goals with enduring perseverance and passion. Several have been the benefits linked to both traits (from better mental health to professional success or healthy aging). However, the underlying psychological and neurocognitive mechanisms that lead to such benefits are still not well understood. With the aim of contributing to filling this gap, the goal of this dissertation has been to investigate the (possible) neurocognitive mechanisms of mindfulness and grit traits in young and older adults.

In the first three chapters of this work (that has been mostly written in English) we summarize the most accepted models of mindfulness and grit traits, cognitive control and the study of individual differences. In chapter IV we introduce the experimental series of this thesis. Following, in chapters from V to IX we report the studies in which we investigate the cognitive (chap. I y III) and neural (chap. II y IV) mechanisms of mindfulness and grit traits in young and older (chap. IX) adults. Finally, in chapter X we discuss the findings from the five reported studies from the perspective of each trait, and in chapter XI we provide a synthesis of the main findings of the thesis in Spanish. We believe our work is a valuable contribution to the understanding of mindfulness and grit traits (and cognitive control), which may serve for future studies to develop evidence based programs to foster these traits.

Prefacio

"Que tus decisiones sean reflejo de tus esperanzas, no de tus miedos."

Nelson Mandela

A medida que el tiempo avanza nuestras decisiones y circunstancias nos llevan por un determinado camino. Al parar a observarlo habrá personas que se sientan satisfechas con su vida, mientras que otras no lo estarán tanto. Dos factores son responsables de esta diferencia: la realidad a su alrededor y la interpretación que hagan de esa realidad. Desde el campo de la psicología positiva se están estudiando cada vez más los elementos que llevan a una vida satisfactoria, en lo objetivo y lo subjetivo. Como parte de estos elementos dos rasgos de personalidad han demostrado predecir éxito y bienestar: la atención plena (*mindfulness*) y la tenacidad (*grit*). El *mindfulness* es definido como la habilidad de mantener la atención en el presente en una actitud libre de juicio, mientras que el *grit* se refiere a la tendencia a involucrarse en retos a largo plazo con tenacidad y pasión continuas. Son numerosos los beneficios que ambos rasgos han mostrado tener en multitud de dominios (desde una mejor salud mental a mayor éxito profesional o envejecimiento saludable), sin embargo, los mecanismos psicológicos en general y neurocognitivos en particular que permiten dichos beneficios aún no se conocen en su totalidad. Por este motivo el objetivo de la presente tesis doctoral ha sido investigar los (posibles) mecanismos neurocognitivos de los rasgos de *mindfulness* y *grit* en adultos jóvenes y mayores.

En los primeros tres capítulos de este trabajo (mayormente escrito en inglés) resumimos los modelos teóricos fundamentales de los rasgos de *mindfulness* y *grit*, de control cognitivo y del estudio de las diferencias individuales. En el capítulo IV presentamos la línea experimental propuesta para la tesis. A continuación, en los capítulos del V al IX presentamos los estudios en los que investigamos los mecanismos cognitivos (cap. I y III) y neurales (cap. II y IV) de los rasgos de *mindfulness* y *grit* en adultos jóvenes y en adultos mayores (cap. IX). Por último, en el capítulo X discutimos los resultados de los cinco estudios reportados desde la perspectiva de cada rasgo y en el capítulo XI ofrecemos un resumen sobre la tesis y sus hallazgos en castellano. Consideramos que este trabajo supone una contribución valiosa al entendimiento de los rasgos de *mindfulness* y *grit* (y del control cognitivo) y que, además, puede ayudar a estudios futuros que pretendan desarrollar entrenamientos para mejorar estos rasgos.

PART 1:

Introduction

CHAPTER I. Mindfulness and Grit as Positive Traits

A fascinating ability of humans is their capacity to evolve, adapt, and improve themselves to embrace a good life. This crucial way for survival can sometimes even lead to high human potential, which is associated with self-satisfaction and success in life. Understanding the traits and their underlying neurocognitive mechanisms (if any) that foster such a drive is key to learning how to cultivate positive growth.

The need to investigate the ability for personal development and self-actualization was pointed out long ago by some authors, as an aspect substantially neglected in human psychology (Maslow, 1954). To overcome this limitation, the field of positive psychology emerged two decades ago (Seligman & Csikszentmihalyi, 2014; Vázquez et al., 2009). The main aim of positive psychology is to investigate the potentialities, strengths, and aspirations of humankind. Thus, scientific research on these topics becomes essential to promote health: the state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity (World Health Organization, 1946).

In positive psychology, dispositional constructs, such as mindfulness and grit, have generated a burgeoning body of research because they have been shown to significantly contribute to well-being (Brown & Ryan, 2003;

Duckworth et al., 2007). Traits refer to the stable, consistent, and enduring disposition of the individual (Allport & Odbert, 1936). From this, mindfulness is described as the virtue of non-judgmental awareness toward the present moment (Kabat-Zinn, 2003a), while grit refers to embodied passion and perseverance toward long-term goals (Duckworth et al., 2007). Adding to the numerous benefits and relevance that are usually highlighted in mainstream media and the ongoing debate in academia, both traits can help in examining the interaction between personality and cognition, given that, in theory, both involve a complex combination of personality and cognitive dimensions.

Actually, mindfulness and grit include, in their theoretical characterization, terms such as self-regulation and flexibility, which are both paramount in cognitive neuroscience. As will be discussed in the next section, although the two traits have been the subject of much research for the past years, their underlying neurocognitive mechanisms remain largely understudied. Hence, in this dissertation, we synergize these two important fields of psychology—personality and cognitive neuroscience—to unveil the subjacent cognitive and neural basis of mindfulness and grit traits. We believe this is crucial for understanding them as natural dispositions and for future studies to examine how they change with training.

Mindfulness

Although mindfulness was initially dismissed as another pop psychology cure-all for an overly stressed society (Mesmer-magnus et al., 2017), a growing body of scientific research has revealed its benefits in physical and psychological health (Conversano et al., 2020; Goldberg et al., 2021; Grossman et al., 2004; Gu et al., 2015; Keng et al., 2011; Roca et al., 2019; Virgili, 2015), cognitive ability (Cásedas et al., 2020; Chiesa et al., 2011; Raffone, & Srinivasan, 2010; Tang et al., 2015), and community and workplace functioning (Creswell, 2017; Good et al., 2016). In fact, mindfulness is far from new. This virtue of awareness was already described in the Vedas, the oldest scriptures of Hinduism, and it can be found in almost all cultures and traditions, from the Indian to the Arabic or the Western (Eifring, 2013; Fell et al., 2010; Hart et al., 2013; Naranjo, 2003; Siegel et al., 2009).

Mindfulness is the capacity to bring unfolding experiences into conscious awareness without subjectivity or attachment (Bodhi, 2010). To understand this now popular concept, it has to be rooted in its origins. Hence, "Mindfulness" is an English translation of the Pali word sati, which connotes awareness, attention, and remembering as a vehicle for enlightenment in Theravada Buddhism (Gethin, 2011; Hanh, 1976; Thera, 2005). In this traditional view, attention controlled 'bending back' consciousness upon the physical, sensory, and psychological current experience of the subject, enabled by remembering the intention to keep the mind in the present. Within this perspective, the purpose of mindfulness is to eliminate needless suffering by understanding the nature of the mind. Insights into the mind's nature will 1) generate space in the mental habits for possible change and 2) help to recognize any other mental quality that needs enhancement. Consequently, mindfulness will help a person to remain peacefully amid whatever happens. In this sense, mindfulness is not a goal but a way of being that can be improved through meditation (Siegel et al., 2009).

This ancient way of being was introduced in the West by psychologist Jon Kabat-Zinn (1982), who defined mindfulness as "the awareness that arises through paying attention, on purpose, in the present moment, and non-judgmentally" (Kabat-Zinn, 2003a, p. 145). Bishop et al. (2004) operationalized this ontological concept, emphasizing two aspects: 1) the self-regulation of attention toward the current experience and 2) the adoption of a set of curiosity, openness, and acceptance toward such experience. Another well-established psychological model of mindfulness is the one by Shapiro (2006), who described three interwoven axioms of mindfulness: the intention of the subject (why), which goes from self-regulation to self-liberation; the attention (what), which is the ability to apply, sustain and bring back the focus of attention to the present moment; and the attitude of acceptance, openness, and curiosity toward one's own experience (how). From the above-mentioned models of mindfulness, the common variable is the regulation of attention and the quality from which this attention sprouts and acts. This also parallels other mindfulness theories that stress components of attention and emotion regulation, alongside body awareness and perspective change of the self (Hölzel et al., 2011; Lutz et al., 2008; Malinowski et al., 2013). Indeed, this form of conscious awareness is thought to produce a shift in perspective that is called re-perceiving, decentering, or silent witness, which allows for 1) encountering and being exposed to previously difficult thoughts and emotions that will reduce their capacity for disruption; 2) transforming previously rigid cognitive and emotional styles by bringing objective awareness of the automatic processes of the mind; and 3) providing an opportunity to choose new and more congruent values (Shapiro, 2006).

In this scenario, mindfulness has been conceptualized as a personality trait since the frequency with which people enter this state of awareness varies in a natural way across individuals (Brown & Ryan, 2003; Giluk, 2009; Grossman & Van Dam 2011). In fact, the mindfulness trait has a heritability coefficient of 0.32 (Waszczuk et al., 2015). The dispositional tendency of mindfulness can be further cultivated through mindfulness meditation practices (i.e., Chiesa & Malinowski, 2011; Eberth & Sedlmeier, 2012). Thus, for instance, the Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 2003b), the Mindfulness-Based Cognitive Therapy (MBCT; Teasdale et al., 2000), or the Integrative Body-Mind Training (Tang et al., 2007) train practitioners in entering such a state through meditation, which can be either static or integrated in the daily activities (Crescentini & Capurso, 2015; Davis & Hayes, 2011; Wheeler et al., 2017), and that can engage either focused-attention or open monitoring practices (i.e., Travis & Shear, 2010). Expanding the psychology of mindfulness in the West, several authors have also revealed some risks, such as the decontextualized simplistic approach and the oversight of negative effects frequently present in current mindfulness research and practice (Britton, 2019; Grossman, 2010; Van Dam et al., 2018).

Since the introduction of mindfulness as a topic for psychological scientific inquiry, distinct measures have been developed to quantify mindfulness and its relation to other psychological constructs. Most of these measures are based on questionnaires that tap into dispositional mindfulness and its enhancement with later practice. The most widely used scale in earlier studies on the topic was the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), in which mindfulness is understood as a single construct related to attention by employing 15 items to measure it, such as, "I find myself doing things without paying attention" (negatively worded). Major concerns have been raised regarding the MAAS because 1) it does not capture the acceptance or the non-judgmental attitudes of mindfulness (Baer et al., 2006; Sauer et al., 2013), and 2) all items are negatively worded, probably leading to measuring the propensity to experience lapses of attention (Grossman & Van Dam, 2011; Van Dam et al., 2010). In comparison, the Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006), another well-established measure, understands mindfulness as a multifactorial construct. The FFMQ comprises 39 items of five different facets selected after performing exploratory factor analysis on the items of five frequently used mindfulness questionnaires (MAAS, KIMS, FMI, CAMS-R, and SMQ). The five resulting facets are 1) Observing: the tendency to notice or attend to internal and external experiences (i.e., "I remain present with sensations and feelings even when they are unpleasant or painful"); 2) Describing: the tendency to describe and label experiences (i.e., "I'm good at finding the words to describe my feelings"); 3) Acting with awareness: the ability to bring full awareness to current activity (i.e., "I find it difficult to stay focused on what's happening in the present", reversed item); 4) Non-judging: the non-evaluative stance toward inner experiences (i.e., "I tend to evaluate whether my perceptions are right or wrong", reversed item); and 5) Non-reactivity: the tendency to allow thoughts and feelings to come and go, without getting caught up by them (i.e., "I watch my feelings without getting lost in them").

As previously mentioned, mindfulness has been largely studied in the past few decades (Chiesa & Serretti, 2009; Davis & Hayes, 2011; Glomb et al., 2011; Ludwig & Kabat-Zinn, 2008; Montero-Marin et al., 2016; Roca et al., 2021; Roca & Vazquez, 2020; Shapiro et al., 2006; Tang et al., 2015). However, research has mainly focused on mindfulness meditation practices but little on its dispositional aspect. Additionally, the studies regarding dispositional mindfulness have mostly focused on its benefits but little on its underlying psychological mechanisms. To give a brief overview, at the personality level, mindfulness has been (negatively) related to neuroticism and negative affect and positively linked to conscientiousness (Giluk, 2009; Rau & Williams, 2016). Besides, mindfulness traits have benefits in personal and professional contexts. Particularly related to well-being (Short & Mazmanian, 2013) and psychological health (Tomlinson et al., 2018), dispositional mindfulness seems to be positively related to confidence, emotional regulation, and life satisfaction (Mesmer-magnus et al., 2017). Emotional intelligence (Miao et al., 2018) and social functioning (Donald et al., 2019) have also been related to dispositional mindfulness. Additionally, this trait has been negatively correlated to perceived life stress, negative emotions, anxiety, and depression (Mesmer-magnus et al., 2017). At the professional level, Mesmer-magnus et al.'s (2017) meta-analysis showed that the mindfulness trait may benefit job satisfaction, performance, and interpersonal relations, and reduce burnout and work withdrawal. In fact, they showed that dispositional mindfulness adds incremental predictive variance over more traditional predictors of employee burnout and work performance.

In summary, while previous research has revealed some benefits of dispositional mindfulness, unravelling the neurocognitive mechanisms underlying the trait is necessary. Despite the roles that attention, self-regulation, and flexibility play in conceptualizing mindfulness as a trait, the study of the link of dispositional mindfulness to these processes remains in its infancy (Anicha et al., 2012). A recent meta-analysis on the studies conducted to examine the role of cognition in dispositional mindfulness highlighted the relationship between some cognitive processes and the facet acting with awareness of trait mindfulness (Verhaeghen, 2021). Indeed, results of previous studies revealed the role of cognitive control in the relationship between dispositional mindfulness and well-being (Short et al., 2016). Also, at the neural level, some studies have supported this relationship (Kong et al., 2016; Lim et al., 2018; Lu et al., 2014). These studies' findings are promising because they show dispositional mindfulness to be associated with cognitive control and mind-wandering networks; however, they still need replication and further exploration.

Grit

History shows that humans have achieved great things, such as inventing the spacecraft, reaching the top of the biggest mountains, ending apartheid, or developing vaccines for the virus that causes COVID-19. These achievements are all preceded by an important inversion of effort and perseverance, although they do not seem sufficient to succeed. A big dose of passion and purpose was also crucial for these attainments. Grit is the personality trait that captures the individual's tendency to get involved in long-term goals despite setbacks with enduring stamina and passion (Duckworth et al., 2007). Grit trait emerges from the idea that performance is more than just expressing individuals' cognitive abilities or "talents"; instead, it involves the sustained effort one exerts over time in achieving one's goals (perseverance of effort) and the passion one has for one's challenge (consistency of interest) (Duckworth et al., 2007). In addition, adaptability to situations, the flexibility to actively adapt to changing environments, has also been proposed to be crucial for grit trait (Datu et al., 2017). Duckworth and Quinn (2009) developed a self-reported scale for measuring grit. Items of the perseverance of effort facet refer to persisting in achieving a goal despite all difficulties that arise in the process (i.e., "I am diligent"), items of the consistency of interest dimension refer to the constant maintenance of interest toward the superordinate goal (i.e., "My interests change from year to year", reversed item).

Although research on motivation has a long tradition in psychology since the earliest days of James and Wundt and has been systematically studied (Atkinson, 1964), grit is a relatively new construct, and it is presented as different from other motivation-related concepts (Duckworth, 2016). However, some similarities require consideration. One important aspect of grit is that the long-term goals that gritty individuals choose to follow frequently have an intrinsic value (Duckworth, 2016), which fits well into the classical self-determination theory (Deci & Ryan, 2002). According to this theory, hard effort and perseverance are demonstrated on meaningful aims to which people feel passion rather than on externally rewarded goals. Another related concept is growth mindset (Dweck, 2016), the belief that talents can be developed through hard work, good strategies, and input from others. Although independent constructs, a growth mindset is thought to be required to develop grit (Hochanadel & Finamore, 2015). In addition, some have cast doubt on the similarity of grit and the Big Five trait of conscientiousness (Credé et al., 2018; Credé, 2017), which refers to the tendency to be self-controlled, responsible to others, hardworking, orderly, and rule-abiding (Roberts et al., 2014). However, Duckworth et al. (2007) emphasized that the difference lies in the long-term orientation of perseverance demonstrated by gritty people. Not only do high-grit people finish tasks at hand but they pursue a given goal over the years.

Findings from a number of studies using the above-mentioned scale support the idea that grit is crucial for overcoming challenges and achieving success. In fact, grit has been linked to educational and work achievements above and beyond IQ and conscientiousness (Duckworth et al., 2007; Strayhorn, 2014). In education settings, grit has also been related to school satisfaction (Clark & Malecki, 2019; Ivcevic & Brackett, 2014; Li et al., 2018). At the career level, grit has been shown to be predictive of longevity in the workspace (Eskreis-Winkler et al., 2014), work performance (Mueller et al., 2017; Suzuki et al., 2015), fewer career changes (Duckworth & Quinn, 2009), and less counterproductive behavior at work (Ceschi et al., 2016). At the personal level, grit has been linked to general higher well-being (i.e., Jiang et al., 2020; Salles et al., 2014), life satisfaction (Clark & Malecki, 2019; Vainio & Daukantaitė, 2016), positive affect (Hill et al., 2016), and satisfaction with peer relationships (Lan & Moscardino, 2019). In addition, grit has been linked to lower depression (i.e., Datu et al., 2019; Musumari et al., 2018), reduction of risk of suicidal ideation (i.e., Kleiman et al., 2013; White et al., 2017), and successful aging (Kim & Lee, 2015). Inspired by all these benefits and the evidence that two-thirds of the variance in grit is explained by the environment (Rimfeld et al., 2016), training programs are being developed to promote grit in educational contexts (i.e., Baruch-Feldman, 2017). For example, grit promotion can be found in character education, wherein grit is taught as a positive feature and is fostered by increasing self-control, growth mindset, learning strategies, and resilience (The Grit Enhancement Program; Shechtman et al., 2013; Sinclair, 2021).

How grit promotes such achievements remains unknown. Here, emotion regulation and self-regulation are two abilities that fit well with the theoretical understanding of grit (Knauft et al., 2019; Myers et al., 2016). Similarly, it is thought that the key to tackling challenging and tough situations for gritty individuals is their ability to regulate their own psychological experiences (Ceschi et al., 2016; see also the model of grit, resilience, and recovery: Ceschi et al., 2021). Additionally, some authors have assumed that successful executive functions underlie grit (Hwang & Nam, 2021). However, research on the neurocognitive mechanisms underlying grit is scarce. Some studies have shown preliminary results on the association between grit and the processing of contextual cues and flexibility (Kalia et al. 2018; 2019), and others have shown that individual differences in grit trait are associated with differences in the function and structure of the prefrontal cortex and striatum, which are key regions for executive control and reward processes (Myers et al., 2016; Nemmi et al., 2016; Wang et al., 2017; Wang et al., 2018). While these findings sound promising, some cognitive functions that fit well with the theoretical understanding of grit remain unexplored.

In the following section, we will review some extended frameworks of cognitive control to deeply understand the existing literature linking cognition and mindfulness and grit traits and then articulate our own hypotheses on the possible neurocognitive mechanisms underlying each trait.

CHAPTER II. Cognitive Control

To adapt to an ever-changing environment, humans need to face new situations and override automatic responses, which entail maintaining and regulating thoughts and actions according to internally represented goals. The system allowing for such regulation is called cognitive control. Cognitive, or executive, control enables intelligent goal-directed behavior and is recruited in almost every psychological process, from action to language processing or creativity (Cohen, 2017). Note that for this thesis, we refer to the processes enabling goal-directed behavior as cognitive control, executive control, or executive functions indistinctly, although we discuss some theoretical differences below.

The traditional view of cognitive control has defined it as opposing automatic responses. Stereotyped responses ("bottom-up" processing) such as the automatic orientation to an unexpected sound allow frequent behaviors to be executed quickly and without effort. However, they are highly inflexible, hard to generalize to novel situations, and require substantial time and experience to be acquired. Conversely, controlled behavior ("top-down" processing) is thought to consume cognitive resources (for later updates about this characteristic see: Botvinick & Braver, 2015; Edin et al., 2009; Kool et al., 2010; Kurzban et al., 2013). In addition, exerting control over behavior is considered slower (regarding automatic behavior) and more vulnerable to interference

(Miller & Cohen, 2001). However, it is controlled behavior that allows for flexible performance and adaptation in new situations. For example, when we aim at engaging in a new cognitive task (i.e., we recently moved to a new neighborhood and now need to buy some bread), cognitive control needs to assemble together various mental processes and representations to flexibly switch to a new representation of "my neighborhood," where new streets and shops are activated and previous ones are override to visit the selected shop and return home.

A half-century-long research on the topic has produced several theoretical models of cognitive control. From the first descriptions (Atkinson & Shiffrin, 1968; Kahneman, 1973; Posner, 1975; Shiffrin & Schneider, 1977), theories have been developed emphasizing distinct aspects of this function (i.e., Baddeley, 1992; Botvinick & Cohen, 2014; Braver, 2012; Dosenbach et al., 2007; Duncan, 2010; Miyake et al., 2000; Norman & Shallice 1986; Petersen & Posner; 2012; Posner & Petersen, 1990). Many approaches to the construct make the scientific taxonomy of cognitive control elusive. For instance, the first theories that introduced the concept stemmed from the field of neuropsychology and termed it executive functions. The neurophysiological study of patients with frontal lobe damage (i.e., Phineas Gage) marked the beginning of the study of control and regulation behavior and their link with the prefrontal cortex. Then, the field of attention described cognitive control (sometimes termed Supervisory Attentional System) as the mechanism that intercedes in certain circumstances to control cognitive processing to establish the criteria of information selection (Norman & Shallice 1986). Likewise, Baddeley's (1992) influential model of working memory included three components. Two "slave" systems maintain speech-based information (the phonological loop) and visuospatial information (the visuospatial sketchpad), and a third one regulates processing. This component was called the central executive and was usually linked to the frontal lobes (corresponding to what Norman and Shallice termed the Supervisory Attentional System).

Indeed, cognitive control has long been linked to the prefrontal cortex (PFC) (i.e., Egner & Hirsch, 2005; Koechlin et al., 2003; MacDonald et al., 2000; Miller, 2000; Ridderinkhof et al., 2004), although other cortical and subcortical brain regions play a key role in executive functioning (Botvinick & Cohen, 2014). From an evolutionary perspective, the PFC is the last to develop during the first stages of the lifespan (Diamond, 2002) and has been shown to be affected in aging (Paxton et al., 2008) and pathological conditions, such as schizophrenia (Edward et al., 2010). Hence, early neural descriptions of cognitive control included the PFC and the anterior cingulate cortex (ACC) as part of the Anterior Attentional System (Executive Control Network) (Posner & Petersen 1990). A major feature of the PFC is its high connectivity with other cortical regions, such as the temporal, parietal, and cingulate cortices (Della-maggiore et al., 2000; Petrides & Pandya, 2009), and various subcortical structures, such as the basal ganglia or the hippocampus (Alexander, 1986;

Lehéricy, 2004). This privileged anatomical situation makes the PFC sufficiently flexible to play a fundamental role in higher order functions, such as cognitive control (Rougier et al., 2005). In addition, that the PFC is highly interconnected reveals the need to study it regarding the complex spatiotemporal dynamics that operate in the brain network architecture (Cole et al., 2013). Hence, recent models of control have adopted a complex dynamic network perspective, such as the Multiple Demand Network (Duncan, 2010), the model of fronto-parietal and cingulo-opercular networks (Dosenbach et al., 2006, 2008), or the Dual Mechanisms of Cognitive Control theory (Braver, 2012; Braver et al., 2021).

The richness of approaches to cognitive control evolving during its study has generated a breakthrough in the understanding of this process and its neural bases. In this thesis, we will focus on two approaches to the topic. On the one hand, we followed Miyake et al.'s (2000) framework due to its richness in explaining the components that constitute cognitive control. On the other hand, we selected Braver's (2012) Dual Mechanisms of Cognitive Control theory because of its fine description of the modes that cognitive control can adopt. Further, we selected several brain indexes that are thought to capture the complex dynamics of cognitive control and that have been broadly employed to study individual differences.

The Unity and Diversity of Executive Functions

While earlier theories of cognitive control conceived it as a single, central control mechanism, over time, this unitary view had been questioned. Studies with patients and on individual differences have suggested that different mechanisms underlie cognitive control (Burgess et al., 1998; Duncan et al., 1997; Godefroy et al., 1999). Within this perspective, cognitive control is thought to modulate the operation of various cognitive subprocesses (executive functions) that regulate the dynamics of human cognition. A seminal framework on executive functions (EF) based on empirical work is the one by Miyake et al. (2000; see also Friedman & Miyake, 2004; Miyake & Friedman, 2012). To build their model on executive functions, they performed latent variables analyses over different measures from tasks that theoretically recruit executive control to see whether this function entails a unitary mechanism or, conversely, comprises different mechanisms. The structural equation modeling over the latent variables showed that, although there were shared features that indicated the existence of a unitary construct, the model comprised three different, but not totally independent of each other, functions: switching, working memory updating, and inhibition.

These three separable functions contribute differently to complex executive tasks. Thus, switching refers to the mechanism that allows individuals to shift flexibly between tasks, operations, or mental sets (Rogers & Monsell, 1995). That is, cognitive control can be exerted to enable and disable current task sets already established in procedural memory as a function of internal goals or instructions (for reviews of this specific function, see Kiesel et al., 2010; Vandierendonck et al., 2010). However, switching is also understood as the capacity to perform a new operation while handling proactive interference (Allport & Wylie, 2000). That is, when a person has a particular mental set activated, he/she will persist even when the context changes, which could produce interference over the new mental set needed in the new context. This cost can be prevented by preparation, although it does not disappear (Monsell, 2003). The switching process is thought to rely on the frontoparietal network (Brass & Von Cramon, 2002; Muhle-Karbe et al., 2014). There is a family of experimental paradigms to investigate "task-switching" (Rogers & Monsell, 1995). In these paradigms, a specific number of tasks are defined and trained so that participants understand all of them and fix them in procedural memory. The different tasks normally employ multivalent stimuli (i.e., colored shapes) so that they fit all tasks, but a cue signals the task that must be done in each trial (i.e., respond to the color of the image vs. to the shape) (Monsell & Mizon, 2006). The individual's ability to switch across tasks can be calculated by the switch cost index, which compares the performance (i.e., reaction times) on trials that maintain the same task (no-switch or repeat trials, better performance) to those that change tasks (switch trials, more challenging) (Rogers & Monsell, 1995).

The function of updating refers to coding and monitoring information in working memory alongside its revision to replace old items that are no longer relevant with newer relevant ones (Morris & Jones, 1990). Working memory is thought to be a system with a limited capacity that works at the intersection of attention and memory. The capacity of working memory refers to the number of representations that the system can maintain active in spite of interference (Cowan, 2010; Kane & Engle, 2002; Oberauer, 2009). While traditional models of working memory generally understood it as a mental workspace that both keep information available "online" and govern the encoding manipulation and retrieval of such information (for an extended conceptualization, see Baddeley, 2012; Wilhelm et al., 2013), Miyake's et al. (2000) model emphasized the role of updating information, which exceeds the simple maintenance of task-relevant information in its requirement to dynamically manipulate the contents of working memory (Cohen et al., 1997; Morris & Jones, 1990; Smith & Jonides, 1997). Working memory has traditionally been related to the DLPFC, among other regions (Smith & Jonides, 1997; for a general review, see Baddeley, 2003). A prototypical task to measure working memory capacity and updating is the O-Span task, wherein several words should be stored in memory while verifying different equations, and, in every block of the task, the information should be updated. Updating is measured as the percentage of intrusions of words from previous blocks, and general working memory capacity is calculated by multiplying recollected words and correct equations (Turner & Engle, 1989; Redick et al., 2012).

Finally, the inhibitory function within this perspective allows individuals to deliberately override dominant or proponent responses when needed (Miyake et al., 2000). More generally, inhibition is the mechanism that enables organisms to override actions, memories, or emotions by deactivating representations or processes underlying them (Anderson & Hulbert, 2021). For instance, to successfully inhibit a motor response, there is a need to coordinate signal detection, action selection, and suppression of motor output (Verbruggen et al., 2014; for a classical conceptualization, see Logan & Cowan, 1984). Again, the suggested regions handling this function are the DLPFC and the ventrolateral PFC (Valle et al., 2020; Kuhl et al., 2007; see also Aron, 2007). A classical task thought to recruit inhibition is the stroop task (Macleod, 1991; Roelofs et al., 2006; Stroop, 1935), wherein participants must name the ink color of a color word, such as GREEN, when the color and word can be either congruent (i.e., GREEN in green ink) or incongruent (GREEN in black ink). The interference generated by automatically processing the word's meaning and its inhibition is usually quantified through conflict costs (CC), an inverse estimate of inhibitory control, whereby responses to incongruent trials are less accurate and slower than responses to congruent trials (Roelofs et al., 2006; Strobach et al., 2014).

EFs are our very valued tool to confront everyday challenges. The fine description of each subcomponent of cognitive control that this framework provides allows for a separate measure of each of them. Thus, conforming a sophisticated approach for the study of individual differences (Friedman et al., 2008; Miyake & Friedman, 2012).

The Dual Mechanisms of Control Theory

Another fruitful framework for cognitive control considered highly sensitive to individual differences is the "Dual Mechanisms of Cognitive Control" (DMC) theory proposed by Braver (Braver et al., 2009; Braver, 2012). The DMC shifts the emphasis on variability toward the forms that cognitive control can adopt. Hence, the DMC specifies that cognitive control can be deployed in two qualitatively distinct modes: proactive and reactive control modes. The proactive control mode acts by actively maintaining task-relevant information sustainably (tonically) to direct behavior following internal goals (as an early selection mechanism). Thus, it biases attention, perception, and action in a goal-driven manner so that it anticipates and prevents interference before it occurs. Conversely, the reactive mode of control handles the detection and resolution of interference at the time it occurs (as a late corrective function) so that it responds to changing environmental demands in a transient phasic manner. Hence, reactive control is mobilized only after a highly interfering event is detected. Within this perspective, proactive control is conceptualized as a bias that can facilitate processing of expected cognitive-complex upcoming events, while reactive control reflects the reactivation of task goals elicited by detecting interference or episodic associations. A classic example of each control mode in daily life is a situation in which a person wants to visit a shop after work. A proactive strategy would be to keep active the intention to visit the shop during the whole day of work, while a reactive strategy would be to only transiently activate the intention when it is formed (i.e., in the morning) and reactivate it by an appropriate trigger event (i.e., noticing the shopping list at the end of the journey). Using proactive control may be more effective (the person will not forget to visit the shop), but it is also more demanding for working memory. In contrast, using reactive control may be more efficient (less resource-consuming) but will not bias the scheduling of other activities (i.e., a late meeting) incompatible with the intention. Using one or the other control mode in this example depends on different factors, such as the lapse of time between the intention formation and the moment to perform the action (Braver et al., 2009; Braver, 2012).

At the neural level, the dissociation between proactive and reactive modes of control is considered possible due to the separable dynamics of brain activity. Thus, proactive control entails the anticipatory and sustained activation of the lateral PFC, enabling goal maintenance. Conversely, reactive control would rely on the transient activation of the lateral PFC (and other areas) with the engagement of conflict monitoring areas (ACC) during interference, or posterior cortical or medial temporal lobe regions when elicited by associations.

Thus, it is the temporal dynamics of activity in (relatively) the same regions (and others) that enable the adoption of one or the other control mode in response to external or internal conditions. Further, the DMC proposes that this variation in control modes is implemented through a dopaminergic system described in the gating model, wherein phasic dopaminergic signals allow for sustaining inputs in the PFC (Braver, 2012; Braver et al., 2009; Chiew & Braver, 2017).

Only the effective use of both control modes allows the complex balance between maintaining the representations of the current goal against distractions while also flexibly updating these representations as goals and environmental factors change. While both control modes could, in principle, operate separately, it is its dynamic coordination that allows individuals to be more flexible and adaptive in changing situations (Amer et al., 2016; Burgess & Braver, 2010; Munakata et al., 2012). Furthermore, both control modes can dynamically shift due to multiple influences caused by within-individual and within-group variabilities that can be accounted for through the DMC framework and tasks. For instance, theories emphasize that aging brings deficits in all forms of context processing, from context representation, maintenance of context relevant information, and updating of context changes (Braver & West, 2008; Yee et al., 2019). Generally, healthy young adults tend to rely more on their proactive control, while healthy older adults usually exhibit a more reactive tendency, probably because the proactive mode is more demanding (i.e., Paxton et al., 2008). Similarly, in some PFC-related disorders, such as schizophrenia, individuals exhibit impoverished proactive control (i.e., Barch et al., 2001; MacDonald & Carter, 2003). Although proactive control has been associated with the functioning of intact brain activity (younger healthy individuals), efficient performance seems to depend on the ability to adjust and combine both types of control as required by the situation. Some individual differences studies suggest that better performance is sometimes achieved by the flexible adjustment of both control modes (Morales et al., 2013, 2015).

A well-established task to measure the proactive and reactive tendency of individuals is the AX-Continuous Performance Task (AX-CPT; Braver et al., 2009; Cohen et al., 1992). The AX-CPT is a delayed response task that requires the maintenance and updating of context information for successful performance. On each experimental trial of the task, participants must respond to a typically letter cue–probe pair that appears sequentially. Participants are instructed to respond affirmatively to a specific cue–probe pattern of letters ("A" cue followed by "X" probe; AX trials), while any other combination of letters requires a negative response. Responses are entered when the probe appears. These target trials (AX) occur at a high frequency (generally 70%), which prompts the association between the "A" cue and the affirmative response, and between the probe "X" and affirmative response. Consequently, the early preparation to answer may induce proactive errors when the pattern is not correct due to the probe letter ("A" cue but non-X probe; AY trials). In contrast, reactive errors occur when the pattern is not correct due to the cue letter (non-A cue but "X" probe; BX). In AY trials, interference arises due to the contextual cue that has been maintained and should be overcome upon probe presentation. AY trials are taken as proactive errors, as interference in this kind of trial is thought to reflect a preparatory control. However, in BX trials, the previous contextual information must be used to inhibit the interference of the probe-related tendency toward an affirmative response; such interference is thought to reflect reactive control. Additionally, the task includes control trials in which neither the cue nor the probe generates interference (non-A cue and non-X probe; BY). The reliance on reactive control would be captured in reaction times slowing or errors with BX trials that would reflect the time to engage control after probe presentation, while the reliance on proactive control would be reflected in slower responses or errors to AY trials, reflecting the time to engage control after probe presentation to overcome the tendency activated in the earlier cue presentation. Thus, the individual tendency toward one control mode is calculated using the Behavioral Shift Index (BSI), which is the subtraction of reactive errors/slowing to proactive errors/slowing compared to control trials (Braver et al., 2009; Chiew & Braver, 2017; Gómez-Ariza et al., 2017; Morales et al., 2015). AX-CPT task is considered specially suitable to tap into individual differences in various domains (i.e., Braver, 2012; Morales et al., 2013).

Although the two approaches (Miyake's Model and the DMC) differ in many respects, they are not necessarily in contradiction since context monitoring and updating are assumed to be part of proactive control, and interference control can be approached reactively by inhibiting responses once the stimuli provoking them emerge. Hence, although they focus on different aspects of cognitive control, they both provide useful frameworks and methods for investigating different aspects of individual differences in cognitive control. In the following section, we will discuss the existing findings relating mindfulness and grit traits to cognitive control and will introduce several neural indexes that have been demonstrated to provide useful insights into the study of individual differences.

CHAPTER III. Individual Differences in Cognitive Control

As highlighted in Chapter I, mindfulness and grit traits provide an interesting scenario for exploring the relationship between personality and cognition (and their neural substrates) because they both involve a complex combination of personality and cognitive dimensions. In fact, there is much evidence of the interplay between personality and cognition (Katz et al., 2016). Literature examining how individual differences affect cognitive control is ample (Engle et al., 1999). Among the observable factors that mainly influence cognitive performance are demographic factors, motivation, and personality traits (Katz et al., 2016), alongside metacognition (Fernandez-Duque et al., 2000) and self-regulation abilities (Barkley, 2001). Hence, the study of the neurocognitive mechanism underlying the traits of mindfulness and grit will help to deepen our understanding of both the nature of the traits, and the variability of cognitive control.

Mindfulness gathers the constructs of attention and self-regulation in its conceptualization (Bishop et al., 2004). In addition, the role of cognitive functions has been demonstrated in mindfulness meditation practices (i.e., Fox et al., 2014; Tang et al., 2015). However, the underlying neurocognitive mechanisms of dispositional mindfulness and how individual differences in cognitive control are linked to the trait remain largely understudied. A positive relationship exists between dispositional mindfulness and attention performance (Verhaeghen, 2021). Specifically, the meta-analysis by Verhaeghen reveals that both accuracy and reaction times (RTs) in attentional tasks tend to improve as a function of dispositional mindfulness, suggesting that such effects are not due to speed-accuracy trade-offs but to more efficient attention mechanisms. Among other processes, inhibition has been particularly linked to mindfulness as a trait that mediates the relationship between the trait and creative thinking (Noone et al., 2016). Also, executive functions (especially inhibitory control and working memory) have been linked to dispositional mindfulness during adolescence (Riggs et al., 2015). While some studies have reported links between dispositional mindfulness and cognitive control (Anicha et al., 2012; Lin et al., 2019; Jaiswal et al., 2018), null results have also been found (Di Francesco et al., 2017). Following these lines, some studies have attempted to examine how the mindfulness trait is associated with control modes (Chang et al., 2018), although these studies have produced mixed results compared to mindfulness interventions (Li et al., 2018). Similarly, in the case of older adults some contradicting results have also been found when mindfulness has been studied as a disposition or as the result of training (Fountain-Zaragoza et al., 2016, 2018; Whitmoyer et al., 2020). In addition, at the neural level, dispositional mindfulness relates to greater grey matter volume in several regions (including bilateral ACC and PCC) controlling executive attention, emotion regulation, and self-referential processing (Lu et al., 2014). Other studies on the neural substrates of the mindfulness trait linked it to a specific pattern of local synchronization of spontaneous brain activity in several regions involved in emotion processing, body awareness, self-referential processing, and executive control (Kong et al., 2016) and to a state of task readiness (Lim et al., 2018). Specifically, Lim et al. (2018) found enhanced within-network connectivity in the default-mode (DMN) and salience networks, and greater anti-correlations between task-positive networks and the DMN in high mindfulness individuals. Overall, these results suggest that particular patterns of cognitive (and neural) activity underlay mindfulness trait. However, further research is required to better understand these potential associations.

Furthermore, grit is understood as having a strong self-regulation component (Ceschi et al., 2021), although studies on the cognitive underpinnings of grit are scarce. Hence, Kalia et al. (2018) examined some potential associations between attention and grit using a standardized attentional task (the Attention Network Test, ANT; Fan et al., 2002). In this study, they explored the relationship between grit and attentional networks and found an association with the alerting function, which they attributed to either better sustained attention or less sensitivity to warning cues by gritty individuals. Kalia et al. (2019) also found a positive association between the perseverance of effort facet of grit and performance on difficult Sudoku problems, which was mediated by reduced cognitive flexibility. Moreover, grit has been shown to be protective against late life cognitive declines (i.e., Kim & Lee, 2015; Rhodes &

Giovannetti, 2021). At the neural level, the few available reports show congruency in revealing a role of the prefrontal cortex and striatum, which are linked to self-regulation and motivation processes, in expressing grit at rest (Myers et al., 2016; Nemmi et al., 2014; Wang et al., 2017; 2018). Nemmi et al. (2016) found that this trait was associated with differences in the volume of the nucleus accumbens in children, which has been related to reward-seeking. Similarly, Myers et al. (2016) found, also in children, that grit was associated with ventral striatal and bilateral prefrontal networks, considered crucial for cognitive-behavioral control, perseverance, and emotional regulation. Finally, in two studies with healthy adolescents, Wang et al. (2017, 2018) found that higher grit scores were associated with greater volume in the right putamen, smaller volume in the left DLPFC, and lower regional fractional amplitude of low-frequency fluctuations in the right dorsomedial PFC. Because these areas are involved in self-regulation, action planning, and motivation (Kelley et al., 2015), these results suggest that certain profiles of cognitive functioning could characterize gritty people. However, to date, studies are very limited, and a wider scope of cognitive functions that fit with the theoretical understanding of grit still requires exploration.

Neural Markers of Individual Differences

Connectivity between the neural networks implicated in cognitive control has been classically investigated while participants are engaged in an experimental task and from the perspective of structural connectivity (the comprehensive collection of white matter tracts connecting neurons). More recently, however, the focus has moved to functional connectivity, which infers a network structure based on coordinated activity while subjects are either at rest or at task (Biswal, 2010; Raichle, 2010). Particularly, the resting-state functional connectivity approach was developed after the observation of high correlations between the somatomotor cortices in the two hemispheres at rest (Biswal, 1995) and has been demonstrated to be functionally meaningful, highly reproducible, and related, but not identical, to structural connectivity (Cole et al., 2012; Honey et al., 2009; Shehzad et al., 2009). Indeed, the control-related areas mentioned in the previous section seem to maintain synchrony even at rest (Fox et al., 2005). In addition, while functional connectivity has been mainly studied by functional magnetic resonance imaging (fMRI) through the blood oxygen level dependent (BOLD) signal (Fox & Raichle, 2007), it can also be understood regarding the temporal coherence or correlation among the oscillatory firing rate of neuronal assemblies (Friston, 1994). In fact, the highly flexible nature of cognitive control fits well with the idea of dynamic changes in synchronization that flexibly alter the pattern of communication structure, such as the "communication through coherence" hypothesis proposes (Fries, 2015). Brain oscillations are rhythmic fluctuations in the activity of populations of neurons that allow for communication from an activated neural group that engages in synchronization (sequences of excitation and inhibition) and, when coherent, communicate with downstream neurons, resulting in a burst that provides a non-linear boost in input strength (Buzsáki & Draguhn, 2004; Cohen, 2017). This approach to brain communication suggests that constrained small networks are represented in synchronicity at high frequencies, while long-range communication on which cognitive control seems to rely occurs through lower frequencies (Fries, 2015). Several frequency bands have been studied regarding cognitive control (i.e., Bressler & Richter, 2015; Capilla et al., 2014). For instance, the theta band (4–8 Hz) over the midfrontal cortex that has been robustly linked to situations that require action monitoring (Cohen & Cavanagh, 2011; Eisma et al., 2021).

The study of brain activity at rest revealed the existence of the Default Mode Network (DMN), a neural network that gets activated at rest and deactivated while engaged in a task (Raichle, et al., 2001). This network shows a high degree of functional connectivity among regions and includes precuneus, PCC, medial prefrontal cortex (MPFC) and medial, lateral and inferior parietal cortex (Raichle et al., 2001). In fact, when the energy consumed during rest and at task is compared, the consumption during the task slightly exceeds that for rest (Raichle & Mintun, 2006). Although task deactivation is characteristic of the DMN, notably, while DMN activity attenuates in the rest–task transition, its activity does not totally deplete during task. The deactivation degree of DMN during a task depends on how demanding the task itself is (i.e., Singh & Fawcett, 2008). In addition, the presence of activity in the DMN during tasks has been linked to errors and lapses of attention (Eichele et al., 2008; Weissman et al., 2006). The PCC is implicated in the general continuous sampling of external and internal environments (Raichle et al., 2001) and is also thought to be implicated in working memory (Greicius et al., 2003). On the other hand, the MPFC is thought to be implicated in emotional processing and cognitive regulation balance implemented in ventral and dorsal regions (Raichle et al., 2001). This two main poles of the DMN are associated with mind-wandering, introspective processes, and emotional and self-referential processing (Gusnard & Raichle, 2001; Mantini & Vanduffel, 2013). While most research on the DMN has used fMRI (i.e., Greicius et al., 2003, 2007), some studies have considered oscillatory activity using EEG (i.e., Laufs et al., 2003; Scheeringa et al., 2008). Because fMRI provides only an indirect measure of neural activity and no consensus exists regarding how this activity is linked to changes in BOLD contrast (i.e., combined neuronal spiking, local field potentials, changes in spontaneous rhythms, etc.) (Huettel et al., 2003), other brain imaging techniques, such as EEG, are also used to study DMN. EEG provides excellent temporal resolution for measuring direct spontaneous oscillatory activity (Khader et al., 2008; Liu et al., 2017). The study of DMN through frequency bands has revealed the importance of alpha in long-range communication to allow for functional interactions in the whole network, and of beta and gamma bands to support interactions between relatively closer node pairs (Mantini et al., 2007; Samogin et al., 2019). The beta and alpha activity is associated with the PCC node, whereas gamma frequency is associated with the MPFC and other self-referential processing areas (Berkovich-Ohana et al., 2012, 2014; Mantini et al., 2007). Thus, the study of the changes in the gamma band from rest to task can be a valuable tool to explain how DMN varies across individuals (Berkovich-Ohana et al., 2012).

Research on oscillatory activity has produced several indexes to tap into cognitive control that have been widely employed and that are sensitive to individual differences (i.e., Arns et al., 2013). One of these is the theta/beta ratio (TBR) (Angelidis et al., 2016; Putman et al., 2010; 2014; van Son et al., 2018) that is computed from the ratio of the activity in the theta band (4–7 Hz) and the activity in the beta band (13–30 Hz). In addition to measuring cognitive control in healthy adults (i.e., Angelidis et al., 2016), TBR relates to motivated decision making (Massar et al., 2012; 2014; Schutter & Van Honk, 2005), mind-wandering (van Son et al., 2019), and to a stronger decline in cognitive control after stress induction (Putman et al., 2014). Additionally, TBR has shown high test–retest reliability and is useful for predicting attentional control scores over one week (Angelidis et al., 2016). Using this metric originated in the study of impulsiveness-related disorders, such as Attention Deficit Hyper Activity Disorder (ADHD), wherein patients exhibit increased theta and decreased beta activities compared to healthy controls (Arns et al., 2013; Clarke et al., 2001; Snyder & Hall, 2006). Indeed, theta and beta frequencies are likely to reflect activity in different neural circuits (Massar et al., 2014), and higher frontal TBR is thought to index a failure to exert top–down control over automatic processing of subcortical information. One important source of scalp-recorded theta (through EEG) is the ACC (Di Michele et al., 2005; Scheeringa et al., 2008; Tsujimoto et al., 2006; Womelsdorf et al., 2010). Frontal theta frequency has been linked to emotional and motivational processes (Azanova et al., 2021; McNaughton & Gray, 2000; Mitchell et al., 2008). Conversely, beta activity is thought to reflect GABAnergic inhibitory activity and can appear when the cognitive state requires maintenance and when interference should be overcome. In fact, in resting-state studies, frontal beta activity reflects top–down control of motivation drives (Hofman et al., 2013; Massar et al., 2014; Putman et al., 2010; Schutter & Van Honk, 2005). Overall, TBR has been considered a well-established index for measuring cognitive control (Angelidis et al., 2016) and provides a useful tool for tapping into individual differences.

Finally, non-linear indexes of brain complexity have also been employed to examine individual differences (i.e., Catarino et al., 2011; Ibáñez-Molina et al., 2018). As reviewed, the brain signal is variable, and this variability is often functional (Friston, 2010; Garrett et al., 2013). The way the nested networks of the brain are coupled is thought to follow nonlinear dynamics (Stam, 2005). Given the complex biological signals arising from brain functions, methods exceeding the assumption of linear combination of activity from multiple areas are required. In this sense, non-linear approaches from chaos and information theory have been proposed to be more convenient for its study, as they tap into nonrandom fluctuations over multiple time scales. In fact, these methods have been shown to offer information that complements what is provided by traditional measures (Klonowski, 2016). Complexity measures are sensitive to the level of randomness or disorder in a temporal distribution of values in a series, and they are thought to reflect a lack of synchrony between distributed neural generators (Escudero et al., 2015). Entropy and fractal dimensions are frequently used as complexity measures. While entropy reveals the amount of disorder in a system, the fractal dimension describes the self-similarity of the system (Catarino et al., 2011; Mandelbrot, 1977; Ruiz-Padial & Ibáñez-Molina, 2018). Differences in measures of complexity have been linked to cognitive ability (Liu et al., 2020), biological coding (Borst & Theunissen, 1993; Costa et al., 2002), the interplay between neural adaptation and behavior (Sharpee et al., 2014), the state of consciousness (Demertzi et al., 2019), and pathological disorders, such as autism spectrum conditions (Catarino et al., 2011) or schizophrenia (Ibáñez-Molina et al., 2018). Importantly, complexity has been linked to diverse mental states, such as vigilance (Shi et al., 2013). In fact, complexity tends to increase during cognitive tasks and as a function of task difficulty (Gregson et al., 1990; 1993; Lamberts, 2000; Müller et al., 2003). Given the above-mentioned evidence, complexity measures provide a complementary approach to the study of individual differences.

In conclusion, although some attempts have been made to explore the relationship between cognition and mindfulness and grit traits, there remains a long path ahead to fully understand the neurocognitive mechanism of both traits. Hence, some fine cognitive control frameworks, such as Miyake's et al.'s (2000) model and the DMC theory, may provide fruitful insights. In addition, several neural indexes (such as frontal gamma, TBR, and complexity indexes) have been considered appropriate for the study of individual differences and may help unveil the neural mechanisms of mindfulness and grit traits.

CHAPTER IV. Aims and Outline of the Experimental Series

Health and well-being are two of the most precious aspects of life, and personality factors can substantially impact these aspects (Schmutte & Ryff, 1997; Weiss et al., 2008). Traits such as mindfulness and grit seem to foster psychological health, life satisfaction, and success (Brown & Ryan, 2003; Duckworth et al., 2007). How people are and who people become with time and experience are determinant of well-being. Particularly, the ability to keep attention anchored to the present in an attitude of acceptance enables individuals to remain peacefully amid whatever happens (Brown & Ryan, 2003). In addition, the tendency to engage in long-term goals with enduring passion and perseverance indicates later life satisfaction and success (Duckworth et al., 2007). Moreover, those dispositions seem to play also a positive role in healthy aging (i.e., De Frias, 2014; Fountain-Zaragoza et al., 2016; Kim & Lee, 2015; Rhodes & Giovannetti, 2021). Although the study of mindfulness and grit traits has been increasingly showing various psychological benefits, the neurocognitive mechanisms (if any) that underlie these traits remain largely unknown. Considering the evidence reviewed in the previous sections, we endeavor to unveil the neurocognitive mechanisms of mindfulness and grit traits in younger and older adults. Given the theoretical relationship between mindfulness and grit traits with self-regulation (Bishop et al., 2004; Duckworth

& Gross, 2014), it seems reasonable to think that cognitive control plays a role in both traits. In addition, neural signatures of these relationships can be expected. Research on the neurocognitive basis of mindfulness and grit traits is imperative in gaining a more precise and nuanced understanding of the nature of these traits and the mechanisms through which they benefit healthy aging, which may allow developing evidence-based training to foster them. Conversely, the study of these relationships will deepen our understanding of cognitive control and its variability across individuals.

Thus, the first goal of this dissertation was to determine whether cognitive control plays a significant role in trait mindfulness at the behavioral level. Chapter V reports the first piece of research exploring the control modes that underlay dispositional mindfulness. From the perspective of the dynamic nature of cognitive control, two control modes can be deployed and flexibly shifted (see Chapter II), the proactive and reactive modes (Braver et al., 2009). This conceptualization renders the study of the relationships between distinct variables with cognitive control more precise because differences may emerge from a better general performance and a different style of control (Braver, 2012). Previous research has indicated a relationship between cognition and mindfulness meditation (Cásedas et al., 2020; Tang et al., 2015), and some studies suggest the existence of such a relationship also in dispositional mindfulness (Verhaeghen, 2021). However, the cognitive control tendency of mindfulness has rarely been studied, although its importance has been highlighted (Lin et al., 2021). The few studies that have explored such a relationship (Chang et al., 2018; Incagli et al., 2020; Li et al., 2018) found non-convergent results when mindfulness was measured as a trait, a state, or after a training program. Also, the use of different questionnaires to explore the level of mindfulness could have influenced their results. Hence, to clarify the role of cognitive control and its different modes in mindfulness trait, we aimed at replicating Chang et al.'s (2018) findings regarding mindfulness trait using two different measures of dispositional mindfulness (the MAAS and the FFMQ) and two complementary tasks to measure control modes (the AX-CPT and adapted cued task-switching), which provide indexes of control mode and flexibility. We expected to replicate Chang et al.'s (2018) finding of a more balanced use of cognitive control in mindful individuals. In addition, we expected that high mindfulness individuals would also show a more flexible performance when switching between tasks. These results are compatible with the idea that an increased focus on the present without judgment can make mindful people less attached to previous contextual information, which allows them to flexibly adapt to new contexts. This research has been published in the journal Psychological Research (Aguerre et al., 2020).

In addition to a particular pattern of control (enhanced cognitive control and flexibility due to less attachment to previous contextual information), the tendency to keep attention in the present is thought to be linked to less mind wandering. A clear mind without ruminating and divagating thoughts is characteristic of low activity in the DMN. Indeed, mindfulness research on meditation has shown mindfulness meditation to be linked to less involvement of the DMN at rest (Berkovich-Ohana et al., 2012, 2014). Research related to dispositional mindfulness in this regard has also specified this direction, but further research is needed to fully comprehend this association (Lim et al., 2018). The second goal of this dissertation was to clarify whether mindfulness traits are linked to lower involvement of the DMN. Chapter VI reports a piece of research in which we explored the neural mechanisms of dispositional mindfulness. In this study, we followed an oscillatory perspective of brain communication by employing total power and frontal gamma power (from rest to task) and complexity measures (entropy and fractal dimension) of EEG. We expected high mindfulness individuals to have patterns of brain activity related to lower involvement of the DMN at rest (reduced frontal gamma power) and a state of "task readiness" reflected in a more similar pattern from rest to task (reduced overall quantitative EEG power at rest but not at task). In addition, we wanted to explore whether brain complexity indexes showed such a pattern. This study is currently under review in the journal of Scientific Reports.

The third goal of this dissertation was to explore the possible cognitive mechanisms underlying grit trait. Chapter VII reports the third piece of research that considers the relative role of cognitive processes and personality traits in expressing grit. Grit has been amply presented as a non-cognitive trait that can predict success above intelligence (Duckworth et al., 2007). However, its definition is closely linked to self-regulation concepts. This is why we aimed to explore the relative role of cognition and other self-regulation traits (mindfulness and impulsiveness) in its expression. As a young research topic, few studies have attempted to explore the relationship between grit and cognition (Kalia et al., 2018, 2019), and the results of these studies only partially answered the question. While Kalia et al. (2018) found gritty people to benefit less from alerting cues and Kalia et al. (2019) found a benefit in solving difficult Sudoku problems at the expense of decreased flexibility, a whole range of cognitive mechanisms remain non-studied regarding grit. Hence, we selected Miyake et al.'s (2000) framework on the diversity of executive functions, together with Braver's (2012) account of DMC and explored the link between these precise forms of control and grit trait. Additionally, we included two personality traits (mindfulness and impulsiveness) to better understand the variance that both personality and cognition account for. Mindfulness has previously been liked to grit (i.e., Raphiphatthana et al., 2018), and from the framework of the present dissertation, replicating such a relationship is mandatory. Also, impulsiveness is a key trait in understanding the nature of grit, as previous concerns have been raised in differentiating grit and other self-control-related traits (Credé et al., 2017). Although this research is exploratory (among other reasons due to the lack of previous studies), we expected grit to be related to both personality and cognition, such that enhanced cognitive function would help gritty people to achieve long-term goals. This study is currently in its second round of review in the journal PLoS ONE.

After this, we aimed to gain an understanding of the neural underpinnings of grit. In Chapter VIII, we describe a piece of research investigating how grit is related to brain indexes of cognitive control and effort during task engagement. Previous research has shown that there are stable individual differences in grit trait, and that they might be caused by underlying structural and functional variations in the brain at rest (i.e., Nemmi et al., 2016; Wang et al., 2017). However, it is also possible that other variations occur only when gritty people engage in a task due to differential information processing. The few preceding studies converge in showing that grit is mainly associated with the function and structure of the prefrontal cortex and striatum, which are key regions for executive control and reward processes (i.e., Myers et al., 2016; Wang et al., 2018). While these results are suggestive, some factors limit their conclusions (from reduced sample size to demographic variables). To overcome previous limitations, we aimed at adopting a hypothesis-driven approach in a large sample of young adults with diverse educational and work experiences to investigate the electrophysiological correlates of grit at rest and while performing a learning task. Additionally, we selected a measure of impulsiveness to better understand the neural similarities and differences between grit and related self-control constructs. Because previous research has shown the implications of the prefrontal cortex in expressing grit, we selected an EEG index of executive control: the frontal TBR. Additionally, we computed non-linear indexes of complexity thought to provide more sophisticated insights about neural connectivity (entropy and fractal dimension), as they have been suggested to represent effort while performing cognitive tasks. We expected high grit participants to have lower TBR, reflecting better control (top–down processes) over subcortical information (reward information of the striatum). Furthermore, given the link of perseverance of effort facet of grit to effort exerted during task performance, we expected it to be linked to higher complexity during task engagement. This work has been published in the journal Frontiers in Psychology (Aguerre et al., 2021).

Finally, we wanted to explore whether the patterns of cognitive control linked to mindfulness and grit traits would also be present in older adults. Cognitive control is thought to be one of the most affected cognitive processes in aging (Braver & Barch, 2002; Braver & Cohen, 2000) and some individual differences in the severity and timing of cognitive declines have been linked to non-genetic factors, such as education or physical activity (Ghisletta et al., 2012; Prakash et al., 2015; Scarmeas et al., 2004). Given the protective role that mindfulness and grit traits are thought to play in several health domains of older adults (i.e., De Frias, 2014; De Frias & Whyne, 2015; Fountain-Zaragoza et al., 2016; Kim & Lee, 2015; Rhodes & Giovannetti, 2021; Wenner & Randall, 2016), we investigated whether different (more efficient) patterns of cognitive control may also be related to the traits later in life. In the case of mindfulness, there have been already some attempts to link dispositional mindfulness and modes of control from the DMC framework (Braver, 2012) in older adults (Fountain-Zaragoza et al., 2016). These studies found an enhanced reactive control in mindful older adults (Fountain-Zaragoza et al., 2016, 2018). However, other studies comparing how cognitive control modes changed after a meditation training program failed to find such effects in this population (Whitmoyer et al., 2020). On the other hand, albeit gris has been claimed to prevent cognitive decline (Rhodes, et al., 2017), no study to date has explored the possible link between this trait and control modes in the elderly. With the aim of shedding some light about this isuue, in Study 5 (Chapter IX) we explored how mindfulness and grit traits relate to the use of control modes in older participants. We expected to replicate findings from younger adults where mindfulness and grit were associated with a balanced control (Chapters V and VII). In addition, we aim at replicating the relationship between mindfulness and grit traits also in the elderly population. This manuscript is currently under preparation.

Altogether, the wide field of cognitive neuroscience provides several cognitive models from which to test the possible underpinnings of mindfulness and grit traits at the behavioral and neural levels. In the following five chapters, we will show the results that aim to answer the former inquiries. We believe that this research will deepen our understanding of the neurocognitive mechanisms of both traits (in the youth and the elderly). Alternatively, it will help to more broadly understand individual differences affecting cognitive control.

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PART 2:
Experimental Section

CHAPTER V. Dual Mechanisms of Cognitive Control in Mindful Individuals

Study 1[1]

Little research has adopted a multicomponent approach to examine the relationship between mindfulness and cognitive control. Studies addressing this issue have produced mixed results that may be due to the incorporation of different questionnaires to assess mindfulness and to the assessment of different stages and types of mindfulness itself. In the present study we aimed to investigate to which extent dispositional mindfulness relates to a dynamic use of control modes as understood from the Dual Mechanisms of Control Theory. Further, we aimed to test this hypothesis by including two different frequently used mindfulness questionnaires in order to explore their confluence. Hundred thirty young adults completed two well-established assessment tools of mindfulness (Mindful Attention Awareness Scale and Five Facets Mindfulness Questionnaire) and two well-validated experimental tasks measuring proactive/reactive control modes (AX-Continuous Performance Task and Cued Task-Switching Paradigm). Data analyses were performed considering the continuous values in Multiple Regression Analyses, as it is thought to better capture individual differences. Results replicate previous findings suggesting that mindful individuals tend to use proactive and reactive control in a balanced manner in comparison to low mindfulness individuals, who tend to rely more on proactive control. Moreover, mindful individuals showed greater flexibility when the two processing modes were available. Hence, the major effects were found by using the two questionnaires. Altogether our findings indicate that mindful individuals, who have been characterized by an enhanced focus on the present moment without judgment, are less attached to previous contextual information, which allows them to exhibit a more flexible performance.

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Introduction

Cognitive control underlies the human ability to drive behavior according to goals, especially in novel situations or in situations where inappropriate action plans are triggered automatically to adapt to ever-changing environments (Braver, 2012; Norman & Shallice, 1986). Interestingly, cognitive control has been linked to some mental states such as mindfulness (Moore & Malinowski 2009; Moore et al., 2012; Tang et al., 2007; Van den Hurk et al., 2010). Mindfulness is the term popularized by Kabat-Zinn (1990; 2003) to refer to the state of non-judgmental attention toward the present experience. Although mindfulness has been associated with a variety of traditions (Manuello et al., 2016), it has not been until the last two decades that the scientific community has drawn attention to its potential benefits as a tool to understand some human cognitive functions (Hölzel et al., 2011; Kabat-Zinn, 2003; Teasdale, 1999; Thera, 2005).

Mindfulness is an ability assumed to be naturally present in all individuals to some degree (dispositional), even though it can also be intentionally cultivated until it fully manifests (Brown & Ryan, 2003; Grossman & Van Dam 2011; for a more extended conceptualization, see Wheeler et al., 2017). Both dispositional and learned mindfulness have been assessed by using a number of questionnaires, with the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003) and the Five Facets Mindfulness Questionnaire (FFMQ; Baer et al., 2006) being two of the most frequently used assessment tools. While using the MAAS involves the assumption that mindfulness is a single factor related to awareness (Brown & Ryan, 2003), making use of the FFMQ entails the view that mindfulness is a multifactorial construct that may be measured through the following five factors: 1) Observing: the tendency to notice or attend to internal and external experiences (i.e., “I remain present with sensations and feelings even when they are unpleasant or painful”); 2) Describing: the tendency to describe and label experiences (i.e., “I'm good at finding the words to describe my feelings”); 3) Acting with awareness: the ability of bringing full awareness to current activity (i.e., “I find it difficult to stay focused on what's happening in the present”, reversed item); 4) Non-judging: the non-evaluative stance toward inner experiences (i.e., “I tend to evaluate whether my perceptions are right or wrong”, reversed item); And 5) Non-reactivity: the tendency to allow thoughts and feelings to come and go, without getting caught up by them (i.e., “I watch my feelings without getting lost in them”) (Baer et al., 2006). Despite the interchangeable use of these measures in the literature, some authors have shown their concern about the capacity of these different questionnaires to assess a common underlying latent variable (Chiesa, 2013; Van Dam et al., 2018). Special concern relates to the MAAS scale as some authors think that a) it does not measure the acceptance component of mindfulness (Sauer et al., 2012) nor the non-judgmental awareness dimension (Baer et al., 2006); and b) because items are negatively worded they might measure perceived inattention (Grossman & Van Dam, 2011; Chang et al., 2018).

Using the above-mentioned scales, a number of studies have focused on the cognitive processes underlying mindfulness. Thus, conflict monitoring, selective and executive attention have been related to deliberate (learned) mindfulness in early meditators, whereas sustained attention, working memory or inhibitory control have been linked to more experienced meditators (see Chiesa et al., 2011; Gallant 2016; Tang et., 2015; Tang et al., 2007). Dispositional mindfulness, on the other hand, has been associated with a) disengagement of attention from appetitive cues in addicts (Garland, 2011), b) low cognitive reactivity (Raes et al., 2009) and c) enhanced perceptual skills for the observing factor and flexible cognitive control for the non-reactivity factor from the FFMQ (Anicha et al., 2012). Of particular relevance for the current research is that although there have been some attempts to relate mindfulness to different mechanisms of cognitive control, these have produced mixed results (Chang et al., 2018; Li et al., 2018).

One way of conceptualizing cognitive control is through the “Dual Mechanisms of Cognitive Control” (DMC) theory proposed by Braver (Braver, 2012; Braver et al., 2009). Specifically, the DMC framework proposes that two different cognitive control modes may be deployed: 1) a proactive mode, which acts by actively maintaining task-relevant information in a sustained manner to direct behavior in accordance with internal goals (as an early selection mechanism); and 2) a reactive mode, which relates to the detection and resolution of interference at the time it occurs (as a late corrective function).

Both control modes have advantages and disadvantages. Proactive control engages mental effort to prepare the cognitive system to prevent or minimize interference. This feature makes it very efficient but highly demanding on working memory. In contrast, reactive control is less demanding because it relies on the transient activation of goal-directed information once interference arises. Importantly, it is the dynamic coordination of the two cognitive control modes that allows individuals to be more adaptive in changing situations (Amer et al., 2016; Burges & Braver, 2010; Munakata et al., 2012). Hence, since mindfulness is characterized by an enhanced focus on the present moment without judgment, it is hypothesized that high mindfulness individuals would be less attached to their initial processing mode and, therefore, will show a more flexible use of proactive and reactive control strategies (Chang et al., 2018).

A well-established experimental task that provides sensitive and reliable measures of proactive and reactive control modes is the AX-Continuous Performance Task (AX-CPT; Braver et al., 2009). In the AX-CPT participants are presented with cue-probe pairs and are instructed to respond "yes" whenever they see an A as a cue followed by an X as a probe (usually this condition appears in 70% of the trials). A "no" response is required to any other cue-probe combination, which gives rise to three relevant conditions: BX trials (non-A cue followed by an X probe); AY trials (A cue followed by non-X probe); and BY trials (non-A cue followed by non-X probe). Proactive and reactive control modes can be assessed by comparing the three different types of “no” response trials. For example, because BX trials trigger dominant but inappropriate responses (“yes” to the “X”), cognitive control is needed to withdraw the “yes” response. Hence, more errors and longer reaction times in the BX condition than in the (baseline) BY condition (where the probe does not trigger the “yes” response) might indicate a tendency to rely more on reactive control. In contrast, increased errors and longer reaction times to AY trials (relative to BY trials, where the cue does not target the yes response) would be expected on the basis of higher reliance on proactive control, since A-cues bias for “yes” responses. Reactive control would be necessary in this kind of trials to withdraw the proneness towards the “yes” response when the non-X probe is presented. Hence, proactive control might be beneficial for BX trials but detrimental for AY trials, while reactive control will be reflected on an impairment on BX trials but a benefit on the AY condition. The tendency towards one or another control mode can be assessed by the behavioral shift index (BSI), a measure computed as (AY-BX)/(AY+BX) for errors and reaction times (Braver et al., 2009; Chiew & Braver, 2014; Gómez-Ariza et al., 2017; Morales et al., 2015), whereby higher scores reflect proactive dominance and lower scores reflect a more balanced proactive/reactive control mode. Importantly, optimal performance on the AX-CPT would require both, proactive and reactive control, to keep the errors at a minimum while getting faster reaction times.

Two recent studies have tested the hypothesis that high mindfulness might relate to better adjustment between proactive and reactive strategies to different situations and tasks demands (Chang et al., 2018; Li et al., 2018), although their findings are not totally convergent. In the first experiment reported by Chang et al. (2018), the MAAS was administered to conform two mindfulness groups (high and low dispositional groups), which performed a version of the AX-CPT. In their second experiment Chang et al. compared three groups: a group induced to high mindfulness through training, a group engaged in passive relaxation and a non-intervention group. Both experiments revealed that the lower mindfulness groups (low dispositional and non-induced mindfulness groups) were slower in the AY trials than in the BX trials, whereas the high mindfulness groups (high dispositional and training-induced mindfulness groups) did not differ in the time to respond to AY and BX trials. Similarly, analyses on the BSI indicated that the lower mindfulness groups showed higher scores than the high mindfulness groups, which suggests that high mindfulness may be associated with a more balanced use of proactive and reactive control, whereas lower mindfulness individuals may be more reliant on proactive control. In contrast, in the study reported by Li et al. (2018) the FFMQ was administered before and after randomly assigning participants to either a mindfulness training group or a control group, which also performed a version of AX-CPT before and after intervention. A proactive control enhancement (higher BSI scores; fewer errors on BX trials) was found in the mindfulness group that was absent in the control group. Hence, while one study indicates that mindfulness is related to a better adjustment of proactive and reactive control modes, the other shows that only proactive control is benefited by mindfulness practice. As proposed by Li et al. (2018), these divergent results may be due to different dynamics of control modes on dispositional, induced and early stages of practice of mindfulness, but also to some limitations of the studies. Along these lines, at least two methodological factors might have led to discrepancies between the two studies. On the one hand, two different questionnaires (MAAS and FFMQ), which are thought to assess distinct aspects of mindfulness, were administered to participants. On the other hand, the sample size (final n = 15) in the Li et al.'s study could have been too small to be sensitive enough to stable group differences.

The present study aimed to shed some light on the relation between individual differences on dispositional mindfulness and modes of cognitive control. Hence, the main goal was to replicate the findings of the first experiment by Chang et al. (2018), even though introducing some procedural changes. Specifically, we took mindfulness scores as a continuum rather than a categorical variable (groups), which is thought to be the optimal way of capturing variance on personality traits (West et al., 1996; Cohen, West & Aiken, 2014). In addition, we introduced the two questionnaires used by Chang et al. (2018) and Li et al. (2018) (MAAS and FFMQ, respectively) to a) tap into the mindfulness trait, b) be able to determine the extent to which the data from each scale converge and c) get a better understanding of the nature of the construct and its possible components. To examine the relation between modes of cognitive control and individual differences in dispositional mindfulness, we used a version of the AX-CPT in which distractor letters are presented between every cue and probe (Ophir et al., 2009). While this version of the task does not change the proactive bias usually found in healthy young adults (for a meta-analytic review, see Janowich & Cavanagh, 2018), it has shown to be sensitive to individual differences and experimental manipulations intended to modulate the balanced use of proactive and reactive control modes (i.e., Fröber & Dreisbach, 2016; Gómez-Ariza et al., 2017; Maraver et al., 2016; Morales et al., 2013; Ophir et al., 2009).

In addition, we employed the Cued Task-Switching Paradigm (CT-S; Chevalier et al., 2015) to further capture proactive and reactive control, but also to have an independent measure of flexibility that may also be related to mindfulness and strategic use of the cognitive control modes. In the cued task-switching paradigm, participants have to sort objects by either their shape or their color. The task is composed of three blocks wherein the sorting cue (different colors/different shapes) appears either before or simultaneously to target display. In the "Proactive Encouraged" condition the cue is presented and terminated before the target onset so that proactive control is required to succeed. In the "Proactive Impossible" condition, the task cue is presented at the same time as the target, so that responding relies on reactive control. And finally, in the “Proactive Possible” condition the cue is presented first but remains visible after target onset so that cue-based proactive preparation is possible but not necessary. All three blocks are counterbalanced across participants, but trials on each block switch between sorting criteria in an unpredictable manner, so that half of trials involve switching and the other half do not. The participants preference for a specific control mode would be reflected on better performance on either the “Proactive Encouraged” or “Proactive Impossible” blocks, while the general flexibility of the participants would be reflected on lower switching costs when moving from one sorting criterion to another (no switch trials - switch trials on accuracy or RTs; Chevallier et al., 2015; Monsell, 2003). Importantly, in the “Proactive Possible” block, participants can display their natural preference between the two control modes. Higher reliance on the cue is related to higher switching cost and longer maintenance of the cue in working memory (Chevallier et al., 2015). To the extent that mindful individuals show less attachment to the cues and better adjustment of proactive and reactive control modes, we would expect lower switching costs in the Proactive Possible block in these individuals.

In sum, we expected high mindfulness individuals (as measured by both questionnaires) to show dynamic coordination of control modes, which would be reflected in better performance in conditions where the two processing modes are equally needed. More specifically, we predicted that mindfulness would be better predicted by conditions sensitive to balanced control (AY and

BX taken together and Proactive Possible condition) than by conditions related to proactive (AY and Proactive Encouraged) or reactive (BX and Proactive Impossible) control. More importantly, we predicted that the dynamic coordination of control modes that has been proposed to be present in mindful individuals would be reflected on closer to zero BSI scores (linked to more balanced control) and lower switching cost on the Proactive Possible block from the cued task-switching paradigm (linked to flexibility when both control modes are available). These results would be in line with findings reported by Chang et al. (2018).

Method

Participants

A hundred thirty-four people ($M_{age} = 22.92$, $SD_{age} = 4.1$, 72% female) took part in the experiment in exchange for course credits (1/40min) or monetary reward (7€/1h). The sample size was determined in advance based on the correlation between BSI and MAAS as reported by Chang et al (2018). A power analysis (G*Power 3.1.9.2; Erdfelder et al., 1996) revealed that 113 participants were enough to detect a reliable association with 80% power and alpha set at 5%. However, we decided to include about 20 additional participants to be able to conduct more complex statistical analyses. All participants had a normal or corrected-to-normal vision. All participants gave informed consent before performing the experiment that was carried out following the Declaration of Helsinki (World Medical Association, 2013).

Materials and Procedure

Participants were tested individually in two sessions that lasted 90 and 120 min, respectively. In the first session they were administered the Spanish versions of the Mindful Attention Awareness Scale (MAAS; Soler et al., 2012) and the Five Facets Mindfulness Questionnaire (FFMQ; Cebolla et al., 2012), the AX-CPT (Morales et al., 2013) and the cued task-switching paradigm (CT-S hereinafter) based on Chevalier et al. (2015). As part of a larger study, the first session also included other questionnaires (Grit and BISS) and cognitive tasks (O-Span, Conflict Task), whereas the second session included MRI and EEG recordings as well as the administration of the Stop-Signal task and a retrieval practice procedure. The results regarding these measures are intended to be included in a different forthcoming paper and, consequently, are not presented here. Stimuli presentation and data acquisition were controlled by E-prime experimental software (Schneider et al., 2002). The order of the tasks presented here was counterbalanced across participants and was ran at the beginning of the experiment.

MAAS. This is a 15-item self-reported single-factor scale that focuses on the attention/awareness component of mindfulness. The answers to the items (i.e., “I find myself preoccupied with the future or the past.”) range from 1 (almost always) to 6 (almost never) and higher scores reflect greater mindfulness. It has a good reliability index (Cronbach’s $\alpha = 0.89$; Soler et al. 2012).

FFMQ. This is a scale of 39 items that assess five facets of mindfulness: observing (i.e., "I notice the smells and aromas of things"), describing (i.e., "It's hard for me to find the words to describe what I'm thinking", reversed item), acting with awareness (i.e., "I snack without being aware that I'm eating", reversed item), non-judging of inner experience (i.e., "I disapprove of myself when I have irrational ideas", reversed item) and non-reactivity to inner experience (i.e., "I watch my feelings without getting lost in them"). Items in FFMQ are ranged from 1 (never or very rarely true) to 5 (very often or always true), with higher scores reflecting greater mindfulness. The Cronbach's α of the factors goes from 0.80 to 0.91 (Cebolla et al. 2012).

AX-CPT. This task was used to index the proactive/reactive control mode of the participants. Specifically, we used the version employed by Morales et al. (2013; see also Gómez-Ariza et al. 2017). Stimuli were presented on a black background. In each trial five letters were presented centrally for 300 ms each (cue – three distractors – probe), with an inter-stimuli interval of 1000 ms. Cues and probes were presented in red font while distractors were presented in white. Participants were instructed to respond "yes" whenever they saw an A as a cue (in the first position) followed by an X as a probe (in the fifth position). Participants were asked to respond "no" (upon probe presentation) to any other cue-probe combination and to the distractors (items in positions 2 to 4). No response was required to the cue. Responses "yes" or "no" were entered by pressing the "Z" or "M" keys of the keyboard with the index finger of each hand. Response letters were counterbalanced across participants. The task was composed of 10 practice trials, where feedback was provided, plus an experimental block with 100 trials. The target trials (AX) were the most frequent ones (70%) and the rest of the trials (AY: "A" cue – non "X" probe; BX: non "A" cue – "X" probe; or BY: neither "A" cue nor "X" probe) occurred in a 10% of the remaining cases (see Figure 1).

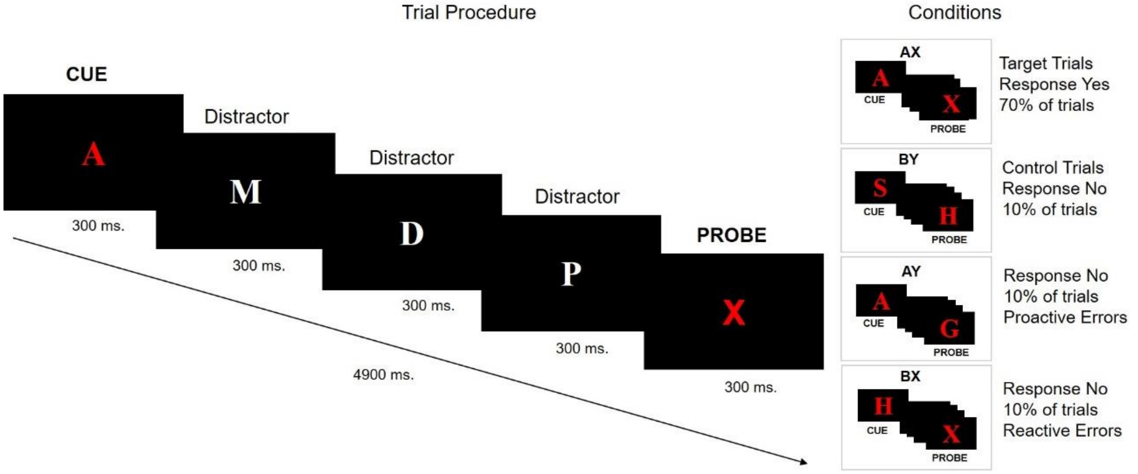
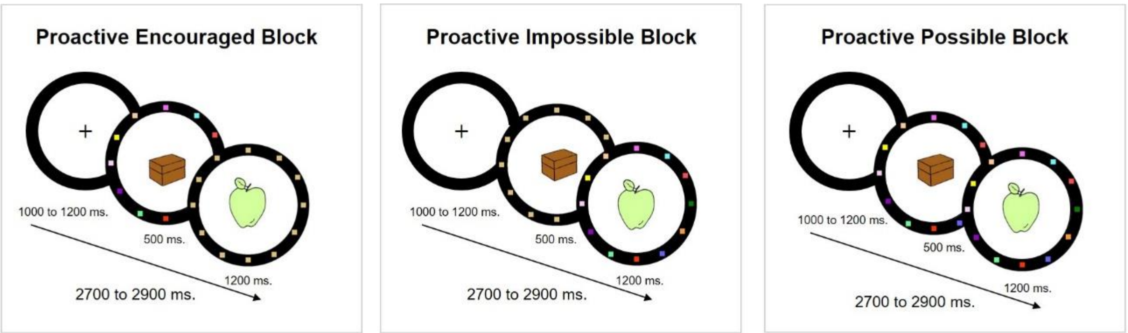


Figure 1. AX-CPT procedure: On the left a typical trial of the task is presented, with cue and probe colored in red and three distractors in white color placed between cue and probe. On the right the four possible conditions are presented, AX are the target trials (a "yes" response is required, 70% of trials); BY or control trials ("no" response, 10% of trials); AY or proactive error condition ("no" response, 10% of trials) and BX or reactive error condition ("no" response, 10% of trials).

CT-S. We adapted the cued task-switching paradigm introduced by Chevalier et al. (2015) to be used with adults. In this task participants had to sort objects by either their shape or their color. The task had three blocks and three combinations of shape and color were used, one for each block (balloon-airplane-blue-red; apple-banana-green-yellow; ball-bat-orange-purple). On each trial one 8 x 6 cm two-dimensional target (i.e., a blue balloon) was presented within a black circle at the center of the screen. Participants were asked to answer by pressing different keys with one of their four fingers (index and middle fingers of each hand), which previously were associated with the possible colors and shapes of the block, as a function of the task cue. Task cues were displayed on the black circle (12 beige geometrical shapes signaled to participants that they had to respond to shape, whereas 12 squares of different colors signaled them to respond to color). On each trial, a fixation cross within the black circle was presented for 1000–1200 ms (jittered intertrial interval), followed by a brown box, which contained the object that they had to classify next. After 500 ms. the target replaced the box and remained on the screen until a response was entered or for up to 1200 ms. Critically, the timing of the cue presentation was manipulated across conditions that were blocked (Figure 2). The order of the blocks was counterbalanced across participants. In the "Proactive Encouraged" condition the cue was presented (along with the box) and terminated before target onset. Then, the target appeared with a neutral cue so that proactive control was required to provide a correct response. In the "Proactive Impossible" condition, the brown box and the neutral cue were presented first and the task cue was presented at the same time as the target, so that reactive control was necessary to respond correctly. Finally, in the "Proactive Possible" condition the task cue was presented along with the brown box and remained visible after target onset, so that both reactive and proactive control modes were possible. Each block started with 8 practice trials where feedback was provided. Each experimental block had 64 trials with pauses every

16 trials. In each block, 32 trials were no-switch trials (the relevant task was the same), and the other 32 were switch trials, wherein the relevant task changed. Switch and no-switch trials alternated unpredictably.



Task cue (color cue in this example) is presented and terminated before target onset along with the brown box, then the target appeared with a neutral cue. Therefore, proactive preparation is required.

The brown box is presented with a neutral cue, then task cue (color cue in this example) is presented at the same time as the target. Therefore, proactive preparation is not possible.

Task cue (color cue in this example) is presented before and during the target, therefore proactive preparation is possible but not necessary.

Figure 2. CT-S procedure: A typical trial of each kind of block is presented. Trial cue switches between shape and color. In the example a color trial is presented. On the Proactive Encouraged block, the cue (squares of different colors in this case) is presented and terminated before target onset (proactive control is required). On the Proactive Impossible block, the target is preceded by neutral information (squares of the same color) and the cue is presented along with the target (reactive control is required). In the Proactive Possible block, the cue is presented before target onset but remains visible during the target presentation, so that proactive control is possible but not necessary.

Results

Following the criterion used by Chang et al. (2018), six participants were excluded from the analyses because of their extremely high error rate in the AX-CPT (<70% correct responses). Descriptive results of all measures are presented in Table 1.

Table 1. Descriptive results. If not otherwise specified, data refers to means (and standard deviations).

	Score		*Minimum*	*Maximum*
MAAS	3.85 (0.91)		1.53	5.8
FFMQ	127.73 (18.39)		76	171
	Errors		*RT*	
AX-CPT (Total)	0.07 (0.05)		373 (77)	
AX	0.05 (0.04)		374 (77)	
AY	0.26 (0.19)		521 (93)	
BX	0.08 (0.15)		297 (91)	
BY	0.02 (0.05)		314 (103)	
	Score		*Minimum*	*Maximum*
BSI	0.41 (0.19)		-0.2	0.94
	No Switch		Switch	
	ACC	*RT*	*ACC*	*RT*
CT-S (Total)	0.78 (0.15)	642 (80)	0.69 (0.15)	717 (94)
Proactive Possible	0.82 (0.18)	592(100)	0.70 (0.22)	680 (119)
Proactive Encouraged	0.79 (0.21)	598 (108)	0.73 (0.2)	668 (124)
Proactive Impossible	0.75 (0.17)	752 (94)	0.63 (0.18)	828 (101)
	Score		*Minimum*	*Maximum*
Switch Cost in Proactive	74 (50)		-62	203
Switch Cost in Proactive	0.10 (0.07)		-0.12	0.31

Mindfulness Measures

To determine convergence between the two questionnaires, we performed Pearson correlation analyses between the scores of the MAAS, the FFMQ total and its five factors. Results are shown in Table 2. Since both questionnaires strongly converge, we decided to run the following analyses on a composite score of both questionnaires computed as (Z score of MAAS + Z score of FFMQ)/2. All analyses were also run separately for each questionnaire and are available in Supplementary Material 1, 2 and 3 at the end of this chapter.

Table 2. Correlations between Mindfulness Scores.

	FFMQ	*Observing*	*Describing*	*Acting with*	*Non-judging*	*Non-reactivity*
MAAS	0.63***	0.18	0.24**	0.75***	0.41***	0.25**
FFMQ		0.49***	0.69***	0.59***	0.63***	0.54***
Observing			0.28**	0.06	- 0.05	0.26**
Describing				0.14	0.27**	0.30***
Acting with					0.35***	0.15
Non-judging						0.13

**p < 0.01, ***p < 0.001 Asterisks represent statistically significant correlations after controlling for multiple

Basic Effects

For the AX-CPT, statistical analyses were performed on error rates and mean reaction times for correct responses in each type of trial. Responses under 100 ms. and over 1000 ms. (less than 1% of the data) were removed from the analyses (following Morales et al., 2013). The behavioral shift index was computed as the sum of (AY - BX)/(AY + BX) for errors and RTs. A correction was made for trials where errors were equal to zero such that (error + 0.5)/(frequency of trials + 1) (following Morales et al., 2013 and Braver et al., 2009). For the CT-S, accuracy was calculated as the percentage of correct responses on switch and no switch trials. Following the procedure used by Chevalier et al. (2015), RT was calculated for correct responses after identifying outliers (RT greater than M + 3SD and values lower than 200 ms., less than 1% of the trials). The switch cost index was calculated subtracting the mean accuracy in switch trials from the mean accuracy in non-switch trials in the proactive possible block (Monsell, 2003). Descriptive results of both tasks are shown in Table 1.

To check that the tasks were working correctly and the basic effects were present we run repeated-measures analyses of variance (ANOVAs). For the AX-CPT, we first run an ANOVA on error rates and then on RT with type of trial (AX, AY, BX and BY) as the factor. For the CT-S, we run a factorial ANOVA for each dependent variable with type of trial (switch and no-switch) and block (Proactive Encouraged, Proactive Impossible and Proactive Possible blocks) as factors.

AX-CPT. The ANOVA on error rates showed a reliable main effect of trial type, $F(3,381) = 126.85$; $p < 0.001$; partial $\eta^2 = 0.5$. Bonferroni-corrected post-hoc comparisons revealed that participants produced more errors in AY than in BX, BY and AX trials (all $p_s < 0.001$). In addition, they committed more errors in BX than in BY trials ($p < 0.001$).

The ANOVA on RT also revealed a statistically significant main effect of trial type, $F(3,375) = 563.21$; $p < 0.001$; partial $\eta^2 = 0.82$. Post-hoc comparisons showed that responses to AY trials were slower than those to BX, BY, and AX trials (all $p_s < 0.001$). RT in AX trials was longer than in BX trials ($p < 0.001$). In addition, AX trials involved longer RTs than BY trials ($p < 0.001$).

CT-S. The ANOVA on accuracy showed the main effect of block to be reliable, $F(2,254) = 10.1$; $p < 0.001$; partial $\eta^2 = 0.07$. Post-hoc comparisons indicated that participants exhibited lower accuracy in the Proactive Impossible block than in the Proactive Encouraged and the Proactive Possible blocks (both with $p < 0.001$). There was also a main effect of trial type that confirmed lower accuracy in switch than in no-switch trials, $F(1,127) = 252.57$; $p < 0.001$; partial $\eta^2 = 0.66$. The interaction block x trial type was also statistically significant ($F(1,254) = 12.31$; $p < 0.001$; partial $\eta^2 = 0.09$). Follow-up comparisons showed that whereas for no-switch trials all conditions were statistically different from one another, for switch trials only the difference between Proactive Possible and Proactive Encouraged did not reach statistical significance.

The ANOVA on RTs showed that there was a reliable main effect of block, $F(2,254) = 192.18$; $p < 0.001$; partial $\eta^2 = 0.60$. Post-hoc comparisons showed that responses were slower in the Proactive Impossible block than in the Proactive Encouraged and the Proactive Possible blocks (all $p_s < 0.001$). There also was a main effect of trial type, $F(1,127) = 334.46$; $p < 0.001$; partial $\eta^2 = 0.72$, with longer RTs in switch trials than in no-switch trials. The interaction did not reach statistical significance, $F(1,254) = 2.44$; $p = 0.09$; partial $\eta^2 = 0.02$.

Multiple Regression Models

To define mindfulness in terms of cognitive control modes, we tested three different regression models (proactive, reactive and balanced) using forced entry analyses on the composite mindfulness score. For the proactive model we included the conditions thought to relate the most to proactive control: namely, AY trials (errors and RTs) and Proactive Encouraged block (total accuracy and

RTs in the block). For the reactive model we included the conditions more related to reactive control: BX trials (errors and RTs) and Proactive Impossible block (total accuracy and RTs in the block). Finally, for the balanced model, we included the conditions thought to capture the balance between reactive and proactive control modes: AY and BX trials (errors and RTs) and Proactive Possible block (total accuracy and RTs in the block). The same analysis run separately for MAAS and FFMQ is available in Supplementary Material 1.

In addition, we conducted regression analyses on the composite mindfulness scores by using the indexes a priori thought to be predictive of mindfulness: namely, the BSI in the case of the AX-CPT and the switching cost (SC herein after) in the case of the Proactive Possible block of the CT-S. Regarding the latter, we decided to use the index based on accuracy because the previous analysis had shown this variable to be the most sensitive. Again, the analyses separately for MAAS and FFMQ are available in Supplementary Material 2. In the case of the FFMQ, we also included the analyses by considering each of its facets independently.

Finally, we conducted analyses to explore the hypothesis that mindfulness would be related to better flexibility due to the dynamic use of control modes. Specifically, we correlated mindfulness scores and performance after errors, measured as the percentage of correct responses and RTs (for correct responses) after having committed an error in both experimental tasks. Separate correlations of both questionnaires are available on Supplementary Material 3.

Multiple regression with Proactive, Reactive and Balanced Models. The regression analysis on the composite mindfulness scores failed to show statistical significance for the reactive model (p = 0.22; ΔR^2 = 0.04). However, the proactive (p = 0.02; ΔR^2 = 0.09) and the balanced (p = 0.007; ΔR^2 = 0.14) models showed statistical significance, even though it was the balanced model the one that accounted for the largest proportion of variance (see Table 3). A similar pattern emerged when the models were run on MAAS and FFMQ separately (see Supplementary Material 1).

Table 3. Proactive, reactive and balanced models for errors/accuracy and RTs with the mindfulness composite score as the dependent variable.

	R^2	ΔF	*B*	*SE*	*β*	*p*
Proactive Model	0.09	2.98				0.022
Constant			2.01	0.86		
AY Errors			-1.3	0.43	-0.27	0.003
AY RTs			-0.00	0.00	-0.2	0.033
Proactive Encouraged ACC			-0.44	0.46	-0.09	0.339
Proactive Encouraged RTs			0.00	0.00	-0.06	0.571
Reactive Model	0.04	1.44				0.224
Constant			0.00	0.84		
BX Errors			-0.24	0.66	-0.03	0.71
BX RTs			0.00	0.00	0.18	0.056
Proactive Impossible ACC			0.81	0.56	0.15	0.148
Proactive Impossible RTs			-0.00	0.00	-0.14	0.126
Balanced Model	0.14	3.1				0.007
Constant			0.55	0.85		
AY Errors			-1.23	0.47	-0.26	0.009
AY RTs			-0.00	0.00	-0.31	0.009
BX Errors			0.61	0.68	0.08	0.370
BX RTs			0.00	0.00	0.27	0.024
Proactive Possible ACC			0.68	0.46	0.15	0.137
Proactive Possible RTs			-9.02E-6	0.00	-0.00	0.992

Multiple regression with proactivity (BSI) and flexibility (switch cost) indexes. Before running multiple regression analyses with the BSI and SC (from the Proactive Possible block), we performed a correlation analysis between the two indexes. The analysis showed no statistically significant relationship between the indexes ($r = -0.1, p = 0.24$). Hence, we run a multiple regression analysis with the BSI and the SC (from the Proactive Possible block) as potential predictors of the composite mindfulness score. The results revealed reliable effects ($p < 0.000$; $\Delta R^2 = 0.15$): lower BSI and lower SC predicted higher scores on mindfulness ($p < 0.001$; $\beta = -0.3$; $p = 0.001$; $\beta = -0.28$, respectively) (See Table 4 and Figure 3). The same pattern was present when we run the analyses with MAAS and FFMQ separately and with Acting with Awareness and Non-Reactivity to Inner Experience facets of FFMQ (See Supplementary Material 2).

To better understand the negative association between mindfulness and the BSI and characterize mindful individuals in terms of control modes, we split the whole sample in two groups (low mindfulness: 1 SD below the mean and high mindfulness: 1 SD above the mean) and performed one-sample t tests with the test value = 0. The results with both questionnaires showed that the BSI of the two groups differed significantly from 0 (all $p_s < 001$). Thus, while both groups' performance on the AX-CPT is consistent with the predominance of proactive control (as expected in healthy young adults), this tendency was less marked in individuals with higher mindfulness.

Table 4. Multiple Regression Model of BSI and SC for the composite mindfulness score.

	R^2	ΔF	*B*	*SE*	β	*P*
Model	0.15	11.13				0.000
Constant			0.83	0.2		
BSI			-1.4	0.38	-0.3	0.000
SC			-2.16	0.63	-0.28	0.001

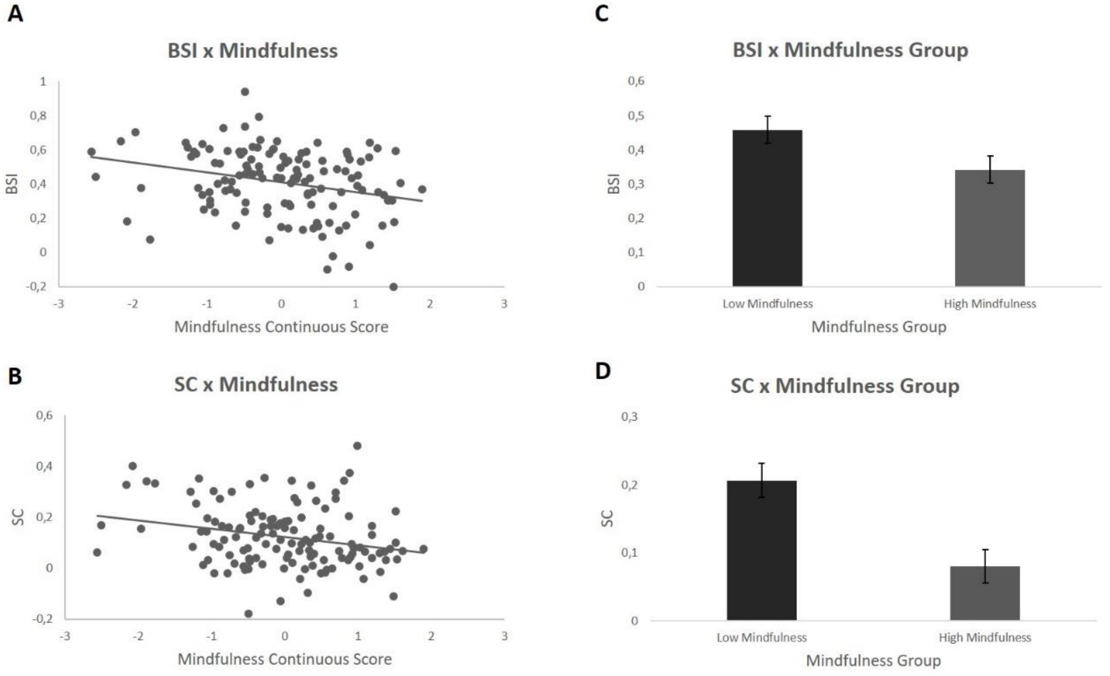


Figure 3. Dispersion graphic of mindfulness as a continuous score and BSI (A) and SC (B); and bar graphic when mindfulness groups where divided (as 1SD bellow and above the mean) on BSI (C) and SC (D).

Basic correlations between mindfulness and performance after errors. The correlation analyses between mindfulness composite score and performance after errors (either on the AX-CPT or the CT-S) revealed some statistically significant associations. Specifically, mindful individuals showed better performance (more correct responses) on the AX-CPT after committing an error than less mindfulness individuals ($r = 0.25$, $p = 0.004$). Similar patterns were found in correlations with MAAS and FFMQ separately (See Supplementary Material 3).

Discussion

The goal of the present study was to gain understanding of the relationship between intrinsic dispositional mindfulness and the use of cognitive control modes from the Dual Mechanisms Framework (Braver et al., 2009). So far, little research has focused on the dynamics of cognitive control in mindful individuals, since the general approach to this issue has essentially adopted a single-process account. In addition, the few studies that have explored dual mechanisms of control have obtained mixed results (Chang et al., 2018; Li et al., 2018). The present study succeeded at replicating the main findings obtained by Chang et al. (2018) and provided some extra insights about the dynamics of cognitive control in mindful individuals. Our study suggests that more mindful individuals, as characterized by two different but well-established questionnaires, tend to make a more balanced use of proactive and reactive control than less mindful individuals, who tend to rely more strongly on proactive control. In addition, mindful individuals seem to benefit from situations where both control modes are possible, showing greater flexibility and less engagement to previous contextual information than low-mindfulness individuals.

Thus, results of the multiple regression analyses on the two mindfulness questionnaires indicated that mindfulness was better explained by a balanced model, that included both control modes (AY, BX and Proactive Possible conditions) than by a proactive (AY, Proactive Encouraged conditions) or a reactive (BX, Proactive Impossible) model. More mindful individuals tended to have fewer errors and RTs in AY trials but longer RTs in BX trials than less mindful individuals. Coherent with this finding, analyses on the BSI revealed a more balanced use of control modes (lower scores) in high mindfulness individuals than in low mindfulness individuals, who showed higher reliance on proactive control, even though both tended towards proactive control. These findings join those reported by Chang et al. (2018) in supporting the view that dispositional mindfulness makes individuals less guided by their initial thoughts and, therefore, more open to context relevant changes (see Kashdan & Rottenberg, 2010; Chang et al., 2018). Note that we used a distractor version of the AX-CPT (i.e., Gómez-Ariza et al., 2017; Morales et al., 2013; Ophir et al., 2009), and that future research should examine whether a similar pattern of enhanced balanced control in high mindfulness individuals is also found when a less demanding non-distractor version of the AX-CPT is used.

In addition, variables indexing flexibility from the cued task-switching (CT-S) paradigm were also predictive of mindfulness. It is remarkable that the switching cost in the proactive possible block, wherein both reactive and proactive strategies were possible, was negatively related to mindfulness as characterized by both questionnaires. Thus, when the two control modes were possible, mindful individuals showed better performance since they exhibited more flexibility at disengaging from a contextual cue and engaging in the information provided by the new cue. It is interesting that this higher flexibility is associated with the possibility of using any of the two cognitive control modes and not to a general switching mechanism (the switching cost was not statistically significant when the three blocks of the CT-S were pooled together). The difference in the switching cost in the Proactive Possible block between high and low mindful individuals could be due to a more successful resolution of proactive interference as a result of differences in the coordination of the control modes (Burgess & Braver, 2010). This pattern of results matches the one observed in bilinguals, who show some advantages in conditions in which the task cues are presented before and during target onset (Prior & MacWhinney, 2010), or in versions of the AX-CPT in which both processing modes are needed (Morales et al., 2015). The fact that mindful individuals showed better performance after errors may be interpreted as due to the dynamic combination of the two control modes that help them to react and disengage from the negative affect of committing an error and to shift to the context relevant task. However, more evidence is needed to answer the question of whether the obtained pattern is due to a general flexibility mechanism or to a better balance between proactive and reactive control.

Surprisingly, switching costs were larger in the Proactive Impossible condition than in the Proactive Encouraged condition. The interpretation of this finding is not obvious since we expected the opposite pattern. However, it is possible that even though proactive control is associated with the maintenance of tasks cues in working memory, and this might be expected to impair switching from one task to another, the fact that our participants (young adults) were in general very good at proactive control may have allowed them to efficiently process the new cue and update working memory, so that the old cue was quickly replaced by the new one. In contrast, efficient cue processing and working memory updating would not be a helpful strategy in the Proactive Impossible condition where only efficient reactive control would permit reduced switching costs. While this interpretation is speculative and needs further testing, the important point here is that mindfulness does not seem to play a role in producing such a pattern.

In contrast to previous studies (Chang et al., 2018, Li et al., 2018) that only used one questionnaire, we chose to include two popular mindfulness questionnaires (MAAS and FFMQ; which differ in how they define the dimensional attributes of mindfulness) to assess the validity of the measures and, in turn, of the construct. Importantly, the present results show that the two questionnaires highly correlate despite their uni- and multi- factorial natures. MAAS scores also correlated with four subscales of the FFMQ, and all the associations between mindfulness and cognitive control were detected with both questionnaires. In the case of the FMMQ, BSI predicted scores in the "Acting with awareness" and the "Non-reactivity to inner experience" facets. These results go in line with findings from the Li et al., (2018) study that showed that the BSI was negatively related to the "Acting with awareness" facet of FFMQ and with the idea that MAAS focusses on the "Acting with awareness" facet of mindfulness (Coffey & Hartman, 2008). Further, the "Non-reactivity to inner experience" component has also shown to relate to cognitive control in previous studies (Anicha et al., 2011; Noone et al., 2016). In sum, even though some of the concerns stated by Chang (2018) were about the capacity of the findings to extend to other mindfulness scales, our results show high degree of consistency between questionnaires, which overcomes previous limitations and concerns.

It is worth pointing out that the present results with young participants also indicate that the relation between mindfulness and cognitive control differs from the relation between age and cognitive control. Cognitive control has shown to be predominantly reactive in young children, turning to proactive in young adults and becoming reactive again in older adults (Munakata et al., 2012; Paxton et al., 2008). This U-inverted function relating proactive control and age has been interpreted as reflecting performance benefits of proactive control, even though it requires more cognitive resources and sometimes might lead to interference with new learnings and to confirmation bias (Munakata et al., 2012). In this line, the pattern presented by mindful individuals might be optimal for good performance engaging less cognitive resources when possible, and also open to new contextual information. This would help mindful individuals to adapt to fluctuating situational demands (Kashdan & Rottenberg, 2010). It would still be interesting to examine if children and older adults varying in dispositional mindfulness show similar patterns.

One of the most remarkable findings of the present study is that the balanced use of proactive and reactive control by mindful individuals can be captured by different mindfulness questionnaires (MAAS and FFMQ). However, some mixed results regarding mindfulness and dual modes of control in the literature (Chang et al., 2018; Li et al., 2018) need further investigation. Future research should explore whether the strategic use of the cognitive control modes that we have found with high dispositional mindfulness is also achieved when mindfulness is induced by intervention in naïve individuals (Li et al., 2018), and whether this use varies with the degree of experience (Chiesa et al., 2012). It is possible that, in line with the finding by Li et al. (2018), early stages of mindfulness practice may lead to an improvement of proactive control while more extended practice may also improve reactive control, which would result in a more balanced strategic use of the control modes with greater experience.

In conclusion, the present study provides evidence for a multicomponent approach to the explanation of dispositional mindfulness effect in cognitive control. The use of two different questionnaires assessing mindfulness (MAAS and FFMQ), two different tasks measuring the engagement to contextual information in terms of control modes (AX-CPT and CT-S) and the adoption of a continuous dimensional approach in a large sample of individuals, allow us to provide a clearer picture of the relation between mindfulness and cognitive control. Future research might consider how this pattern of cognition interact with age and with different stages and types of mindfulness trainings (i.e., focus-attention, open-monitoring).

Supplementary Material 1

Table 1. Proactive, reactive and balanced models for errors/accuracy and RTs on MAAS scores.

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Proactive Model	0.12	4.23				0.003
Constant			6.22	0.84		
AY Errors			-1.4	0.42	-0.3	0.001
AY RTs			-0.00	0.00	-0.28	0.003
P. Encouraged ACC			-0.29	0.45	-0.06	0.518
P. Encouraged RTs			0.00	0.00	-0.06	0.537
Reactive Model	0.03	0.97				0.42
Constant			3.39	0.84		
BX Errors			-0.28	0.66	-0.04	0.669
BX RTs			0.00	0.00	0.16	0.095
P. Impossible ACC			0.8	0.56	0.14	0.158
P. Impossible RTs			-0.00	0.00	-0.07	0.439
Balanced Model	0.16	3.95				0.001
Constant			4.71	0.83		
AY Errors			-1.44	0.47	-0.31	0.003
AY RTs			-0.00	0.00	-0.38	0.001
BX Errors			0.63	0.59	0.1	0.286
BX RTs			0.00	0.00	0.17	0.152
P. Possible ACC			0.65	0.44	0.14	0.144
P. Possible RTs			0.00	0.00	0.08	0.390

Table 2. Proactive, reactive and *balanced* models for errors/accuracy and RTs for FFMQ scores.

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Proactive Model	0.06	1.89				0.11
Constant			161.58	17.47		
AY Errors			-21.14	8.75	-0.22	0.017
AY RTs			-0.03	0.02	-0.14	0.136
P. Encouraged ACC			-9.36	9.24	-0.1	0.313
P. Encouraged RTs			0.01	0.02	-0.06	0.555
Reactive Model	0.07	2.17				0.076
Constant			134.18	16.19		
BX Errors			1.23	11.11	0.01	0.912
BX RTs			0.03	0.02	0.19	0.05
P. Impossible ACC			19.17	10.74	0.17	0.077
P. Impossible RTs			-0.04	0.02	-0.19	0.04
Balanced Model	0.11	2.45				0.028
Constant			148.05	17.02		
AY Errors			-18.47	9.68	-.2	0.059
AY RTs			-0.04	0.02	-.2	0.087
BX Errors			8.65	12.26	.07	0.482
BX RTs			0.04	0.02	.23	0.063
P. Possible ACC			6.71	9.11	.07	0.463
P. Possible RTs			-0.02	0.02	-.11	0.243

Supplementary Material 2

Table 3. Multiple Regression Model of BSI and SC for the MAAS.

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Model	0.12	9.29				0.000
Constant			0.62	0.2		
BSI			-1.29	0.39	-0.28	0.001
SC			-1.99	0.64	-0.26	0.002

Table 4. Multiple Regression Model of BSI and SC for the FFMQ

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Model	0.12	8.65				0.000
Constant			143	4.09		
BSI			-25.56	7.94	-0.27	0.002
SC			-38.42	13	-0.25	0.004

Table 5. Multiple Regression Model of BSI and SC for Acting with Awareness component of the FFMQ.

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Model	0.1	6.24				0.001
Constant			31.08	1.43		
BSI			-7.41	2.78	-0.23	0.009
SC			-13.32	4.55	-0.25	0.004

Table 6. Multiple Regression Model of BSI and SC for Non-Reactivity to Inner Experience component of the FFMQ.

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Model	0.06	3.96				0.022
Constant			24.22	1.03		
BSI			-5.22	2	-0.23	0.01
SC			-4.32	3.27	-0.11	0.189

Supplementary Material 3

Table 7. Correlation of MAAS and FFMQ and accuracy and RTs after errors in AX-CPT and CT-S.

	ACC AE AX-XPT	*RT AE AX-CPT*	*ACC AE CT-S*	*RT AE CT-S*
MAAS	0.23**	0.09	0.02	-0.11
FFMQ	0.24**	0.13	-0.02	-0.19*

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CHAPTER VI. Electrophysiological correlates of Mindfulness Trait: A Quantitative and Complexity EEG Study

Study 2[2]

While growing evidence supports that dispositional mindfulness relates to psychological health and cognitive enhancement, to date there have been only a few attempts to characterize its neural underpinnings. In the present study, we aimed at exploring the electrophysiological (EEG) signature of dispositional mindfulness using quantitative and complexity measures of EEG during resting state and while performing a learning task. Hundred twenty participants were assessed with the Five Facet Mindfulness Questionnaire and underwent 5 minutes eyes-closed resting-state and 5 minutes at task EEG recording. We hypothesized that high mindfulness individuals would show patterns of brain activity related to (a) lower involvement of the default mode network (DMN) at rest (reduced frontal gamma power) and (b) a state of 'task readiness' reflected in a more similar pattern from rest to task (reduced overall q-EEG power at rest but not at task), as compared to their low mindfulness counterparts. We expected to find such pattern also with complexity measures. Dispositional mindfulness was significantly linked to reduced frontal gamma power at rest and lower overall power during rest but not at task. In addition, we found a trend towards higher entropy during task performance in mindful individuals, which has recently been reported during mindfulness meditation. Altogether, our results add to those from expert meditators to show that high (dispositional) mindfulness seems to have a specific electrophysiological pattern characteristic of less involvement of the DMN and mind-wandering processes.

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[2] This work is currently under review as Aguerre, N. V., Gómez-Ariza, C. J., Ibáñez-molina, A. J. & Bajo, M. T. Electrophysiological correlates of Mindfulness Trait: A Quantitative and Complexity EEG Study. Scientific Reports.

Introduction

Although there has been an explosion of research on mindfulness over the last years, its neurocognitive bases remain largely unknown. So far, most efforts have been devoted to unravel the neuronal changes produced during and after mindfulness meditation, with little research focusing on individual differences in dispositional mindfulness itself. The study of the natural neural imprints of mindfulness as a personality trait might, however, greatly contribute to our understanding of its psychological scope and its changes with later meditation training and expertise.

Mindfulness is a concept derived from the Buddhist tradition that refers to a virtue of consciousness characterized by two attributes: 1) the self-regulation of attention towards the present moment; and 2) the adoption of a set of curiosity, openness, and acceptance towards the inner and outer experience (Bishop et al., 2004). Dispositional mindfulness refers to the relatively stable tendency to engage in those attributes in everyday life and is traditionally measured with a wide range of questionnaires (i.e., FFMQ, Baer et al., 2006). This tendency has been shown to be naturally present in different degrees in meditation-naïve individuals (i.e., Bilevicius et al., 2018; Lu et al., 2014) and can be trained through the practice of mindfulness meditation (i.e., MBSR, Kabat-Zinn, 2003; MBCT, Teasdale et al., 2000) until it fully manifests (Crescentini & Capurso, 2015; Wheeler et al., 2017). Both, dispositional mindfulness and mindfulness meditation, have been shown to be related to several benefits in physical (Grossman et al., 2004; Sala et al., 2020) and mental health (i.e., lower anxiety and depression, Brown & Ryan, 2003; Keune et al., 2011) and cognitive performance (Tang et al., 2015; Verhaeghen, 2021). Recent cognitive research has shown that, relative to low mindful individuals, those scoring high in dispositional mindfulness tend to be more anchored to the present and perform better when it comes to adapting to contextual changes and recovering after a failure, which has been related to more balanced use of different cognitive control modes (Aguerre et al., 2020). Similarly, mindful individuals show less engagement in mind-wandering (the tendency of the mind to divagate from one thought to another; Mrazek et al., 2012).

While several structural and functional changes have been found in brain regions typically associated with attention control, emotion regulation and self-awareness during mindfulness meditation and in expert meditators (for a review see Tang et al., 2015), little research has focused on the neuropsychological bases of dispositional mindfulness. As part of the few studies focusing on mindfulness trait, Lu et al. (2014) found that higher dispositional mindfulness was linked to greater grey matter volume in the right hippocampus/amygdala and bilateral anterior cingulate cortex (ACC), but less grey matter volume in the bilateral posterior cingulate cortex (PCC) and the left orbitofrontal cortex, which have been associated with executive attention, emotion regulation, and self-referential processing. In a functional magnetic resonance imaging (fMRI) study at rest, Kong et al. (2016) found that high mindfulness trait individuals had enhanced local synchronization of spontaneous brain activity in left orbitofrontal cortex (OFC), left parahippocampal gyrus (PHG) and right insula, which are thought to be implicated in emotion processing, body awareness, and self-referential processing. In contrast, they found reduced local synchronization in the right inferior frontal gyrus (IFG), which has largely been related to executive control. Finally, Lim et al. (2018) employed resting-state fMRI to tap into the dynamic functional connectivity associated with high mindfulness trait and found enhanced within-network connectivity in the default-mode (DMN) and salience networks, and greater anti-correlations between task-positive networks and the DMN, which is thought to reflect task-readiness. Although experiments using MRI are very valuable due to their spatial resolution, this technique is limited when studying complex neural dynamics in the time domain.

Electroencephalography (EEG), a broadly used technique due to its time resolution, has also been used to investigate the neuronal underpinnings of different personality traits and conditions. Neural oscillations reflect the synchronous firing of large populations of neurons mediated by excitatory/inhibitory interactions. Thus, for example, quantitative-EEG (q-EEG), an index of overall power and/or power of different frequency bands of electrophysiological brain activity, has been used to predict stable individual differences in personality (Jach et al., 2020), addiction (Lee et al., 2014), schizotypy (Fuggetta et al., 2014), attention-deficit hyperactivity disorder

(Snyder & Hall, 2006), intelligence (Doppelmayr et al., 2002) and second language learning (Prat et al., 2016). Again, studies using EEG have focused on meditation states and expert meditators (for a review see Cahn & Polich, 2006; Lomas et al., 2015) and, to our knowledge, to date there is no research looking into the electrophysiological correlates of dispositional mindfulness. A study with meditators compared groups of different levels of expertise (distributed by hours spent in formal meditation) and found that higher expertise was associated with lower gamma activity over the prefrontal areas and overall lower gamma power, a marker of reduced activity of the DMN that has been related to lower mind-wandering (Berkovich-Ohana et al., 2012). In a related study, Berkovich-Ohana et al. (2014) found reduced functional connectivity associated with meditation practice and, specifically, a negative correlation between overall left gamma mean phase coherence and mindfulness (meditation) expertise, which supports the notion that there is a mindfulness-induced reduction in DMN activity that relates to self-reference and mind-wandering.

In the present study, we aimed to characterize the electrophysiological brain activity of dispositional mindfulness both at rest and while performing a learning task. To our knowledge, no previous study has addressed this question. Because previous research has shown an association between mindfulness (meditation) experience and frontal gamma power at rest (reduced power in expert meditators thought to be responsible for reduced DMN activity), our main hypothesis was that individuals scoring high in mindfulness, even without any meditation practice, would show lower gamma power over frontal areas at rest, relative to their low-mindfulness counterparts. On the other hand, because fMRI studies have revealed that high mindfulness is associated with a more frequent state of "task-readiness" in addition to decreased mind-wandering during rest (Lim et al., 2018) and that overall q-EEG in healthy adults decreases from rest to task (Stevens et al., 2001), we aimed at exploring whether these patterns differ as a function of dispositional mindfulness. Therefore, we expected high mindfulness participants to exhibit lower overall q-EEG at rest and slighter reductions from rest to task than low trait participants. The latter prediction follows from the assumption that high "task readiness" is already present at rest in high mindfulness individuals and, therefore, the reduction in q-EEG associated with task engagement might be slighter than in low mindfulness individuals.

Additionally, we aimed to explore whether mindfulness-related variations in brain activity can be captured by using measures of complexity, such as sample entropy and fractal dimension. EEG activity provides fine temporal resolution that makes it especially suitable for investigating complex biological signals arising from brain systems. However, given the non-linear nature of EEG, linear methods (as power analyses of q-EEG) may be limited. More recent approaches to interpreting EEG activity have adopted non-linear assumptions from system theories and permit tapping into nonrandom fluctuations over multiple time scales, thus providing more convenient insights about neural connectivity. These methods are increasingly being recognized as a valuable tool for the investigation of typical and pathological states (Costa et al., 2002, 2005; Ouyang et al., 2010). In this respect, several individual differences have been linked to complexity (i.e., age: McIntosh et al., 2008; schizophrenia: Ibáñez-Molina et al., 2018; autism spectrum conditions: Catarino et al., 2011). Two frequently employed methods for computing complexity of EEG signals are entropy and fractal dimension. Entropy is a physical measure of the amount of disorder in a system and it describes the irregularity or unpredictability of a signal. On the other hand, fractal dimension is a non-integer number describing the self-similarity of a system; that is, the extent to which the whole can be fitted by parts of it by shifting and stretching (Mandelbrot, 1977). Again, to our knowledge no study to date has investigated the complexity signatures of mindfulness trait. In addition, few studies have yet focused on complexity indexes during meditation. To our knowledge, only one recent study found an increment in sample entropy during meditation (Vivot et al., 2020). Therefore, we also consider here sample entropy (SampEn) and Higuchi's fractal dimension (HFD) with the aim of further exploring the neural underpinnings of dispositional mindfulness.

Method

Participants

A hundred twenty people (M_{age} = 23.11, SD_{age} = 4.19, Range = 18-33, 69% female) completed the study in exchange for course credits

(0.1credit/40min) or monetary reward (7€/1h). This sample took part in a larger individual differences study from which other non-overlapping findings have been already reported. To confirm that the sample size of the bigger project was enough to capture the desired effects we calculated an a priori power analysis (G*Power 3.1.9.2; Erdfelder, Faul and Buchner 1996) based on the effect of the linear regression reported by Kong (2016), with an $R^2 = 0.14$, as we also adopted an regression approach. The analysis revealed that 68 participants were enough to detect a reliable association with 95% power and alpha set at 5%. Participants provided their written informed consent to participate in the study, which was carried out under the Helsinki Declaration guidelines (World Medical Association, 2013) and was approved by the Ethics Committee of the University Affiliation (number 84/CEIH72015).

Materials and Procedure

Participants were tested individually in two sessions that lasted 90 and 120 min, respectively. In the first session they were administered four questionnaires: the Spanish versions of the Five Facets Mindfulness Questionnaire (FFMQ; Cebolla et al., 2012), the Mindful Attention Awareness Scale (MAAS; Soler et al., 2012), the Barratt Impulsiveness Scale (BISS-11; (Oquendo et al., 2001) and the Grit Scale (Grit; Duckworth & Quinn, 2009); and four experimental tasks: the Cued Task-Switching Paradigm (CT-S; Chevalier, 2015), a Stroop-like Conflict Task (CT; Roelofs et al., 2006), the Operation Span (O-Span; Turner & Engle, 1989) and the AX-CPT (Braver et al., 2009). The second session included MRI and EEG recordings at rest (5 minutes eyes closed) and two experimental tasks: the Stop Signal Task (Stop-It; Verbruggen & Logan, 2008) and an adaptation of the selective retrieval-practice procedure (Anderson et al., 1994) that included simultaneous EEG recordings. As for the mindfulness indexes, we only selected the FFMQ for the present study due concerns expressed about the MAAS (Baer et al., 2006; Sauer et al., 2013; Van Dam et al., 2018). Regarding the EEG indexes, they were obtained from the 5 minutes recording period at rest and from the first 5 minutes recording period during the learning task.

FFMQ. The FFMQ is a thirty-nine items self-reported questionnaire that measures five facets of mindfulness: observing (i.e., 'I notice the smells and aromas of things'), describing (i.e., 'I'm good at finding words to describe my feelings'), acting with awareness (i.e., 'I am easily distracted'), non-judging of inner experience (i.e., 'I disapprove of myself when I have irrational ideas') and non-reactivity to inner experience (i.e., 'I watch my feelings without getting lost in them'). Items in FFMQ range from 1 (never or very rarely true) to 5 (very often or always true), with higher scores reflecting greater mindfulness. The Cronbach's α for the factors of the Spanish translation ranges from 0.80 to 0.91 (Cebolla et al., 2012). In our sample, its range is from 0.68 to 0.90.

Rest. To measure resting-state EEG participants were instructed to be quietly seated with closed eyes and light off for 5 minutes.

Selective retrieval task. To measure EEG while performing a task we selected the first 5 minutes from the study phase of the selective retrieval task. During this recording period participants were quiet with open eyes while memorizing a series of category-word pairs that appeared on the screen one at a time, (i.e. MA-Maturity) for an upcoming memory test.

EEG Recording and preprocessing. The EEG was recorded from 64 scalp electrodes, mounted on an elastic cap, on an extended 10–20 system. Continuous activity was recorded using Neuroscan Synamps2 amplifiers (El Paso, TX) and was first recorded using a midline electrode (halfway between Cz and CPz) as reference. Before data analyses a high-pass filter at 1Hz was applied and the 5 minutes recording was segmented in 2 seconds epochs with 0.5 of overlap. Artifacts were manually removed by carefully inspecting the data using Fieldtrip toolbox73 on Matlab (Oostenveld et al., 2011), bad channels with a high level of artifacts (always below the 10% of the total for each participant) were visually detected and interpolated from neighbor's electrodes.

Q-EEG analyses. EEG data were analyzed using the procedures described in Prat et al. (2016). The mean log power spectrum between 4 and 40 Hz was calculated by first computing each epoch's power spectrum using the Fast Fourier Transform, log-transforming it, and then averaging the resulting power spectra across all epochs. To reduce spectral leakage, a Hanning window was applied to each epoch before computing the corresponding Fourier transform. The mean log power was then separately calculated across theta (4–

7.5 Hz), alpha (8–12.5 Hz), beta (13–29.5 Hz), and low-gamma (30–40 Hz) frequency bands for each channel and in each participant, although analyses will focus in the low-gamma band. Delta (< 4 Hz) and high-gamma (> 40 Hz) frequencies were not calculated due to susceptibility to artifact (Berkobich-Ohana et al., 2012). Total q-EEG was calculated as the average of all frequency bands. The frontal region of interest (ROI) was selected following Berkovich-Ohana et al. (2012): AF3, F5, F3, F1, FC3, FC1, AF4, F2, F4, F6, FC2, FC4.

Complexity analyses. The preprocessed EEG series were used as inputs for analyses of the Sample Entropy (SampEn) and Higuchi's Fractal Dimension (HFD). These measures were estimated using a sliding window procedure with a length of 2 seconds and 90% of overlap in each time step. Estimations were obtained with the median of the resulting complexity series for each participant, electrode and experimental condition.

SampEn is a measure that is sensitive to irregularity patterns in the signal, and it is appropriated for short and noisy time series. The SampleEn algorithm computes the negative of the logarithmic conditional probability that sets of segments of the signal, which are closer than a given tolerance, p, for m contiguous samples, will remain similar at the next time point (length m+1). As other measures of entropy, high values of SampEn are associated with random data series (see seminal works of Pincus & Goldberger, 1994; Richman & Moorman, 2000). The free parameters m and p were selected according to the recommendations of the original work of Richman & Moorman (2000) with values of m = 2 and p = 0.10 times the SD of the EEG series. SampEn has been successfully applied to EEG analysis in multiple areas of research (i.e. Chen et al., 2019; Jordan et al., 2008; Yum et al., 2008).

The fractal dimension was estimated with HFD measures self-similarity of the signal in the time domain (Higuchi, 1988). The algorithm explores the original series for several scales defined with an interval of length k. After a double logarithmic transformation of the length of the signal at each scale k (ln L(k)) and the scale (ln k), the slope of the regression model of both variables is used to estimate the FD value. It is noteworthy that HFD has been successfully applied to the analysis of EEG signals in clinical and non-clinical contexts (Accardo et al., 1997; Ruiz-Padial & Ibáñez-Molina, 2018). HFD depends only on one free parameter, the maximum number of scales k being explored to obtain the slope of the regression model. In this study we selected a maximum k of 55 as an optimal parameter for all EEG series since it was a value at which on average the HFD estimation approximately reached a plateau for all conditions and electrodes.

Results

The data from four participants were removed from the analyses due to either problems during the EEG recording (two participants) and for missing scores in the FFMQ (two participants). The descriptive statistics for the remaining participants (116) and correlations are available in Supplementary Material 1.

Q-EEG Results

First, we run a Pearson correlation analysis between global q-EEG at task and memory performance at baseline. No association emerged from the analysis ($r = 0.047$; $p = 0.61$).

To test our first hypothesis on the relationship between mindfulness and reduced frontal gamma at rest, we run a linear regression between FFMQ scores and frontal gamma q-EEG at rest. The analysis revealed a reliable association in the direction we predicted (see Table 1). The hypothesis on the relationship between mindfulness trait and reduced overall q-EEG at rest but not at task was examined by performing two separated linear regressions. While mindfulness trait was negatively associated with q-EEG at rest, such an association was not reliable at task (see Table 1 and Figures 1 and 2).

In the sake of clarity we also performed a comparison of the main effects in the extreme groups of the continuum of the FFMQ scores (the two extreme groups of the tertile scores; N= 38 each) and found significant differences in both cases: 1) frontal gamma at rest: $t = 2.54$, $p = 0.01$; and 2) global q-EEG at rest: $t = 2.07$, $p = 0.04$; 3) but no differences in global q-EEG at task: $t = 1.99$ $p = 0.05$.

Table 1. Linear regression analyses of FFMQ and frontal gamma at rest and overall q-EEG during rest and task

	R^2	ΔF	*B*	*SE*	*β*	*p*	2.5% CI	97.5% CI
F Gamma Rest	0.03	3.99	-12.64	6.33	-0.18	0.048	-25.17	-0.11
Overall q-EEG Rest	0.05	5.44	-12.98	5.57	-0.21	0.021	-24.01	-1.96
Overall q-EEG Task	0.02	2.65	-11.23	6.91	-0.15	0.110	-24.91	2.45

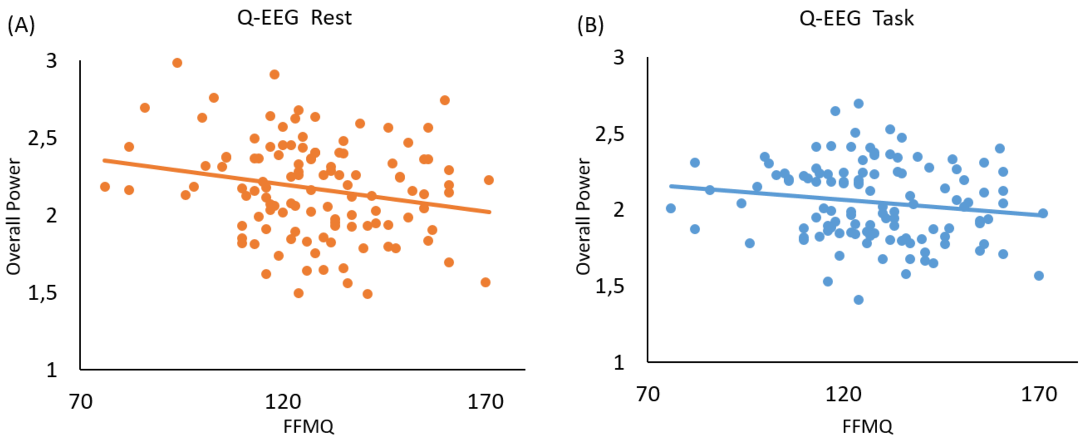

Figure 1. Scatterplot representation of the overall power q-EEG as a function of Mindfulness at Rest (A) and at Task (B).

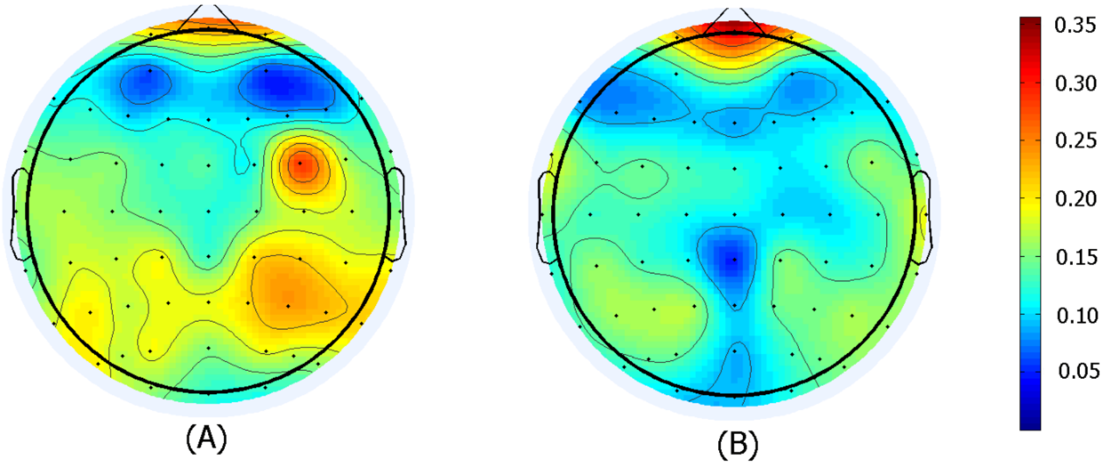

Figure 2. Representation of the change from Rest to Task (subtraction of the overall power at task to overall power at rest) in low Mindfulness individuals (A) and in high Mindfulness individuals (B), groups calculated by the tertiles scores of the whole sample.

Complexity Results

Similar analyses were computed to explore the possible association between mindfulness and complexity measures. Specifically, we run separated linear regression analyses between the FFMQ scores and the indexes of Entropy and Fractal Dimension at rest and at task. Only Entropy at task showed a close-to-significance positive association with mindfulness (See Table 2).

Table 2. Linear regression analyses of FFMQ and Entropy and Fractal Dimension Indexes at rest and at task.

	R^2	ΔF	*B*	*SE*	β	*P*	2.5% CI	97.5% CI
Entropy Rest	0.02	2.51	-72.07	45.45	-0.15	0.116	-162.12	17.97
Entropy Task	0.03	3.81	-73.38	37.58	0.18	0.053	-1.06	147.82
FD Rest	0.00	0.00	0.06	20.78	0.00	1	-41.12	41.23
FD Task	0.00	0.1	9.31	29.29	0.03	0.75	-48.72	67.35

Discussion

To our knowledge, the present study is the first attempt to investigate the electrophysiological underpinning of dispositional mindfulness at rest and in the transition from rest to task. We expected mindfulness trait to be associated with different patterns of brain activity in resting-state so that the higher the scores in the trait the lower the involvement of the default mode network (DMN). In addition, we hypothesized that the resting state configuration of those individuals scoring high in mindfulness would be more similar to its brain configuration at task, which would reflect task readiness, in comparison to their low mindfulness counterparts. Finally, we explored whether dispositional mindfulness relates to changes in complexity of brain activity.

As predicted, results showed that higher scores in mindfulness trait are associated with less involvement of frontal gamma power during rest. This finding is in line with those observed in expert meditators (Berkobich-Ohana et al., 2012), whereby lower frontal gamma has been interpreted as reflecting less involvement of the DMN. Specifically, gamma power increases have been linked to activity in the prefrontal hub of the DMN (Chen et al., 2008; Mantini et al., 2007), which is closely related to self-referential processing (Northoff et al., 2006). These results might be indicating that high mindfulness, independently of whether it results from a dispositional trait or training, can be characterized by brain activity at rest that is thought to reflect lower mind-wandering and self-referential processing. On the other hand, a general reduction in power from rest to task has been observed in healthy individuals indicating a reorganization of the resources to respond to the task requirements (Stevens et al., 2001). We hypothesized that because mindfulness trait would entail a state of "task readiness" even during rest, reorganization to adjust to the task requirements (reduction in power from rest to task) might be less evident for individuals with higher mindfulness scores. The results of the regression analyses support this idea. Thus, mindfulness scores significantly predicted reduced power at rest, but there was no association between mindfulness and power during task engagement. While we cannot attribute this lower power at rest uniquely to a reduced DMN activity, our results provide evidence that high mindfulness individuals exhibit less overall brain oscillations/activity, which could be interpreted as "a quieter mind" at rest. Even though suggestive, the present findings should be held with caution, as the effect sizes of the results are very humble and it is the very first time to our knowledge that the electrophysiological substrates of trait mindfulness are reported. Nevertheless, previous research using MRI have found a theoretically similar link between resting-state activity and mindfulness trait (Kong et al., 2016 in regional homogeneity in resting-state fMRI; Lim et al., 2018 in dynamic functional connectivity in resting-state fMRI; and Lu et al., 2014 in grey matter) that supports the idea of lower involvement of mind-wandering processes and self-referential processing in high mindfulness individuals. Further, studies examining the expert meditators' brain at rest have found the same pattern of reduced DMN activity (for a review, see Tang et al., 2015). While it has been previously argued that mindfulness trait may be a different construct than mindfulness that results from training (Grossman, 2008), growing evidence indicates that both are characterized by reduced DMN activity. However, it remains unknown if this pattern is different at earlier stages of meditation training.

While power-based analyses provided valuable information of the neural underpinnings of dispositional mindfulness, we also wanted to explore the relationship between mindfulness and non-linear measures of brain complexity. Although these analyses failed to show reliable effects, mindfulness trait tended to correlate with entropy at task. Some have argued that the increment in entropy found in several cognitive tasks reflects increments in information processing as a function of the complexity of the task (Lamberts, 2000; Müller et al., 2003; Stam, 2005). Interestingly, a very recent study found that meditation practice increases entropy of brain oscillatory activity (Vivot et al., 2020). Altogether, these findings might be indicating differential information processing in mindful participants with an allocation of attention more anchored to the present.

In sum, our results add to those from expert meditators to show that high (dispositional) mindfulness seems to be linked to less frontal gamma power and lower overall power during resting state, maybe due to less involvement in mind-wandering processes. In addition, increased entropy seems also to characterize mindful individuals suggesting differences, relative to less mindful individuals, in task engagement. Because the present results are the very first in bringing attention to the electrophysiological signature of dispositional mindfulness, further studies are needed to better characterize mindfulness trait in terms of brain activity. In these future directions it would be of interest to add objective measures of mindfulness as the breath counting task (Lim et al., 2018), as well as testing these effects in different stages and techniques of mindfulness meditation to see whether trait and practice mindfulness differ. Delimitating the neural correlates of dispositional mindfulness will be critical to understanding the trait, but also to identify potential indexes of improvement in mindfulness-based therapies.

Supplementary Material 1

Table 1. Descriptive statistics for the main variables. The first column refers to means and standard deviations.

	Score	Minimum	Maximum
FFMQ	128.15 (18.97)	76	171
Rest			
Global q-EEG at Rest	2.17 (0.31)	1.49	2.98
Frontal gamma at Rest	1.52 (0.27)	0.98	2.45
Entropy at Rest	2.11 (0.04)	1.97	2.17
Fractal Dimension at Rest	1.69 (0.08)	1.25	1.84
Task			
Global q-EEG at Task	2.05 (0.25)	1.41	2.69
Entropy at Task	2.07 (0.05)	1.90	2.16
Fractal Dimension at Task	1.68 (0.06)	1.48	1.88
ACC Memory Task (Nrp)	0.58 (0,28)	-0.88	1

Table 2. Pearson correlations of the main EEG indexes at rest and at task and the mindfulness score.

	FFMQ
Rest	
F-Gamma q-EEG at Rest	-0.18*
Global q-EEG at Rest	-0.21*
Entropy at Rest	-0.14
Fract. Dim. at Rest	0.00
Task	
Global q-EEG	-0.17
Entropy at Task	0.20*
Fract. Dim. at Task	0.08
MAAS	0.66

* $p < 0.05$ **$p < 0.01$, *** $p < 0.001$. Asterisks represent statistically significant correlations after controlling for multiple comparisons with the Banjamini-Hochberg method with false discovery rate at .25 (Benjamini & Hochberg, 1995).

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CHAPTER VII. The Relative Role of Executive Control and Personality Traits in Grit

Study 3[3]

Although grit is predictive of wellbeing, educational achievement, and success in life, it has been conceptualized as largely distinct from cognitive ability. The present study investigated the link between grit and executive functions, since regulation abilities might underlie the expression of grit. A hundred thirty-four people were administered personality questionnaires (grit, impulsiveness, and mindfulness) and four experimental tasks tapping into Miyake's and Braver's models of executive functioning (including measures of flexibility, inhibition, working memory, and control mode dimensions). Multivariate analyses showed that two factors (trait and executive functioning) were reliably predictive of grit, although it was the trait factor (characterized by high impulsivity and low mindfulness) that explained more variance. Although gritty participants did not demonstrate enhanced executive functioning, they exhibited a less proactive control mode than their low grit counterparts, which converges with the idea that they do not drive their behaviour by initial contextual cues but they keep attentive until all information is available.

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[3] The work presented in this chapter has been submitted and is in its second round of review as Aguerre, N. V, Gomez-Ariza, C. J., & Bajo, M. T. The Relative Role of Executive Control and Personality Traits in Grit. PLoS ONE

Introduction

To crown the top of Mt. Everest is not an easy challenge, nor is it to finish a PhD. Some people will spend a good few years of their lives training and working day after day to achieve these challenges, whereas other people prefer short-term goals. To engage and achieve long-term goals require grit, a personality trait that refers to the tenacious pursuit of a dominant superordinate goal despite setbacks (Duckworth & Gross, 2014; Duckworth & Seligman, 2005). In the last decade, grit has received attention within the discipline of positive psychology as well as in the fields of motivation and education. Thus, research indicates that grit significantly contributes to wellbeing (i.e., Duckworth et al., 2007; Jiang et al., 2019), lower depression (i.e., Datu et al., 2019; Musumari et al., 2018), and reduction of risk of suicidal ideation (i.e., Kleiman et al., 2013; White et al., 2017). In addition, grit has also been shown to significantly predict success in work and personal life (i.e., Eskreis-Winkler et al., 2014; Mueller et al., 2017) as well as academic achievement (i.e., Clark & Clark, 2019; Duckworth et al., 2007).

As mentioned, grit is conceptualized as a personality trait reflecting perseverance and passion for long-term goals and it is usually assessed with the Grit Scale (Duckworth et al., 2007), which comprises two factors: perseverance of effort (PE) and consistency of interest (CI). Perseverance of effort reflects effort toward one's enduring or superordinate goal (i.e., 'Setbacks don't discourage me'), whereas consistency of interest refers to the ability to focus on a small set of relevant goals related to the pursuit of a larger, more important objective (i.e., 'New ideas and projects sometimes distract me from previous ones', inversed item). A number of studies have examined the relationship between grit and other personality factors. For example, some studies have shown a positive relationship between grit and conscientiousness (tendency to be hardworking and self-disciplined), self-regulation (tendency to appraise before and during performance), and engagement (tendency to get deeply involved in an activity) (i.e., Muenks et al., 2017; Werner et al., 2019). Similarly, grit seems to be negatively related to impulsiveness, which refers to the tendency to perform swift actions without conscious judgment (Griffin et al., 2016; Moshier et al., 2016), and positively related to mindfulness (Raphiphatthana et al., 2018, 2019). Mindfulness is usually defined as a state of non-judgmental attention toward the present experience (Kabat-Zinn, 1990) and thought to comprise five factors as measured with the FFMQ (Five Facets Mindfulness Questionnaire; Baer et al., 2006); namely, observing, describing, acting with awareness, non-judging of inner experience and non-reactivity to inner experience. A secondary goal in the present study was to replicate the already observed associations between grit, impulsiveness, and mindfulness. The main goal was to gain understanding of the relative role of trait variables and cognitive (executive) functions in the description of grit.

While predictive of academic success, grit has been conceptualized as largely distinct from cognitive ability (Duckworth et al., 2007; Duckworth &

Quinn, 2009; Perkins-Gough, 2013). Indeed, grit and cognitive ability have been shown to be orthogonal in several studies (i.e., Duckworth et al., 2007; Eskreis-Winkler et al., 2014). Nevertheless, it should be noted that these studies have mainly employed admission tests to measure cognitive functions (Credé et al., 2017) and very few studies have adopted an experimental approach to look into the cognitive bases of grit (Kalia et al. 2018). Kalia et al. (2018) used the Attention Network Test (ANT; Fan et al., 2002) to examine the relationship between grit and different attentional functions (alerting, orienting, and executive attention). Their results only showed an association with the alerting function, so that the perseverance of effort facet of grit negatively correlated with the alerting effect (the benefit in reaction time that usually follows the presentation of an alerting cue as compared with no alerting cue), which they attributed to either better sustained attention or less sensitivity to warning cues by gritty individuals. More recently, Kalia et al. (2019) found a positive association between the perseverance of effort facet of Grit and performance on difficult Sudoku problems that was mediated by reduced cognitive flexibility (as measured by the Wisconsin Card Sort Test). Thus, those participants who scored higher in grit (and exhibited less cognitive flexibility) persisted more and performed better when solving hard problems. Although these results suggest that certain profiles of cognitive functioning could characterize gritty people, they do not specify the cognitive mechanisms underlying grit. The present study aimed to explore whether grit is related to executive functioning by using a wide range of experimental tasks based on two well-established frameworks of executive functioning.

Executive functions refer to a variety of control mechanisms in charge of guiding behaviour in a goal-driven manner to deal efficiently with changing environments (Miyake et al., 2000), and, in principle, it seems reasonable to think that these control functions may underlie the development and expression of grit. On the one hand, personality traits that strongly relate to grit have been shown to be associated with executive functions (self-regulation: Hofmann et al., 2012; impulsiveness: Hinson et al., 2003; mindfulness: Anicha et al., 2012). On the other hand, activity in specific regions within the prefrontal cortex (PFC), which has been systematically shown to underpin executive functioning (i.e., Yuan & Raz, 2014), has been related to grit (Myers et al., 2016; Wang et al., 2017). However, no previous study to date has directly examined the relationship between grit and executive control. In an attempt to fill this gap, the main aim of the present study was to explore the potential link between grit and executive functions.

A classical classification of executive functions is the one proposed by Miyake et al. (2000; 2012), who identified three different executive control functions that conformed a unique construct while being clearly separable from each other: switching, inhibition, and working memory updating. Switching involves shifting flexibly between tasks or mental sets; inhibition entails the capacity to resist interference or for conflict resolution; and updating refers to the monitoring of information in working memory together with its revision to replace old items that are no longer relevant with newer relevant ones. These three executive components are usually measured with task-switching, conflict, and working memory tasks. These tasks provide indexes for: 1) switching cost (SC), which represents worse performance in trials involving switching between different tasks as compared with trials with task repetitions (Chevalier et al., 2015; Monsell, 2003); 2) conflict cost (CC), an inverse estimate of inhibitory control, whereby responses to incongruent trials are less accurate and slower than responses to congruent trials (Roelofs et al., 2006), and 3) working memory (WM) index, measured as a result of the number of items successfully stored in memory while accurately performing a mental operation task (Turner & Engle, 1989).

While the framework proposed by Miyake et al. (2000, 2012) has been very useful in classifying functions and tasks as well as in studying individual differences when confronting everyday challenges (Friedman et al., 2008), other theoretical frameworks emphasizing more dynamic manners of facing these challenges have also been helpful. For example, the dual mechanisms of cognitive control (DMC) account proposed by Braver (Braver et al., 2009; Braver, 2012) posits that two different cognitive control modes may be put into work: 1) a proactive mode, which acts by actively maintaining task-relevant information in a sustained manner to direct behaviour in accordance with internal goals; and 2) a reactive mode, which relates to the detection and resolution of interference at the time it occurs. The interaction between these two control modes is dynamic so that people might be more prone to one or another mode (Jimura et al., 2010) and some situations might favour one mode over another (Burgess & Braver, 2010; Mäki-Marttunen et al., 2019). Also, it is the dynamic coordination of the two modes of control that allows individuals to be more adaptive in changing situations (Munakata et al., 2012).

A well-established task to estimate the individuals' control mode preference is the AX-Continuous Performance Task (AX-CPT; Braver et al. 2009), wherein participants are instructed to respond to a probe on the basis of a contextual cue that signals a specific response in 70% of the trials (AX), while in the remaining trials (AY, BX and BY) a 'no' response is required either by cue or probe indication. A proactive control tendency is signalled by more errors when the contextual cue to respond 'yes' appears but a non-target probe forces an alternative response (AY). In contrast, reactive control is characterized by increased errors when the contextual cue signals a 'no' response but the probe elicits the dominant response (BX). The participants' proactive vs. reactive tendency is calculated by the Behavioural Shift Index (BSI) wherein higher scores reflect a proactive tendency (Braver et al. 2009; Gómez-Ariza et al., 2017). In the present study, we used classical executive functions tasks following the Miyake et al.'s classification (Miyake et al., 2000) as well as the AX-CPT to examine the relationship between executive control components and grit.

In summary, with the present study we aimed to gain understanding of the relationship between executive functioning and grit but also considering personality traits. Specifically, we selected two personality traits (impulsiveness and mindfulness) and four executive control indexes (switching and conflict costs, working memory, and BSI) to examine their relationship to grit. On the one hand, we expected to extend previous findings showing a negative association between impulsiveness and grit and a positive relationship between mindfulness and grit in a Spanish sample of healthy young adults (Griffin et al., 2016; Raphiphatthana et al., 2018). On the other hand, and although our study is to some extent exploratory given the lack of previous research, we expected individuals scoring high on grit to exhibit a specific profile of executive functioning. From the conceptualization of grit that was described above, it seems reasonable to expect that enhanced ability for conflict resolution (better inhibition), working memory capacity and proactive control would be linked to higher scores in grit since the efficient use of these processes would contribute to downregulating irrelevant goals while keeping in mind the selected superordinate objective. Also, enhanced ability for task switching would seem to be necessary to take alternative pathways towards the superordinate goal after a failure, even though the above-mentioned results from a recent study suggest that tenacity might work at the expense of cognitive flexibility (Kalia et al., 2019). To test these hypotheses, we first examined simple relationships between executive indexes and trait variables, and grit. Then, we explored the possible combined trait-executive profiles performing principal factor analyses and we tested regression models from the predicting factors over grit. Finally, to determine the variables from each factor that better accounted for grit, separated regression analyses with the indexes that loaded onto each factor were conducted.

Methods

Participants

A hundred thirty-four people (M_{age} = 22.92, SD_{age} = 4.1, $\text{Range}_{\text{Age}}$ = 18-33, 72% female) participated in the study in exchange for course credits (1/40min) or monetary reward (7€/1h). This sample has been previously reported in a related study aimed to examine the relationship between mindfulness and cognitive control modes (Aguerre et al., 2020). Both studies are part of a larger research project on individual differences so that participants were administrated several different experimental tasks and questionnaires along with two assessment sessions. Importantly, both studies focus on different issues without significant overlap concerning aims or findings. All participants were provided with general information about the study and gave written informed consent following the Declaration of Helsinki (World Medical Association, 2013) prior to being administered any of the tasks.

Materials and Procedure

Participants were assessed across two sessions of 90 and 120 min, respectively. All participants were tested individually in isolated cubicles. In the first session, four questionnaires and four experimental tasks were administered. The questionnaires were a translated version of the Grit Scale (Grit; Duckworth & Quinn, 2009), the Spanish version of the Barratt Impulsiveness Scale (BISS-11; Oquendo et al., 2001), the Five Facets Mindfulness Questionnaire (FFMQ; Cebolla et al., 2012) and the Mindful Attention Awareness Scale (MAAS; Soler et al., 2012). The experimental tasks were the Cued Task-Switching Paradigm (CT-S; Chevalier et al., 2015), a Stroop-like Conflict Task (CT; Roelofs et al., 2006; Stroop, 1935), the Operation Span (O-Span; Turner & Engle, 1989; Maraver et al., 2016) and a distractor version of the AX-CPT (Braver et al. 2009; Morales et al., 2013). During the second session, the participants were administrated a Stop-Signal Task (Stop-It; Verbruggen et al., 2008) and a Selective Retrieval-Practice task (RIF; Anderson et al., 1994) in addition to MRI and EEG recordings. The results of the second assessment session are intended to be included in a different forthcoming paper and, consequently, are not presented here. The present study only concerns the first assessment session. All questionnaires and experimental tasks were counterbalanced across participants. Stimuli presentation and data acquisition were controlled by E-prime experimental software (Schneider et al., 2002).

GRIT. The Short Grit Scale is an 8-item self-reported questionnaire that assesses two factors of grittiness: perseverance of effort (i.e., 'I finish whatever I begin') and consistency of interest (i.e., 'My interests change from year to year', inversed item). Answers to the items go from 1 (very much like me) to 5 (not like me at all). The highest score on this scale is 5 (extremely gritty) and the lowest score is 1 (not at all gritty). Cronbach's α of the factors goes from 0.60 to 0.79 (Duckworth & Quinn 2009).

BISS-11. This is a questionnaire of 30-items composed of three scales of impulsiveness: cognitive impulsiveness (i.e., 'I am a happy-go-lucky'), motor impulsiveness (i.e., 'I do things without thinking'), and non-planned impulsiveness (i.e., 'I plan tasks carefully', inversed item). Items in BISS-11 are ranged from 1 (rarely/never) to 4 (almost always/always), with higher scores reflecting greater impulsiveness. The Cronbach's α of this questionnaire is 0.83 (Oquendo et al., 2001).

FFMQ. Self-reported questionnaire that measures five facets of mindfulness in 39 items. The facets are: observing (i.e., 'I notice the smells and aromas of things'), describing (i.e., 'It's hard for me to find the words to describe what I'm thinking', inversed item), acting with awareness (i.e., 'I snack without being aware that I'm eating', inversed item), non-judging of inner experience (i.e., 'I disapprove of myself when I have irrational ideas', inversed item) and non-reactivity to inner experience (i.e., 'I watch my feelings without getting lost in them'). Answers in FFMQ go from 1 (never or very rarely true) to 5 (very often or always true), higher scores reflect higher degree of mindfulness. The reliability indexes of the factors go from 0.80 to 0.91 (Cebolla et al., 2012).

CT-S. We employed an adaptation for adults of the cued task-switching paradigm introduced by Chevalier et al. (2015) as a measure of switching. The task goal was to sort objects either by their shape or by their colour as indicated by a trial cue. In every trial, three screens were presented. In the first one, a fixation cross appeared in the centre of the screen with a jittered inter-trial interval between 1000-1200 ms In the second screen a box surrounded by the task cue or a neutral cue was presented for 500 ms. In the third screen the two-dimensional target (8 x 6 cm; i.e., a blue balloon), surrounded by the task cue or a neutral cue, was presented in the centre of the screen until a response was entered or for up to 1200 ms. The neutral cue consisted of 12 beige squares that were not informative of the dimension of the target to respond to. While the task cue could be 12 beige different geometrical shapes that indicated a shape response, or 12 squares of different colours that indicated a colour response. The task was divided into three blocks with a different combination of shape and colour (balloon-airplane-blue-red; apple-banana-green-yellow; ball-bat-orange-purple). Critically, the timing of cue presentation was blocked and the order of the blocks was counterbalanced across participants. In the 'proactive impossible' block, the neutral cue was presented with the box and the task cue was presented with the target so that reactive control was required to give a correct answer. In the 'proactive possible' block the task cue was presented along with the box and remained visible after target onset so that either proactive or reactive control could be used. Finally, in the 'proactive encouraged' block there was an early presentation of the task cue (along with the box) and the neutral cue was presented along with the target so that proactive control was necessary to respond. Participants were required to give a response by pressing different keys with one of their four fingers (index and middle fingers of each hand), previously associated with each colour and shape. The task had 216 trials, 8 practice trials wherein feedback was provided and 64 experimental trials per block with pauses every 16 trials. In each experimental block, 32 trials were no-switch, the task was the same as the previous trial, and 32 trials were switch, the relevant task changed from the previous trial. Switch and no-switch trials alternated unpredictably. A switching cost index (SC) can be calculated by subtracting switch trials to no-switch trials on accuracy or the other way on RTs; the lower the SC the greater the flexibility of the participant (Chevallier et al. 2015; Monsell 2003). We used a SC based on accuracy in the proactive possible block because this is the neutral block and previous findings have shown it to be the most sensitive (Aguerre et al., 2020).

CT. This task was used to measure the capacity for conflict resolution (inhibition). The task employed was an adaptation of the original paradigm (Roelofs et al., 2006; Stroop, 1935) that requires participants to respond either to the direction of an arrow (pointing to left or right) or to the meaning of a word ('left' or 'right') that was placed inside the arrow. The answers were given by pressing either the '1' key of the keyboard to respond 'left' or the '5' key to respond ‘right’. A cue presented previously signalled if participants had to respond to the direction of the arrow or to the meaning of the word; the cue was either an ‘f’ (from ‘flecha’, arrow in Spanish) or a ‘p’ (from ‘palabra’, word in Spanish), respectively. Each trial consisted of the presentation of three consecutive items. First, a fixation point (a centred cross) was presented for 400ms. Then, the cue (‘f’ or ‘p’) appeared in the centre of the screen for 500ms. After this, the arrow containing a word was presented in the centre of the screen until a response was entered or up to 1500ms. The task had 8 practice trials in which feedback was provided plus an experimental block of 40 trials. Twenty trials were congruent (the direction of the arrow matched the meaning of the word: 10 left, 10 right), and the remaining 20 trials were incongruent (the direction of the arrow mismatched the meaning of the word: 10 left, 10 right). Half of the trials required a response to the word, while the other half required a response to the arrow. Different types of trials were presented randomly. An interference index (reflecting conflict cost; CC) was computed by subtracting reaction times on incongruent trials from reaction times on congruent trials (Stroop, 1935).

O-SPAN. This task was used to assess working memory capacity. We employed the Spanish version of the original task introduced by Turner and Engle (1989) (see Maraver et al., 2016). This is a dual working memory task wherein participants had to verify mathematical equations while keeping in memory sets of words of increasing set sizes. Stimuli were presented centrally on a white background. In each trial, an operation-word pair was presented. First, a solved mathematical operation [i.e., (14/2) + 2 = 9] was presented for 3750 ms, participants had to mark it as correct or incorrect by pressing the 'd' key (correct) or 'k' key (incorrect) on the keyboard. Following, a word was presented for 1250 ms to be stored in memory. The number sets of operation-word pairs increased along with the task from 2 to 6. After each set participants were asked to type all the words that they remembered from the set. To prevent recency effects participants were told that the only rule upon writing the set words was to avoid writing first the last word memorized, otherwise, the order of recall was not important. The task was composed of 10 practice trials and 18 experimental trials (three trials per set size). A WM index was calculated by multiplying the number of successfully recalled words and the number of correctly solved equations (Conway et al., 2005).

AX-CPT. This task provides an index of the participants' predominant mode of cognitive control (proactive vs. reactive). Specifically, we used the version described in Morales et al. (2013), which has shown to be sensitive to individual differences. The task required participants to answer affirmatively to a specific pattern of letters, an 'A' letter (cue) followed by an 'X' letter (probe). To any other pattern of letters participants were required to answer 'no'. Each letter was presented in the centre of the screen on a black background for 300 ms, with an inter-stimulus interval of 1000 ms. In every trial cue and probe were presented in red font. Additionally, between cue and probe, three letters were presented as distractors, in white font. Participants were instructed to respond ‘no’ to distractors. The task comprised 110 trials, 10 practice trials where feedback was provided, and 100 trials of the experimental block. The frequency of the target trials (AX) was 70%, while any other cue-probe combination (AY: ‘A’ cue – non ‘X’ probe; BX: non ‘A’ cue – ‘X’ probe; or BY: neither ‘A’ cue nor ‘X’ probe) were presented in a 10% of the remaining cases. The tendency towards a control mode was assessed by computing the behavioural shift index [(BSI), computed as (AY-BX)/(AY+BX)] for errors (Braver et al. 2009; Gómez-Ariza et al., 2017). Higher scores in the BSI indicate greater dominance of proactive control, while lower scores indicate reactive control dominance.

Results

Prior to performing analyses, we identified two participants with missing scores (in the BISS and the AX-CPT) and 8 participants who exhibited extremely poor performance (below 30% of accuracy in the CT-S or the O-Span) probably due to instructions misunderstanding. These participants were excluded from the analysis (Gonthier et al., 2016).

Descriptive statistics for the main variables of the study are presented in Table 1. General accuracy and RTs are reported along with the main indexes of each task that were entered into the factor analysis. Namely, the SC (switching cost) index in the proactive possible block from the CS-T, the CC (conflict cost) from the CT, the WM (working memory index) derived from the O-Span, and the BSI (Behavioural Shift Index) from the AX-CPT.

Table 2. Descriptive statistics for the scores from the personality questionnaires and experimental tasks. The first column refers to means (Ms) and standard deviations (SDs).

	Score	*Minimum*	*Maximum*
Trait Scales			
Grit-overall	3.42 (0.69)	1.75	4.87
PE-Grit	3.63 (0.69)	1.75	5
CI-Grit	3.2 (0.89)	1	5
BISS	52.28 (19.84)	10	108
FFMQ	127.64 (18.29)	76	171
Executive Tasks			
Cued Switching-Task			
ACC	0.74 (0.14)	0.3	0.97
RT	676 (85)	383	886
SC	0.12 (0.12)	-0.18	0.51
Conflict Task			
ACC	0.91 (0.11)	0.35	1
RT	724 (127)	445	1198
CC	75 (67)	-114	237
O-Span Task			
Intrusions	0.04 (0.07)	0	0.75
WM Index	0.62 (0.17)	0.2	0.98
AX-CPT			
ACC	0.88 (0.08)	0.65	0.99
RT	377 (81)	249	742
BSI	0.13 (0.13)	-0.02	0.44

Correlations analyses

We first performed simple Pearson correlations between the main variables of interest and grit (and its facets) to identify its potential predictors. As can be seen in Table 2, the two personality traits highly correlated with grit. As for the variables obtained from the experimental tasks, higher grit scores were linked to longer RTs in the CT-S, greater conflict cost, and lower BSI. Greater conflict cost and lower BSI were also strongly associated with the consistency of interest facet of grit.

Table 2. Pearson correlations of the main variables with grit and its two facets.

	Grit Total	Perseverance of Effort (PE)	Consistency of Interest (CI)
Personality Scales			
BISS	-0.66***	-0.51***	-0.62***
FFMQ	0.47***	0.48***	0.35***
Observing	0.07	0.17*	-0.03
Describing	0.29**	0.29**	0.23**
Acting Awareness	0.56***	0.44***	0.53***
Non-Judging	0.22*	0.2**	0.19*
Non-Reactivity	0.19*	0.34***	0.04
Cued Switching-Task			
ACC	-0.06	0.01	-0.1
RT	0.18*	0.17	0.16
SC	-0.12	-0.1	-0.12
Conflict Task			
ACC	0.02	-0.03	0.05
RT	0.11	0.15	0.05
CC	0.22*	0.15	0.23**
O-Span Task			
Intrusions	0.04	0.02	0.05
WM Index	-0.1	-0.16	-0.03
AX-CPT			
ACC	0.12	0.07	0.13
RT	0.1	0.06	0.12
BSI	-0.21*	-0.08	-0.26**

* $p < 0.05$ ** $p < 0.01$, *** $p < 0.001$. Asterisks represent statistically significant correlations after controlling for multiple comparisons with the Banjamini-Hochberg method with false discovery rate at .1 (Benjamini & Hochberg, 1995).

Factor and multiple regression analyses

Next, we run an exploratory factor analysis with the main variables of interest after transforming their values to Z scores. Thus, the total scores from the BISS and the FFMQ, the switching cost from the CS-T, and the corresponding indexes from the conflict and working memory tasks, and the AX-CPT were submitted to a factor analysis with a varimax rotation method, eigenvalue above 1.00 and maximum iterations for convergence set at 25 to reduce data and identify patterns in the measures.

Table 3. Factor loadings of the main indexes.

	F1	*F2*
BISS	0.79	0.10
FFMQ	-0.83	-0.12
SC (CS-T)	0.49	-0.49
CC (CT)	-0.11	-0.66
WM Index (O-Span)	-0.09	0.62
BSI (AX-CPT)	0.23	0.59

Two factors resulted from the analysis that were also confirmed through visual inspection. Factor 1 accounted for 27% of the variance and was characterized by (low) mindfulness and (high) impulsiveness, whereas factor 2 accounted for 23.82% of the variance and included (low) conflict cost, (high) working memory, and (high) BSI (rotated solution). Factor loadings on the rotated solution are shown in Table 3.

The two factors (one of them concerning traits and the other concerning executive functioning) were then introduced as independent variables in separate regression models on grit and its facets. In the three models, grit and its facets were negatively associated with the trait factor (characterized by high impulsiveness and low mindfulness) and the executive functioning factor (characterized by low conflict cost, high working memory, and enhanced proactive control) (see Table 4 and Figure 1).

Table 4. Regression of the two factors obtained for Grit and its facets.

	R^2	ΔF	B	SE	β	p
Grit	0.47	52.51				
Trait Factor			-0.66	0.07	-0.64	0.000
Executive Factor			-0.23	0.07	-0.22	0.001
Perseverance of Effort	0.31	27.45				
Trait Factor			-0.54	0.08	-0.53	0.000
Executive Factor			0.18	0.08	-0.17	0.024
Consistency of Interest	0.41	41.71				
Trait Factor			-0.6	0.07	-0.6	0.000
Executive Factor			-0.21	0.07	-0.21	0.003

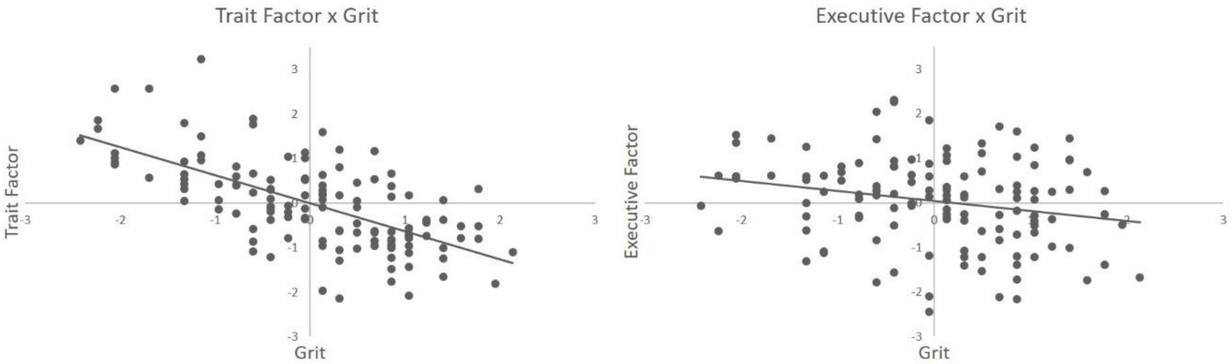

Figure 1. Regression of the two factors obtained for Grit.

Multiple regression analyses of all indexes

Finally, to specify which indexes of each factor were the ones most related to grit, we run separate stepwise multiple regression models with the indexes included in each factor. Thus, we performed a regression analysis with the trait variables (factor one) and another one with the executive indexes (factor two) as independent variables over grit and its two facets. The BISS and the FFMQ showed to be predictive of grit and perseverance of effort facet, while only the BISS was included in the regression model when accounting for consistency of interest. Regarding the executive indexes, only the BSI remained in the model to predict grit and consistency of interest, but none of them were included in the model for the perseverance of effort facet (see Table 5).

To better characterize the negative relationship between grit and the BSI, we split the whole sample into two groups (low grit: 1 SD below the mean and high grit: 1 SD above the mean) and performed one-sample t-tests with the test value = 0. The results with both questionnaires showed that the two groups differed significantly from 0 (all *p*s < 0.001; low grit with BSI $M = 0.2$, high grit with BSI $M = 0.1$). This indicates that although there was a general tendency towards proactive control in both groups (which is usual in healthy young adults; i.e., Gómez-Ariza et al., 2017), this tendency was less strong in gritty individuals.

Table 5. Stepwise multiple regression models from traits and executive indexes separately over Grit and its facets.

	R^2	ΔF	B	SE	β	p
Trait variables						
Grit	0.46	106.36				0.01
BISS			-0.57	0.07	-0.56	0.000
FFMQ			0.19	0.07	0.19	0.011
Perseverance of effort	0.33	69				0.000
BISS			-0.36	0.08	-0.36	0.000
FFMQ			0.3	0.08	0.3	0.000
Consistency of interest	0.39	84.58				0.000
BISS			-0.63	0.07	-0.62	0.000
Executive indexes						
Grit	0.06	7.75				0.006
BSI			-0.26	0.09	-0.24	0.006
Perseverance of effort			-	-	-	-
Consistency of interest	0.09	11.5				0.001
BSI			-0.3	0.09	-0.29	0.001

Discussion

The present study aimed to gain understanding of the relationship between executive functioning and grit also considering personality traits. More specifically, the main goal was to examine whether gritty individuals may be characterized in terms of executive functions and/or different modes of cognitive control. Thus, we selected two traits (impulsiveness and mindfulness) and four indexes of executive functioning [three from the framework proposed by Miyake et al. (2000), and one from the dual mechanisms of cognitive control by Braver et al., (2009)]. We expected individuals scoring high on grit to exhibit enhanced ability for conflict resolution (better inhibition), better working memory capacity, and enhanced proactive control and switching ability since these processes should contribute to achieving long-term goals.

Our results replicate previous findings showing lower levels of impulsiveness and higher levels of mindfulness in people scoring high on grit (i.e., Griffin et al., 2016; Raphiphatthana et al., 2018). More relevant here, our results also show that executive functioning does not seem to be related to grit in the way it was predicted since participants who scored high on grit did not exhibit better performance on the executive tasks than their low-scoring counterparts. Consistently, factor and regression analyses showed that although the two factors (trait and executive functioning) were predictive of grit, it was the trait factor (characterized by high impulsivity and low mindfulness) that explained more variance. Despite this, the executive factor (characterized by low conflict cost, high working memory, and high BSI) was also negatively and reliably related to grit. Hence, our results suggest that the relation between executive functions and grit might be more complex than predicted and in line with Duckworth's suggestion that high grit is not necessarily characterized by better executive functioning (Duckworth et al., 2007; Duckworth & Quinn, 2009; Perkins-Gough, 2013).

Interestingly, the present results reveal that the BSI (a performance index indicating the relative weight of proactive/reactive cognitive control) was the most predictive executive index of grit. Thus, high grit individuals exhibited a less proactive control mode than low grit participants (the former made fewer errors on the AY condition relative to the BX condition), which suggests that they may be less attached to initial contextual cues so that they wait until all relevant information is gathered before coming up with a response. It is worth mentioning that this performance profile on an executive experimental task fits well with the less impulsivity profile (as measured by self-reports) which has also been shown to characterize gritty people (i.e., Moshier et al., 2016; the present study). Our findings are also in line with results by Kalia et al. (2018) showing a) that grit is not linked to differences in executive control and b) a negative association between grit and the alerting effect, whereby high grit participants benefited less from the presence of a contextual alerting cue. We posit that both findings may be indicating that gritty individuals, relative to those scoring low on grit, rely less on contextual information when dealing with a complex task. This could help them to achieve long-term superordinate goals, even though it would not be particularly beneficial for immediate performance.

As for the positive association between mindfulness and grit, our results replicate finding by others with different ethnical groups from the United States, New Zealand, and Thailand (Brennan et al., 2018; Raphiphatthana et al., 2019; Vela et al., 2018). Interestingly, at the facet level, our Spanish sample was similar to the New Zealand's sample in the study by Raphiphatthana et al., (2019), so that the two facets of grit were positively related to the acting with awareness facet and the perseverance of effort facet of grit was specifically related to the non-judging facet of mindfulness (for a deep discussion on the role of grit and mindfulness in western and eastern countries see Raphiphatthana et al., 2019). Hence, altogether our results fit with the idea that gritty people focus on the present moment without judging their inner experience and do not perform swift actions without being conscious of doing so. This scenario may also converge with the idea that gritty individuals do not drive their behaviour by initial contextual cues but they keep attentive until all information is available.

The present study is not without limitations. Its exploratory and cross-sectional nature makes it necessary to be cautious regarding the observed associations. Future research with longitudinal and/or intervention-based approaches could help in further specifying the nature of the link between trait-executive functioning profiles and grit. Despite this, the present study contributes to our understanding of grit and provides strong evidence for the idea that it is not necessarily linked to enhanced executive-control capabilities (Duckworth et al., 2007; Duckworth & Quinn, 2009; Perkins-Gough, 2013). Rather, high grit seems to entail a different (less proactive) cognitive control mode.

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CHAPTER VIII. Electrophysiological Prints of Grit

Study 4[4]

While scientific interest in understanding the grit trait has grown exponentially in recent years, one important gap in the grit literature relates to its biological and neural substrate. In the present study, we adopted a hypotheses-driven approach in a large sample of young adults (N = 120) with diverse educational backgrounds and work experiences in order to investigate the electrophysiological correlates of grit both during rest and while performing a learning task. Additionally, we selected a measure of impulsiveness to better understand the neural similarities and differences between grit and related self-control constructs. Based on previous work that implicated the prefrontal cortex in grit, we hypothesized that high grit participants would have lower frontal theta/beta ratio (a broadly used index that reflects prefrontally-mediated top-down processes, which might indicate better control over subcortical information). Furthermore, we expected the perseverance of effort facet of grit to be linked to higher complexity during task engagement because previous research has shown complexity indexes (entropy and fractal dimension) to be linked to effort while performing cognitive tasks. Our results revealed that although there were no differences at rest as a function of grit, the participants with high grit and high consistency of interest scores exhibited lower frontal theta/beta ratios during the learning task. This pattern suggests that individual differences in grit might be more evident when top-down control processes are at work. Furthermore, there was a positive association between perseverance of effort and entropy at task, which might indicate more effort and engagement in the task. Finally, when controlling for impulsiveness and demographic variables (gender, age, education, and work experience) the effects at the facet level remained statistically significant. While there is still a long way to fully understand the neural mechanisms of grit, the present work constitutes a step toward unveiling the electrophysiological prints of grit.

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Introduction

In a world in which new information emerges every second, sticking with one dream can be challenging. Indeed, not everybody chooses to strive toward a long-term goal and even fewer people maintain their motivation until they have achieved it. Grit is the personality trait that defines those people that do tend to pursue long-term goals with enduring passion and perseverance (Duckworth & Gross, 2014). This newly explored trait has attracted the attention of researchers from different fields (i.e., positive psychology, motivation, and education), given that it has been shown to be able to predict success in various domains and contexts, such as academic (i.e., Clark & Clark, 2019; Duckworth et al., 2007), work achievement (i.e., Mueller et al., 2017), and personal life (i.e., Eskreis-Winkler et al., 2014). More importantly, grit has been shown to be related to different aspects of well-being (i.e., general well-being: Duckworth et al., 2007; Kannangara et al., 2018; Jiang et al., 2020; Kindt et al., 2009; life satisfaction: Li et al., 2018; lower depression: Datu et al., 2019; Musumari et al., 2018; reduction of risk of suicidal ideation: Kaniuka et al., 2020; White et al., 2017). While interest in grit has grown exponentially over the past few years, the neural processes underlying this trait still remain largely understudied.

Grit is conceptualized as comprising two factors (Duckworth & Quinn, 2009): perseverance of effort and consistency of interest. The first factor, perseverance of effort, highlights the long-term stamina or the effort maintained toward one's superordinate goal, whereas the consistency of interest factor taps into the passion for one's goal and the ability to stay committed to interests related to it. Hence, grit is related to both self-control and motivation (Nemmi et al., 2016). The effortful regulation of attention, emotion, and behavior would allow self-controlled individuals to overcome temptations in comparison to their impulsive counterparts (Duckworth, 2011). This ability would help these individuals to achieve long-term goals as well. Interestingly, evidence indicates that self-control and grit correlate moderately ($r = 0.63$; see Duckworth et al., 2007), which suggests that there must be something else besides self-control in the consecution of long-term goals (Duckworth & Gross, 2014; Eskreis-Winkler et al., 2014; Li et al., 2018; Tedesqui & Young, 2018). On the other hand, motivation is thought to contribute to how people behave, think, and feel. Individual differences in motivation reflect the degree of endurance in people's needs, desires and values (Borghans et al., 2008) and, therefore, a certain pattern of motivation would be behind grit. In fact, there is evidence that grit is positively linked to orientation towards engagement and inversely associated with pursuing pleasure in Western samples (Von Culin et al., 2014; see also: Muenks, 2018). In accordance with this conceptualization, the few studies that have already examined the neural basis of grit converge in showing that grit is mainly associated with the function and structure of the prefrontal cortex (PFC) and striatum, which are the key regions for executive control (self-control) and reward (motivation) processes (Myers et al., 2016; Nemmi et al., 2016; Wang et al., 2017; 2018).

For example, Nemmi et al. (2016) examined brain structure as a function of grit in 27 children and found that individual differences in the trait were associated with differences in the volume of the nucleus accumbens, which has been related to reward-seeking (Tobler et al., 2014). In a resting-state functional magnetic resonance imaging (fMRI) study with 20 children, Myers et al. (2016) found grit to be associated with ventral striatal and bilateral prefrontal networks. The ventral striatum was specifically connected to medial prefrontal and rostral anterior cingulate cortices. Importantly, all these regions are thought to be crucial for cognitive-behavioral control, perseverance, and emotional regulation. More recently, Wang et al. (2017) tested resting-state fMRI in 217 healthy adolescents and found a negative relationship between grit and the regional fractional amplitude of low-frequency fluctuations in the right dorsomedial PFC, which is thought to be involved in self-regulation. Furthermore, this association played a mediating role in the link between grit and academic performance. In a related structural MRI study—also with adolescents—, Wang et al. (2018) found greater volume in the right putamen and smaller volume in the left dorsolateral PFC, both regions involved in action planning, motivation, and self-regulation, in gritty participants.

Some other attempts have been made to examine the neural basis of grit by using electroencephalography (EEG). In this regard, Kalia et al., (2018) recorded event-related potentials while participants (undergraduate students) performed the attentional network task (ANT; Fan et al., 2002). Kalia et al. (2018) found that people with higher scores in the perseverance of effort facet of grit were linked to reduced electrophysiological responses (N1) to an alerting cue relative to people with lower scores. According to the authors, this attenuated alerting effect for grittier individuals might be a sign of their more efficient sustained attention due to their stronger intrinsic motivation to perform well. Thus, alerting cues were less effective as a warning signal, since they were already more attentive to the task. More recently, Matthews et al. (2019) included a measure of grit in a study examining the role of worry and resilience in the performance of 68 undergraduate students in a Unmanned Aerial simulation System including different stress-inducing conditions and physiological measures. Although no EEG results were reported regarding the control condition, in the high stress condition there was an association between (high) grit and (lower) gamma activity that the authors interpreted as indicating that grittier individual might also show better stress coping abilities.

While these results are compelling, a number of factors limit the conclusions that can be drawn from them. First, some of the studies employed very small sample sizes. Second, MRI studies primarily focused on the brain state at rest, although it is also possible that differences occur when gritty people engage in a task due to differential information processing. Third, these studies focused only on grit-related traits, leaving out other self-control traits that could provide information regarding the neural similarities and differences between these constructs. Fourth, all studies focused on children, adolescents or grad students with similar life backgrounds, thus limiting the generalizability of their findings. Finally, most studies have used a single brain dimension, although some authors have pointed out that it is necessary to approach the topic using different brain measures (van Zyl et al., 2021). Hence, more studies that use more heterogeneous and larger samples and that employ distinct brain measures in different conditions are required in order to better understand the grit trait.

In addition, it is relevant to examine how different self-control constructs relate to grit by tapping into their commonalities and differences at the neural level. This point is of particular importance because one major concern about the grit construct has been its dissociation from other concepts related to self-control (Muenks et al., 2017; Schmidt et al., 2018; Vazsonyi et al., 2019; Werner et al., 2019). A key self-control related concept that is thought to be closely related to grit (specifically to its consistency of interest facet) is impulsiveness (Schmidt et al., 2018). Impulsiveness is defined as the tendency to perform swift actions without conscious judgment (Patton et al., 1995) and provides an interesting scenario to study the relation between grit and other self-control measures. Impulsiveness is considered to be the opposite of self-control (Duckworth, 2011), but it does not include items related to sensation seeking

(Stanford et al., 2009) that are often included in self-control scales and that have been demonstrated to have a distinct nature from impulsiveness or grit (Duckworth & Kern, 2011). Although impulsiveness is conceptually related to the absence of grit, grit is theoretically thought as more complex than just a low impulsiveness pattern (Duckworth & Gross, 2014). In fact, it has been shown that the two constructs are negatively correlated (Grif et al., 2016). However, this relationship is not very strong and the extent to which grit differentiates from impulsiveness is still unknown. Importantly, on some occasions impulsiveness has been shown to predict academic performance beyond grit (Rennicks, 2018). Hence, in the present study we considered impulsiveness when examining the neural underpinnings of grit in order to deal with potential confounding effects.

Furthermore, as stated, it is also convenient to employ heterogeneous samples and take into account the demographic background of the participants when examining the neural bases of grit. This point is of importance because one concern about the existing literature on the neural substrates of grit is the similar and homogeneous samples that the few studies on the topic included, which limits the generalizability of their findings (van Zyl et al., 2021). For this reason, we selected participants of different educational and work background, two variables that have been closely (positive) related to grit (Duckworth et al., 2007; Mueller et al., 2017), and considered these variables when examining the neural underpinnings of grit.

Finally, to gain further understanding of the neural processes underlying grit, a hypotheses-driven approach should be adopted because it allows researchers to conceptually replicate previous findings. In this vein, electroencephalography (EEG) constitutes an adequate technique that provides high temporal resolution and distinct indexes of brain activity, allowing for the formulation of specific hypotheses. Hence, because grit has a strong self-regulation component and because its expression has been linked to activity in the PFC, we focused on a widely used executive control index: the frontal theta/beta ratio (TBR) (Angelidiset al., 2016; Nasser et al., 2019; Putman et al., 2010, 2014). TBR is thought to reflect prefrontally-mediated attentional control and has broadly been used as a biomarker for impulsiveness-related disorders, such as the attention-deficit hyperactivity disorder (Arns et al., 2013; Barry et al., 2003; Lansbergen et al., 2011; Snyder & Hall, 2006; Zhang et al., 2017). High frontal TBR is usually interpreted as failure in exerting top-down control over the automatic processing of subcortical information. Based on previous work that implicated PFC and striatum structures in grit, we hypothesized that high grit participants would have lower frontal TBR, which might reflect better control (top-down processes) over subcortical information (reward information of the striatum). In addition, we aimed to explore whether 1) impulsiveness mediated the possible effect between TBR and grit, and 2) it had a particular TBR pattern dissociable from grit. In the same vein, we also wanted to explore whether the demographic variables of our heterogeneous sample (gender, age, education and work experience) could partially explain the possible association between TBR and grit.

Complementarily, we included a complexity-based approach to the analysis of EEG recordings by tapping into entropy (SampEn) and fractal dimension (HDF) brain indexes. These indexes, based on non-linear assumptions from system theories, are increasingly being recognized as valuable tools for capturing complex brain signals (Costa et al., 2002, 2005; Ouyang et al., 2010). While extreme patterns of complexity at rest can be indicative of pathology (Ibáñez-Molina et al., 2018), complexity indexes have been linked to effort while performing cognitive tasks (Müller et al., 2003; Sohn et al., 2010; Stam, 2005). Given the relationship between perseverance of effort and task values, self-efficacy, and general effort (Muenks et al., 2017; Zamarro et al., 2020), it is plausible to hypothesize that high grit participants (high perseverance of effort participants in particular) might show higher brain complexity levels during task performance as an indicator of task engagement (Müller et al., 2003; Sohn et al., 2010; Stam, 2005). Again, as with TBR, we explored whether impulsiveness and demographic variables affect the relationship between perseverance of effort and complexity indexes.

In sum, in the present study, we adopted a hypotheses-driven approach on a large sample of young adults with diverse educational backgrounds and work experiences in order to investigate the electrophysiological prints of grit.

Participants completed the Grit Scale (Duckworth et al., 2007) and underwent EEG recordings at rest and while performing a learning task. Additionally, we selected a measure of impulsiveness to better understand the neural similarities and differences between grit and related self-control constructs. As mentioned, we hypothesized that high grit participants would exhibit lower frontal TBRs (both at rest and while performing a learning task), which might reflect more efficient top-down control over reward processes in comparison to their low grit counterparts. In addition, we expected that participants characterized by high levels of effort on the Grit Scale would also be characterized by greater complexity as an indicator of task engagement (Müller et al., 2003; Sohn et al., 2010; Stam, 2005). Finally, we explored whether impulsiveness and some demographic variables were modulating the effects between grit and the brain.

Method

Participants

A total of 120 people (Mage = 23.11, SDage = 4.19, Range = 18–33, 69% female) completed the study in exchange for course credits (0.1 credit / 40 min) or monetary reward (7 € / 1 h). Participants differed in educational levels and job backgrounds. In terms of education, 17 participants had only attended secondary school, 58 were enrolled in university courses (toward a variety of degrees), and 45 had already completed a university degree. Of these graduates, 22 were enrolled in master's courses during the time of their participation in the study. With respect to work experience, 54 participants reported that they did not have any professional experience in any field, whereas 66 participants noted that they did have professional experience (i.e., as waiters, researchers, dancers, doctors, etc.). All participants included in the experiment informed in a written health questionnaire to be free from any health issue, neurological problem, drug consumption or cognitive dysfunction diagnosis. The sample was a part of a larger study that focused on individual differences and other non-overlapping findings resulting from that study have already been reported (Aguerre et al., 2020). Participants provided their written informed consent in order to participate in the study, following the Helsinki Declaration guidelines (World Medical Association, 2013), and approval was obtained from the Ethics Committee of the University of Granada.

Materials and Procedure

Participants were tested individually in two sessions that lasted 90 and 120 min, respectively. In the first session, they were administered four questionnaires: a translated version of the Grit Scale (Duckworth & Quinn, 2009), the Spanish versions of the Barratt Impulsiveness Scale (BISS-11; Oquendo et al., 2001) and the Five Facets Mindfulness Questionnaire (Cebolla et al., 2012), as well as the Mindful Attention Awareness Scale (Soler et al., 2012). They also underwent four experimental tasks: the Cued Task-Switching Paradigm (Chevalier et al., 2015), a Stroop-like Conflict Task (Roelofs et al., 2006), the Operation Span (Turner & Engle, 1989), and the AX-Continuous Performance Task (Braver et al., 2009). The second session included MRI and

EEG recordings at rest (five minutes with eyes closed) and two experimental tasks: Stop Signal (Verbruggen & Logan, 2008) and a learning task (Anderson et al., 1994), with the latter including simultaneous EEG recordings. For the present paper, we selected the grit and impulsiveness measures as well as the EEG recordings (at rest and at task). The remaining measures are to be included in a forthcoming paper addressing related but non-overlapping research questions.

Grit. We translated the original Short Grit Scale into Spanish applying a back-translation method. The scale is an 8-item self-reported questionnaire that assesses two grit factors: perseverance of effort (i.e., "I am diligent") and consistency of interest (i.e., "My interests change from year to year"). Cronbach's α of the factors of the English version is in the 0.60–0.79 range (Duckworth & Quinn, 2009). Importantly, in our sample the Cronbach's α is 0.63 for the perseverance of effort and 0.83 for the consistency of interest facets of grit.

BISS-11. This is a 30-item questionnaire that consists of three impulsiveness factors: cognitive impulsiveness (i.e., "I am happy-go-lucky"), motor impulsiveness (i.e., "I do things without thinking"), and non-planned impulsiveness (i.e., "I plan tasks carefully"). The Cronbach's α of the factors in this questionnaire is 0.83 (Oquendo, 2001).

Learning Task. We used an adaptation of the original selective retrieval practice task by Anderson, Bjork and Bjork, (1994) (see Valle, Gómez-Ariza and Bajo, 2019) that is usually employed to investigate retrieval-induced forgetting. In this task, participants were instructed to memorize a list of words for an upcoming memory test. The task comprises 4 phases: study, practice, distraction and probe phases. In the study phase participants were instructed to memorize a list of category-exemplar pairs (fifty-four Spanish words of nine different orthography-based categories were used; i.e., CA-Camera, CA-Casino, BA-Banana). Next, in the practice phase, they were asked to selectively retrieve half of the items of half of the categories by a given cue (i.e., CA-Cam). Then a distractor task was presented, wherein participants had to solve operational problems. In the probe phase, a recognition test was administered for all the studied items and non-studied words of different and same category. For the present work, we used the EEG signal recorded during the learning phase (5 min.). Final performance in the task was examined from the recognition index (d') for control-baseline items (unpracticed items of unpracticed categories). Given the purpose of the present work, we focused on control-baseline items to examine overall memory performance after study rather than possible retrieval practice effects.

EEG Recording and Preprocessing. Participants were quietly seated with their eyes closed and the light off during the five-minute resting state EEG recording. On the other hand, to obtain the five minutes of the task EEG measure, we chose the first five minutes of the selective retrieval task. The selected recordings corresponded to the first five minutes of the task during which participants were quietly seated with their eyes open, memorizing the category-word pairs. The EEG was recorded using 64 scalp electrodes that were mounted on an elastic cap using an extended 10–20 system. The continuous activity was recorded using Neuroscan Synamps2 amplifiers (El Paso, TX) and was first recorded using a midline electrode (halfway between Cz and CPz) as reference. Before data analyses, a high-pass filter at 1 Hz was applied and the 5-minute recording was segmented into 2-second epochs with 0.5 seconds of overlap. Artifacts were manually removed by carefully inspecting the data using the Fieldtrip toolbox73 on Matlab (Oostenveld et al., 2011). Bad channels, with a high level of artifacts (always below 10% of the total for each participant), were visually detected and interpolated from neighboring electrodes.

Q-EEG Analyses. EEG data were analyzed using the procedures described in Prat et al. (2016). The mean log power spectrum—between 4 and 40 Hz—was calculated by first computing each epoch's power spectrum using the Fast Fourier Transform, followed by log-transforming it, and then by averaging the resulting power spectra across all epochs. To reduce spectral leakage, a Hanning window was applied to each epoch before computing the corresponding Fourier transform. The mean log power was then separately calculated across theta (4–7.5 Hz), alpha (8–12.5 Hz), beta (13–29.5 Hz), and low-gamma (30–40 Hz) frequency bands for each channel and in each participant. The frontal region of interest (ROI) was selected following Berkovich-Ohana et al. (2012): frontal (AF3, F5, F3, F1, FC3, FC1, AF4, F2, F4, F6, FC2, FC4). The theta/beta ratio was calculated for each participant by dividing the absolute theta power in the frontal cluster by the absolute beta power in the same cluster.

Complexity Analyses. The preprocessed EEG series were used as inputs for the Sample Entropy (SampEn) and Higuchi's Fractal Dimension (HFD) analyses. To avoid effects of change in the stability of the signal, these measures were estimated using a sliding window procedure that was 2 seconds in length and had a 90% overlap in each time step. The estimations were obtained from the median of the resulting complexity series for each participant, electrode, and experimental condition. SampEn represents the measure of pattern randomness in the signal. The SamplEn algorithm considers the amount of dispersion after a given time lapse between a set of closely related points in the signal. High values of SampEn are then related to time series with random structures (see seminal works of Pincus & Goldberger, 1994; Richman & Moorman, 2000). The estimation of SampEn is needed to set two free parameters (m, p). In our study, these were selected in accordance with the study by Richman and Moorman (2000), which recommended values of m = 2 and p = 0.10 times the SD of the series. On the other hand, the fractal dimension was estimated using the HFD algorithm (Higuchi, 1988). FD can be considered a measure of the roughness or density of the signal as depicted in a microvolt-time plot. Simple signals resembling a straight line would have a FD close to 1, while signals that tend to fill the entire space would have a FD scoring around 2. The HFD estimator of the FD takes into account the length of the signal (L) at several scales (k). The slope of the regression model for both log transformed variables (ln[k] vs ln[L]) represents the estimated FD (i.e. Ibáñez-Molina & Iglesias-Parro, 2014). Hence, the expected values for HFD are around 1.5 because 1 constitutes the minimum (values forming a straight line) and 2 a maximum (values randomly distributed as a random cloud of points) (for a review see: Kesić & Spasić, 2016). It should be noted that HFD has successfully been applied to analyses of EEG signals in both clinical and non-clinical contexts (Kesić & Spasić, 2016; Ruiz-Padial & Ibáñez-Molina, 2018). In this experiment, we selected a kmax of 55 as an optimal parameter, given that the HFD estimation approximately reached an asymptotic value for all conditions and electrodes.

Results

Data of two participants were removed from the analyses due to artifacts during EEG recordings, while nine participants missed relevant information on the BISS questionnaire. Previous to the main analyses, we ran Shapiro-Wilk tests that confirmed that our independent variables (Grit and BISS) were normally distributed. The basic descriptive statistics are presented in Table 1. We report the results in different sections according to the goals of the study. Thus, in the first section, we report analyses testing our hypothesis about the neural correlates of grit with separate regression models in which we included the brain indexes (frontal TBR, entropy, and FD) at rest and at task as dependent variables and grit and its facets as independent variables. In the second section, we examined the relation between grit and impulsiveness in different ways. First, we report the correlation between grit and impulsiveness and tested the possible overlap between the two traits by testing hierarchical regression models. Further, we report mediation analyses to explore whether the main relationships between grit and the neural indexes were mediated by impulsiveness. Finally, we report regression models including the brain indexes (frontal TBR, entropy, and FD) at rest and at task as dependent variables and impulsiveness as the independent variable to look into the neural pattern associated with this trait and its potential similarities with grit. In the third section, we tested whether the different demographic conditions differed in grit scores. Additionally, to further explore their effects on the relationships between grit and the neural indexes, we conducted hierarchical regression analyses with the same structure than before (frontal TBR, entropy, and FD at rest and at task as the dependent variables and grit and its facets as the independent variables) but now controlling for impulsiveness, gender, age, education and work experience. For completeness, in the last section we report correlations between the main variables and performance in the learning task.

Table 3. Descriptive statistics for the main variables. The first column refers to means and standard deviations (SD)

	Score	Minimum	Maximum
Grit	3.35 (0.71)	1.75	4.87
PE	14.4 (2.88)	7	20
CI	12.47 (3.7)	4	20
BISS	46.41 (13.74)	18	85
Rest			
Global q-EEG at Rest	2.17 (0.31)	1.49	2.98
Theta q-EEG at Rest	2.55 (0.32)	1.8	3.53
Beta q-EEG at Rest	2.26 (0.34)	1.52	3.06
Entropy at Rest	2.11 (0.04)	1.97	2.17
Fractal Dimension at Rest	1.69 (0.08)	1.25	1.84
Task			
Global q-EEG at Task	2.05 (0.25)	1.41	2.69
Theta q-EEG at Task	2.55 (0.23)	1.82	3.16
Beta q-EEG at Task	2.09 (0.28)	1.39	2.79
Entropy at Task	2.07 (0.05)	1.90	2.16
Fractal Dimension at Task	1.68 (0.06)	1.48	1.88
Recognition (d') in the	1.81 (0.62)	-0.36	3

Electrophysiological prints of Grit

To test our hypotheses that high grit scores were related to lower frontal TBR at rest and at task and that the perseverance of effort facet of grit would be related with higher complexity during task, we first ran linear regression analyses over the different neural indices (frontal TBR, entropy, and FD) at rest and at task with grit and its facets as predictors (see Table 2). The analyses showed a negative association between frontal TBR and overall grit score and consistency of interest (facet of grit) while performing the task. On the other hand, the analyses of complexity measures revealed a reliable (positive) association between entropy and perseverance of effort while performing the learning task. These associations were not evident at rest. Figure 1 plots the association between grit and lower frontal TBR at task.

Table 2. Linear regression analyses of grit and its two factors over neural indices (frontal TBR, entropy, and FD) during rest and during the task

	R^2	*ΔF*	*B*	*SE*	*β*	*p*
Grit						
F TBR Rest	0.00	0.05	0.11	0.48	0.02	0.82
Entropy Rest	0.00	0.02	-0.78	1.72	-0.04	0.65
FD Rest	0.00	0.00	0.01	0.79	0.00	0.99
F TBR Task	0.04	4.67	-0.85	0.39	-0.19	0.03
Entropy Task	0.02	2.81	2.4	1.43	0.15	0.09
FD Task	0.01	1.1	1.16	1.1	0.1	0.29
PE of Grit						
F TBR Rest	0.00	0.17	0.81	1.96	0.04	0.68
Entropy Rest	0.01	1.33	-8.08	7.01	-0.11	0.25
FD Rest	0.01	1.03	-3.22	3.17	-0.09	0.31
F TBR Task	0.00	0.58	-1.23	1.62	-0.07	0.45
Entropy Task	0.04	5.11	12.96	5.73	0.21	0.026
FD Task	0.01	1.03	4.55	4.48	0.09	0.31
CI of Grit						
F TBR Rest	0.00	0.00	-0.14	-2.53	-0.01	0.96
Entropy Rest	0.00	0.01	0.99	9.08	0.01	0.91
FD Rest	0.01	0.69	3.41	4.09	0.08	0.41
F TBR Task	0.06	7.13	-5.42	2.03	-0.24	0.009
Entropy Task	0.01	0.69	6.25	7.53	0.08	0.41
FD Task	0.00	0.49	4.05	5.78	0.07	0.48

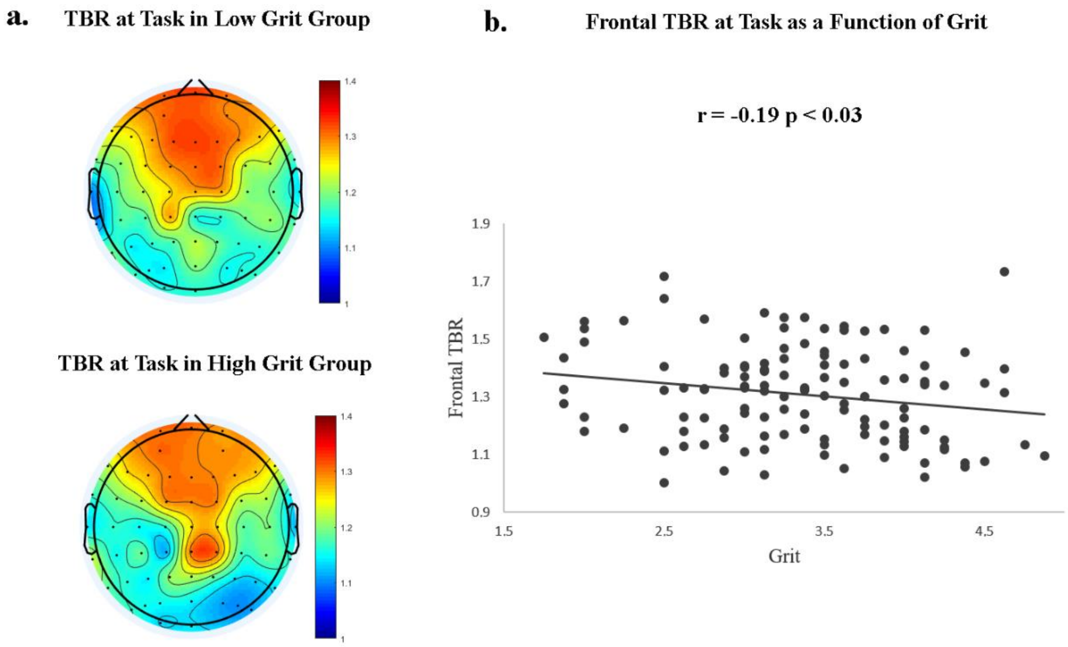

Figure 1. Topographical distribution of the TBR index during task performance as function of the grit group, calculated as 1 SD from the mean (a), and frontal TBR as a function of grit continuous scores (b).

Grit and impulsiveness

As expected, there was a negative correlation between impulsiveness and grit (r = -0.70, p < 0.001; see also Table 7). We examined whether the associations between brain indexes and grit were influenced by impulsiveness, by performing hierarchical regression analyses for the different neural indices (frontal TBR, entropy, and FD) at rest and at task with grit and its facets as predictors and controlling for impulsiveness (see Table 3). These analyses indicated that both the negative relation between frontal TBR at task and consistency of interest and the positive association between entropy at task and perseverance of effort were still statistically significant. In contrast, the association between frontal TBR at task and global grit score did not reach significance after controlling for impulsiveness. Additionally, we performed a mediation analysis to also examine whether the association between grit and the brain indexes was mediated by impulsiveness. These analyses indicated that impulsiveness was not a mediating factor (see Table 4). Finally, the regression model over the neural indexes with impulsiveness as the predictor failed to show any significant relationship (see Table 5).

Table 3 Hierarchical regression analyses of grit and its two factors over neural indices (frontal TBR, entropy, and FD) during rest and during the task controlling for impulsiveness

	R^2	ΔF	B	SE	β	p
Grit						
F TBR Rest	0.00	0.01	0.00	0.02	0.01	0.9
Entropy Rest	0.00	0.49	-0.00	0.00	-0.07	0.49
FD Rest	0.00	0.00	0.00	0.01	0.01	0.95
F TBR Task	0.03	3.39	-0.04	0.02	-0.17	0.07
Entropy Task	0.01	1.28	0.01	0.01	0.11	0.26
FD Task	0.01	1.57	0.01	0.01	0.12	0.21
PE of Grit						
F TBR Rest	0.00	0.6	0.00	0.00	0.02	0.8
Entropy Rest	0.01	1.57	-0.00	0.00	-0.1	0.29
FD Rest	0.01	0.89	-0.00	0.00	-0.9	0.35
F TBR Task	0.00	0.31	-0.00	0.00	-0.05	0.58
Entropy Task	0.04	4.62	0.00	0.00	0.2	0.03
FD Task	0.02	2.17	0.00	0.00	0.14	0.14
CI of Grit						
F TBR Rest	0.00	0.96	0.00	0.00	-0.00	0.96
Entropy Rest	0.00	0.06	0.00	0.00	-0.02	0.81
FD Rest	0.01	0.66	0.00	0.00	0.08	0.42
F TBR Task	0.05	5.9	-0.01	0.00	-0.23	0.02
Entropy Task	0.00	0.01	0.00	0.00	0.01	0.9
FD Task	0.01	0.42	0.00	0.00	0.08	0.42

Table 4. Mediation analyses of consistency of interest and frontal TBR at task with impulsiveness as a mediator; and perseverance of effort and entropy at task with impulsiveness as a mediator

CI of Grit	Estimate	SE	z-value	*P*
Direct effects				
Consistency of Interest → Task_F_TBR	-0.01	0.00	-2.52	0.01
Indirect effects				
Consistency of Interest → BIS → Task_F_TBR	0.00	0.0	0.82	0.41
Total effects				
Consistency of Interest → Task_F_TBR	-0.01	0.00	-2.69	0.01
PE of Grit				
Direct effects				
Perseverance of Effort → EN_Task	0.00	0.00	2.27	0.02
Indirect effects				
Perseverance of Effort → BIS → EN_Task	-6.13e -4	9.54e -4	-0.64	0.52
Total effects				
Perseverance of Effort → EN_Task	0.00	0.00	2.28	0.02

Table 5. Linear regression analyses of impulsiveness (BISS) over neural indices (frontal TBR, entropy, and FD) during rest and during the task

	R^2	ΔF	*B*	*SE*	β	*p*
BISS						
F TBR Rest	0.00	0.00	0.00	0.00	0.03	0.75
Entropy Rest	0.02	.02	0.00	0.00	0.14	0.15
FD Rest	0.02	2.35	-0.00	0.00	-0.15	0.13
F TBR Task	0.01	1.06	0.00	0.00	0.1	0.30
Entropy Task	0.00	0.3	0.00	0.00	-0.05	0.58
FD Task	0.00	0.46	0.00	0.00	-0.07	0.50

Grit and demographics

Because grit has been previously related to demographic variables such as education (Duckworth et al., 2007) and work experience (Mueller et al., 2017) among others, we examined first whether such variables were linked to grit scores, and then if they could be driving the relation between grit and the neural indexes. To answer this question, we performed Pearson correlations between age and education and grit, and then t-tests comparing men (N = 37) and women (N = 81) and people with work experience (N = 66) and without (N = 54) in their grit scores, after checking that grit was normally distributed in all groups. Results showed no association of grit with age (r = 0.14, p = 0.12), education (r = -0.01, p = 0.94), or gender (t (106.66) = -0.9, p = 0.56; M_{Males} = 3.16; M_{Females} = 3.51). However, people with work experience showed higher grit scores than people without work experience (t (106.66) = 2.68, p = 0.01; $M_{\text{Experience}}$ = 3.51; $M_{\text{Non-experience}}$ = 3.16). Next, we ran separate hierarchical regression analyses over the different neural indices (frontal TBR, entropy, and FD) at rest and at task with grit and its facets as predictors, now controlling for impulsiveness, gender, age and education and work experience (see Table 6). The results of these analyses showed that the negative relation between frontal TBR at task and consistency of interest and the positive association between entropy at task and perseverance of effort remained reliable.

Table 6. Hierarchical regression analyses of grit and its two factors over neural indices (frontal TBR, entropy, and FD) during rest and during the task controlling for impulsiveness, gender, age, education and work experience

	R^2	ΔF	B	SE	β	p
Grit						
F TBR Rest	0.00	0.08	0.00	0.02	0.03	0.78
Entropy Rest	0.00	0.34	-0.00	0.00	-0.06	0.56
FD Rest	0.00	0.01	0.00	-0.00	0.00	0.98
F TBR Task	0.04	3.67	-0.03	0.02	-0.14	0.15
Entropy Task	0.01	1.44	0.01	0.01	0.12	0.23
FD Task	0.02	1.64	0.01	0.01	0.12	0.2
PE of Grit						
F TBR Rest	0.00	0.42	0.00	0.00	0.06	0.52
Entropy Rest	0.01	0.96	-0.00	0.00	0.09	0.33
FD Rest	0.00	1.08	-0.00	0.00	-0.1	0.3
F TBR Task	0.00	0.00	0.00	0.01	0.02	0.98
Entropy Task	0.05	5.48	0.00	0.00	0.22	0.02
FD Task	0.02	2.13	0.00	0.00	0.14	0.15
CI of Grit						
F TBR Rest	0.00	0.00	0.00	0.00	0.00	0.97
Entropy Rest	0.00	0.02	0.00	0.00	0.01	0.9
FD Rest	0.00	0.58	0.00	0.00	0.07	0.45
F TBR Task	0.05	6.32	-0.01	0.00	-0.23	0.01
Entropy Task	0.01	0.67	0.00	0.00	0.08	0.42
FD Task	0.00	0.58	0.00	0.00	0.07	0.45

Task performance

Finally, we performed Pearson correlation analyses between the neural indexes (TBR, entropy, FD) at task and memory performance (an index of sensitivity at recognition: *d'*) in the baseline condition of the selective retrieval task. These correlations did not reach statistical significance (see Table 7). We also correlated personality traits (grit and its facets, and impulsiveness) with performance, but these correlations also failed to reach statistical significance (see Table 2).

Table 7. Pearson correlations of the main brain variables, the Grit and BISS scores and performance in the task.

	Grit	PE	CI	BISS	Recognition
BISS	-0.7***	-0.51***	-0.67***		
Recognition (d') in the final stage of the selective retrieval task	0.05	-0.07	0.12	-0.17	
Rest Frontal TBR	0.02	0.04	-0.00	-0.04	0.01
Task Frontal TBR	-0.19*	-0.07	-0.24**	0.08	-0.04
Entropy at Rest	-0.04	-0.11	0.01	0.12	-0.09
Entropy at Task	0.15	0.21*	0.08	-0.06	-0.13
Fract. Dim. at Rest	-0.00	-0.09	0.08	-0.17	-0.07
Fract. Dim. at Task	0.1	0.09	0.06	-0.07	-0.05

* $p < 0.05$ **$p < 0.01$, *** $p < 0.001$. Asterisks represent statistically significant correlations after controlling for multiple comparisons with the Banjamini-Hochberg method with false discovery rate at 0.25 (Benjamini & Hochberg, 1995).

Discussion

In the present study, we aimed to explore the electrophysiological prints of grit during rest and while performing a learning task. One important gap in the grit literature relates to its biological and neural substrates as only a few studies have been carried out to determine its neural mechanisms. Interestingly, despite the fact that there is little research in this area, the results converge to implicate the PFC and striatum, regions systematically associated with executive-control and motivation processes, in the expression of grit. Considering these precedents, we selected an EEG index of executive control—the frontal theta/beta ratio (TBR)—to examine its potential relationship with grit at rest and while engaged in a (learning) task. Furthermore, we selected two complexity indexes—entropy (SampEn) and fractal dimension (HDF)—to explore the possible increase in the dimensional complexity of brain activity during task performance as a function of effort employed by gritty participants. Finally, we also looked into the association between the above-mentioned EEG indexes and impulsiveness in order to determine the similarities and differences of the neural activity underlying grit and impulsiveness. Our results revealed that while there were no differences at rest as a function of grit, neural differences emerged while participants were engaged in the task. Higher overall grit and higher scores in the consistency of interest facet of grit were associated with lower frontal TBRs during the learning task. In addition, we observed an association between perseverance of effort and entropy at task, indicating that the higher the facet of grit scores are, the higher the complexity of the EEG recording is. Importantly, impulsiveness (as measured via the BISS) did not mediate any of the previous associations neither it was found to correlate with any of the neural indexes at rest or while performing the task. Finally, controlling for impulsiveness and demographic factors (age, gender, education and work experience) reduced the associations with overall grit scores that, however, remained statistically significant at the facet level, which highlights the relevance of these facets of grit as predictors.

The link between frontal TBR and grit during task performance is in line with results from previous studies, supporting the implication of prefrontally-mediated executive control in the grit trait (Myers et al., 2016; Wang et al., 2017, 2018). However, it is remarkable that such an association was not present at rest in our sample. TBR is an EEG index of executive control that is widely used (Angelidis et al., 2016; Arns et al., 2013; Nasser et al., 2019). The ratio of theta band power (4–8 Hz) and beta band power (15–30 Hz) is thought to reflect cortical-subcortical interactions (Arns et al., 2013; Schutter & Van Honk, 2005), so that increased frontal TBR might result from a greater need for top-down control over subcortical structures (i.e., due to the triggering of inappropriate automatic responses). A large body of research suggests that mid-frontally generated theta activity is linked to activity in the anterior cingulate cortex (ACC) (i.e., Asada et al., 1999; Scheeringa et al., 2008), which is associated with more difficult situations or when reward is less than expected (Schutte et al., 2017). On the other hand, beta oscillatory activity seems to reflect active inhibitory processes involved in maintaining the current cognitive state (Engel & Fries, 2010) and is thought to be in charge of transmitting “fast-motivational signals” to downstream brain structures (Marco-Pallarés et al., 2015). Because this view aligns with the long-term-maintained motivation of gritty people, TBR could be thought of as a marker of prefrontally-mediated executive control over reward processes that are essential to grit. Such a relationship would be similar to the one reported with other subcortical processes (i.e., emotional processing, see Putman et al., 2014), although we recognize that future studies (i.e., by analyzing ERPs that are sensitive to individual differences in executive control) should more precisely determine to what extent this interpretation of the association between TBR and grit is appropriate. Interestingly, it was the consistency of interest facet of grit that was related to decreased frontal TBR at task, which is in line with the notion that this brain index is particularly related to the control of reward or intrinsic motivation (Putman et al., 2014). Long-term consistency of interest has been associated with more attention allocation to the current context (Aguerre et al., under review), which might allow gritty people to be more "on-task" and to avoid reward override and mind-wandering (van Son et al., 2018, 2019).

Among other results, Wang et al. (2018) found smaller grey matter volume in the left dorsolateral PFC, a region involved in self-regulation, in participants scoring high in grit. According to these authors, a reduction in grey matter would result from optimal synaptic pruning and myelination during development, which would lead to greater efficiency in corresponding psychological process (Blakemore & Robbins, 2012). Nevertheless, this finding is blind in relation to the direction of the association between grit and synaptic pruning so that grit could be either an antecedent or a consequence of greater synaptic pruning. Additionally, Wang et al. (2017) found a negative association between spontaneous brain activity in the right dorsomedial PFC and grit, which may also indicate a more efficient use of a relevant neural hub for self-regulation. Importantly, these associations were found at rest, while our study showed that differences associated with grit were particularly relevant during task performance. However, contrary to our expectations, we did not observe decreased frontal TBR in gritty participants at rest (when, in principle, there is no need for executive control). Instead, gritty participants (in their consistency of interest facet) exhibited lower TBR during the learning task when top-down control processes may be more crucial to keep themselves motivated. Hence, our results can also be interpreted in terms of more efficient executive functioning. When taken as a whole, our results are theoretically convergent with previous findings.

With respect to complexity measures, our results reveal that increased entropy during task performance is linked to a higher perseverance of effort facet of grit, but no evidence of association between the fractal dimension index and grit emerged. Entropy is a measure widely used to study self-organization and pattern formation in the complex neuronal networks of the brain (Stam, 2005). Complexity has been shown to increase during task performance (Bizas et al., 1999; Lamberts, 2000; Micheloyannis et al., 2002; Müller et al., 2003; Stam et al., 1996) as a function of the task complexity (Jie et al., 2014). Brain complexity measures have also been linked to a higher number of simultaneously activated cell assemblies, understood as representational units of thoughts and ideas (Mölle et al., 1999). Considering this evidence from previous studies, higher entropy while performing the learning task might be indicative of more effort and engagement in the task, leading to an increase in the number of activated representational units (and their corresponding cell assemblies) while memorizing a list of words. This would also fit with the idea that gritty individuals show higher general sustained attention during task performance (Kalia et al., 2018) and give support to results from previous studies using different techniques that also found perseverance of effort to be linked to physiological responses of effort during task (Silvia et al., 2013). In any case, we found this relationship with only one of the complexity indexes (entropy), which may be a result of the sensitivity of the measure or of these distinct measures tapping into different aspects of brain complexity (Kreuzer et al., 2014; Raghavendra & Dutt, 2010). The absence of a relationship between EEG complexity measures at rest and grit is in line with the notion that, while there probably is a stable print of grit at rest as reported by previous research (Myers et al., 2016; Nemmi et al., 2016; Wang et al., 2018), gritty people also exhibit a different and unique functional pattern that is observed only while they are engaged in a task.

On the other hand, the fact that impulsiveness did not mediate any of the associations between grit and neural indexes and that impulsiveness failed to show any relation with such indexes is also remarkable. Even when both grit and impulsiveness relate to self-regulation (Duckworth, 2007; 2011) (and they do correlate with one another, see results), they exhibit a different neural pattern so reinforcing the view that they are separable constructs (Duckworth et al., 2007). On the other hand, our results concerning impulsiveness suggest that in healthy participants this trait may not involve the executive control-related neural differences that psychopathological conditions (i.e., attention-deficit hyperactivity disorder) may bring (Arns et al., 2013; Zhang et al., 2017). While higher TBR has frequently been found in impulsivity disorders, its relationship with the impulsiveness trait in healthy participants is much less clear (Lansbergen et al., 2007; Threadgill & Gable, 2018). It has been proposed that

ADHD may represent the extreme end of the impulsivity continuum, characterized by increased frontal TBR, while high impulsiveness in healthy adults would involve more middle-placed positions of the continuum, characterized by average frontal TBRs (Lansbergen et al., 2007). Finally, the fact that controlling for impulsiveness and the demographic variables made global grit effects disappear but not the effects of the two facets of grit that remained significantly linked to distinct brain indexes, lends support to the different nature of the facets of grit (Credé, 2018). While this dissociation would seem to fit well with the hypotheses of the present study, consistency of interest correlated with a brain activity index that others have interpreted as a marker of enhanced control over reward processes (Putman et al., 2014), and perseverance of effort correlated with an index thought to reflect effort during the task (Stam, 2005), which is in line with the results of previous studies that used different techniques (Silvia et al., 2013). This pattern also points to the relevance of incorporating a facet level of analyses in future studies.

While consistent with the association between executive control, task engagement, and grit trait, the present findings should be taken with caution because this is one of the very first studies reporting on the electrophysiological signatures of grit. In addition, there are some considerations for future studies. First, although the TBR is an index with a relatively long history (Arns et al., 2013), its interpretation in terms of interactions between cortical and subcortical brain processes related to grit requires more research. Second, the cross-sectional design used here does not allow us to determine the direction of the association between brain indexes during task and grit. Future studies that employ longitudinal/experimental designs could help address this issue. Third, we only used self-reported measures of the traits of interest. One intriguing possibility for future studies would be to add multiple methods to assess these traits. Convergence of findings with self-reported and performance measures would be of special relevance. In this sense, future studies could add "on-task checks" and "effort checks" to experimental tasks. This could help to determine whether it is (subjective) effort that is exerted during the task and not only the general perseverance of effort of participants, which positively relates to entropy at task.

In sum, the present study is one of the first to unveil the electrophysiological prints of grit. Our results indicate that gritty people have a different neural signature during task, mediated by lower frontal TBR and higher entropy, which may reflect a more efficient involvement in the task. It should be noted that these results that were obtained from a large sample of young individuals with different educational and life backgrounds converge with those obtained in studies that involved children and adolescents, which goes a step further toward the generalization of findings regarding brain mechanisms in grit. While there is still a long journey ahead in order to fully understand the neural mechanisms of grit, continuing in this direction will deepen our understanding of the trait and, more importantly, potentially provide us with the empirical evidence needed to develop targeted programs and strategies to improve grit.

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Chapter IX. Mindfulness, Grit and Proactive and Reactive Control Modes in Older Adults

Study 5[5]

Cognitive control is thought to be one of the most affected cognitive functions with aging. However, individual differences in the severity and timing of cognitive declines do exist as linked to various non-genetic factors, such as education or physical activity. Relatedly, mindfulness and grit traits have been shown to play a positive role in several health domains in older adults. Additionally, both traits have been previously linked to strategic use of cognitive control in younger adults. In the present study, we investigate the extent to which mindfulness and grit dispositions relate to the dynamics of control modes in older adults as understood from the dual mechanisms of control theory. Further, we wanted to examine whether mindfulness was positively correlated to grit. Thus, in the study, fifty-five older adults filled out mindfulness (FFMQ) and grit (Grit) questionnaires and performed a well-validated experimental task that provides indices of proactive/reactive control modes (AX-CPT). Multiple regression analyses showed high mindfulness participants to exhibit enhanced reactive control and a tendency towards better general performance, in comparison to their low mindfulness counterparts. On the other hand, grit was associated with enhanced reactive control but worse general performance (especially in control trials). Both traits showed to be positively correlated. These results go in line with previous studies taping into the control strategy of mindful and gritty younger adults and extend them to older adults. While mindfulness seems to be linked to better processing of context changes, grit seems to be characterized by enhanced awareness of context changes but also by higher contextual interference. Further studies should examine whether these differences in how cognitive control is implemented moderate how these traits foster healthy aging.

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[5] The study presented in this chapter is under preparation as Aguerre, N. V., Gomez-Ariza, C. J., Rivera, M., & Bajo, M. T. Mindfulness, Grit and Proactive and Reactive Control Modes in Older Adults.

Introduction

As we grow older, seemingly simple tasks such as retrieving names or navigating a new neighborhood, become harder. These tasks require executive control, a set of functions that become less efficient with aging as a result of progressive structural and functional brain changes (Maraver et al., 2020; Munakata et al., 2012; Paxton et al., 2008). *Cognitive aging* has been shown to affect quality of life and personal independence (DeCarli, 2003; Lyketsos et al., 2002; Salthouse, 2004). However, individual differences in the severity and timing of cognitive declines do exist (Ghisletta et al., 2012; Raz et al., 2005; WHO, 2015), and they entail a complex interaction between genetics and environmental factors (Cabeza et al., 2018; Payton, 2009). For instance, some life experiences such as education (Scarmeas et al., 2004), physical activity (Prakash et al., 2015), diet (Hedden & Gabrieli, 2004), demanding leisure activities (Stern, 2009) or biligualism (Bialystok et al., 2007; Zhang et al., 2020) seem to have neuroprotective effects against cognitive aging. Personality traits have also been proposed to account for individual differences in cognitive declines (Curtis et al., 2015; Low et al., 2013), and studies have started to investigate whether positive traits have a protective role in several health domains in older adults. This is the case of mindfulness (i.e., De Frias, 2014; De Frias & Whyne, 2015; Fountain-Zaragoza et al., 2016) and grit (i.e., Kim & Lee, 2015; Rhodes & Giovannetti, 2021; Wenner & Randall, 2016).

Although related, mindfulness and grit refer to two distinct personality traits. Mindfulness is defined as the tendency to be anchored to the present within an open and non-judgmental attitude (Bishop et al., 2004; Kabat-Zinn, 2003). This individual tendency is often captured by the Five Facets

Mindfulness Questionnaire (Baer et al., 2006) that comprises five aspects of the trait: observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience. In addition, the natural disposition to mindfulness can be further cultivated by meditation practice (Grossman & Van Dam, 2011). Along with its positive outcomes in young adults, such as better psychological health, cognitive ability and work and social functioning (Donald et al., 2019; Mesmer-magnus et al., 2017; Tomlinson et al., 2018; Verhaeghen, 2021), dispositional mindfulness seems also to have an effect on healthy aging (De Frias, 2014; De Frias & Whyne, 2015; Fountain-Zaragoza et al., 2016). The role that attention is thought to play in mindfulness (Dreyfus, 2011; Chiesa & Malinowski, 2011; Hölzel et al., 2011) has incited research on the possible differences in older adults' cognitive control as a function of dispositional mindfulness (Fiocco & Mallya, 2015; Fountain-Zaragoza et al., 2016; Prakash et al., 2013) and mindfulness meditation (i.e., De Frias, 2014; Fountain-Zaragoza & Prakash, 2017; Lenze et al., 2014; Malinowski et al., 2017; Malinowski & Shalamanova, 2017; McHugh et al., 2010; Whitmoyer et al., 2020; Zanesco et al., 2018).

Also grit has attracted the attention of researchers of cognitive aging (Kim & Lee, 2015; Rhodes & Giovannetti, 2021; Wenner & Randall, 2016). Grit refers to a person's firm determination to achieve long-term goals with an attitude of passion and perseverance (Duckworth et al., 2007), which is measured with the Grit Scale (Duckworth & Quinn, 2009) that taps into the perseverance of effort and consistency of interest factors of grit. Similar to mindfulness, grit has also been shown to relate to a variety of positive outcomes in young adults, from career success to higher well-being (Clark & Malecki, 2019; Eskreis-Winkler et al., 2014; Li et al., 2018; Mueller et al., 2017; Muenks et al., 2018). Importantly, there are also some studies showing grit to be associated with healthy aging (Kim & Lee, 2015; Rhodes & Giovannetti, 2021; Wenner & Randall, 2016). However, in the case of grit its relationship with executive functioning is much less known (Aguerre et al., under review; Kalia et al., 2018). Interestingly, both traits, mindfulness and grit, have been shown to correlate in young adults of different backgrounds (Aguerre et al., 2021; Li et al., 2018; Raphiphatthana et al., 2019; Raphiphatthana & Jose, 2020). Particularly, two characteristics of mindfulness, acting with awareness and non-judging the inner experience, have been shown to predict the development of grit in later months (Raphiphatthana et al., 2018). As a secondary goal of the present study, we aimed to test whether such a relationship was also present in older adults, because no study to date has examined this generalization.

The main goal of the current study was to explore whether mindfulness and grit traits relate to cognitive control in older adults. This goal is based on previous scientific literature showing the positive role of mindfulness and grit in aging (De Frias & Whyne, 2015; Fountain-Zaragoza et al., 2016; Kim & Lee, 2015; Rhodes & Giovannetti, 2021). Hence, it becomes relevant to delineate, if any, the possible mechanisms through which these traits foster helthy aging. Cognitive control is defined as the ability to drive behavior according to goals, especially in the presence of interference or stimuli that trigger automatic responses, or when people face novel situations (Miller & Cohen, 2001; Norman & Shallice, 1986). A well-recognized framework of cognitive control is the “Dual Mechanisms of Cognitive Control” (DMC) theory proposed by Braver (Braver et al., 2009; Braver, 2012), which emphasizes the dynamics of control. The DMC (Braver et al., 2009; Braver, 2012) theory proposes that cognitive control may be exerted in two primary ways: proactively and reactively. When a proactive mode of control is exerted, task-relevant information is maintained in a sustained manner, so that an early selection mechanism is used to direct behavior accordingly to internal goals. On the other hand, when a reactive mode of cognitive control is deployed, a late corrective function is employed only when interference occurs. Both modes should be flexibly used to prompt goal-directed actions or thoughts. Proactive control is needed to actively maintain contextual representation and bias attention, perception and action to prevent interference from cognitively demanding events; while the reactive mode would be needed in response to changing environmental demands or associative retrieval to deal with already triggered conflicts that should be detected and resolved (Braver et al., 2009). It is important to note that only the dynamic coordination of both control modes would allow individuals to adapt to changing situations (Amer et al., 2016; Burgess & Braver, 2010; Munakata et al., 2012). Interestingly, although everyone could, in principle, exhibit both modes of cognitive control, some people tend to show one of the two modes (either proactive or reactive), while some other people seem to use them in a more balanced manner and adjust their use to the situation (Jimura et al., 2010; Mäki-Marttunen et al., 2019).

The individual's tendency to different control modes can be captured with the AX-Continuous Performance Task (AX-CPT; Braver et al., 2009). In the AX-CPT participants are asked to respond to a specific pattern of letters presented sequentially (cue-probe: A-X) and say no to any other combinations (i.e., BX, AY or BY). From the different combinations of these trials distinct errors are possible. Performance that is highly reliant on proactive control may produce errors due to cue bias (AY errors), while a tendency towards reactive control would lead one to commit errors due to high interference from the probe (BX errors). In addition, control trials are presented wherein no conflict exist (BY). The ratio of AY and BX performance provides an index of the individual's tendency towards one or the other control mode, wherein positive scores represent a proactive tendency and negative scores reflect greater reliance on reactive control (Behavioral Shift Index: BSI; Braver et al. 2009).

Cognitive control is thought to be one of the most affected cognitive processes with aging (Braver & Barch, 2002; Braver & Cohen, 2000). In this regard, one of the most extended frameworks of cognitive aging is the Goal Maintenance Deficit theory (Braver & West, 2008; Miller & Cohen, 2001), which proposes that the main deficit in older adult's cognition resides in the impairments in the maintenance of the relevant contextual information of the task at hand that, in turn, has been related to deficits in proactive control in older adults in comparison to young adults (Paxton et al., 2006, 2008). However, the Goal Maintenance Deficit theory emphasizes the role of context processing in all its forms: context representation, maintenance of the context relevant information, and updating of context changes may all play a role in cognitive decline (Braver & West, 2008; Yee et al., 2019). Hence, we wanted to examine whether mindfulness and grit traits are linked to reduced decline in any form of context processing in older adults: namely, context maintenance (proactive control), context updating (reactive control) or the combination of both modes (balanced control). This question might provide relevant insights on the mechanisms through which these traits have protective effects during the aging process (i.e., De Frias & Whyne, 2015; Rhodes & Giovannetti, 2021).

Individual differences in cognitive control have been related to mindfulness and grit traits in young adults (Aguerre et al., 2020; under review; Chang et al., 2018). In the case of mindfulness, high-trait young participants show a balanced proactive/reactive use of cognitive control (Aguerre et al., 2020; Chang et al., 2018). In these studies, scores from the FFMQ and MAAS questionaires were correlated with data from the AX-CPT (among others), with the aim of examining the relationship between mindfulness and cognitive control. Results showed mindful individuals to perform better in both proactive and reactive control, whereas low mindfulness individuals showed a dominance of proactive control (Aguerre et al., 2020; Chang et al., 2018). Moreover, mindful individuals showed greater flexibility and recovery after errors when the two processing modes were available, in comparison to their low mindfulness counterparts (Aguerre et al., 2020). These results have been interpreted as an "open to the present" attention that enables high mindfulness participants to override initial thoughts when needed and perform taks more flexibly. In the case of young adults in the pick of their cognitive capacities, a balanced use of cognitive control may represent the most efficient manner of using their resources. However, it is not clear whether this pattern would also be evident in older adults. Interestingly, previous research has shown that high-trait mindfulness older adults do differenciate from low mindfulness older adults in exhibiting better perfromance in situations requiring reactive control. Moreover, fewer task-unrelated thoughts, a component of mind-wandering, mediated the association between mindfulness trait and better performance in proactive control in this population (Fountain-Zaragoza et al., 2016). In a follow up study, Fountain-Zaragoza et al., (2018) showed that individual differences in mindfulness trait and mind-wandering processes accounted for important variance in attentional performance across age. However, these findings do not match those obtained in studies focusing on mindfulness trainings in older adults (Whitmoyer et al., 2020). Specifically, Whitmoyer et al., (2020) compared a group of older adults who underwent 4 weeks of mindfulness-based attention training to an active control group in their perfomance in several attentional tasks (including the AX-CPT). However, no improvements in attentional performance after training was found when compared to the control group. Thus, based on findings with young and older adults (Aguerre et al., 2020; Chang et al., 2018; Fountain-Zaragoza et al., 2016, 2018), we expected high mindfulness older adults to show a balanced use of cognitive control with particular better performance in reactive trials. If so, this would provide support to previous work that has emphasized the differences between dispositional and trained mindfulness. In addition, these results would give us some insights on the possible mechanisms through which mindfulness may foster healthy aging (De Frias, 2014; De Frias & Whyne, 2015; Fiocco & Mallya, 2015; Fountain-Zaragoza et al., 2016).

As for grit, albeit conceptualized as largely distinct from cognitive ability (Duckworth & Quinn, 2009), it has been shown to be beneficial for some cognitive-related outcomes, such as success in school and work-life (i.e. Clark & Clark, 2019; Mueller et al., 2017; Eskreis-Winkler et al., 2014). In addition, grit is one of the noncognitive factors that have been shown to protect against late-life cognitive impairment, maybe by promoting cognitive reserve (Rhodes et al., 2017). Regarding cognitive control, there are only few studies trying to investigate the underlying mechanisms of grit (Aguerre et al., under review; Kalia et al., 2018, 2019). While these studies have failed to find evidence of enhanced executive control, a pattern towards a balanced used of proactive/reactive cognitive control has been reported (Aguerre et al., under review). Following these lines, we hypothesized that as long as grit is a factor influencing cognitive reserve, older adults scoring high in grit would show a performance pattern similar to that one of gritty younger participants. That is, we expect that high grit old participants will show a more balanced practive/reactive mode of control than their lower grit counterparts.

In sum, on the basis of the previous research we conducted the present study with older adults wherein mindfulness (FFMQ; Baer et al., 2006), grit (Grit Scale; Duckworth & Quinn, 2009), and cognitive control modes (AX-CPT; Braver et al., 2009) were assessed . We aimed at exploring whether the pattern of practive/reactive control varied as a function of mindfulness and grit. We hypothesized that high mindfulness and high grit older adults would show a balanced practive/reactive use of cognitive control as compared to their low mindfulness and grit counterparts. Finally, we expected measures of mindfulness and grit to be positively related.

Method

Participants

Fifty-five older adults (M_{age} = 66.48, SD_{age} = 4.68, Range = 60-82) completed the study after signing the informed consent form. The study followed the Helsinki' declaration guidelines (World Medical Association, 2013) and was approved by the Ethics Committee of the University of Granada. The sample size was determined in advanced on the basis of the effect size (R^2= 0.14) of the regression model of control style (included AX-CPT and switching task) over mindfulness scores (FFMQ) in Aguerre et al's., (2020) study. The power analysis (G*Power 3.1.9.2; Erdfelder, Faul and Buchner 1996) revealed that 55 participants were enough to detect a reliable association with 90% power and alpha set at 5%.

Materials and Procedure

The experiment was conducted online using Gorilla Experiment Builder (Anwyl-Irvine et al., 2020) to secure older participants' health in the pandemic period due to COVID-19. This platform has been demonstrated to be an accurate behavioral recording tool (Anwyl-Irvine et al., 2020). Participants underwent two sessions of an hour each that included the Spanish versions of the personality questionnaires (FFMQ: Cebolla et al., 2012; Grit Scale: Duckworth & Quinn, 2009) and the AX-CPT (Morales et al., 2013). Additionally, the sessions included other experimental tasks (Global-Local task: Soriano et al., 2018; A syntactic learning task: Williams & Kuribara, 2008), as well as control measures (Sociodemographic and LSNS-6; 7MT: del Ser Quijano et al., 2004), that are not presented in the current paper.

Grit. Eight item self-reported questionnaire that measures perseverance of effort (i.e., 'I am diligent) and consistency of interest (i.e., 'My interests change from year to year') facets of grit. Cronbach's α of the factors ranges from 0.60 to 0.79 (Duckworth & Quinn, 2009).

FFMQ. Thirty-nine items self-reported questionnaire that assesses five facets of mindfulness: observing (i.e., 'I notice the smells and aromas of things'), describing (i.e., 'I'm good at finding words to describe my feelings), acting with awareness (i.e., 'I am easily distracted'), non-judging of inner experience (i.e., 'I disapprove of myself when I have irrational ideas') and non-reactivity to inner experience (i.e., 'I watch my feelings without getting lost in them'). Responses go from 1 (never or very rarely true) to 5 (very often or always true), and higher scores represent greater mindfulness. The Cronbach's α for the factors of the Spanish translation goes from 0.80 to 0.91 (Cebolla et al., 2012).

AX-CPT. We used the version described in Morales et al., (2013), which has been shown to be sensitive to individual differences. Participants were instructed to answer affirmatively to a specific pattern of letters, an 'A' letter (cue, in red font) followed by an 'X' letter (probe, in red font), and to give a 'no' response to any other pattern of letters (AY: 'A' cue – non 'X' probe; BX: non 'A' cue – 'X' probe; or BY: neither 'A' cue nor 'X' probe). Additionally, between cue and probe, three letters were presented as distractors, in white font, to which participants had to respond 'no'. Response to the pattern of letter should be entered upon probe presentation. 100 experimental trials were administered in the task, from which 70% were the target trials (AX), while any other cue-probe combination was presented in a 10% (AY, BX, BY). Errors and RTs give information on the general performance of participants and performance in each control mode. In addition, the tendency of control modes was computed by the behavioural shift index (BSI), that is calculated as (AY-BX)/(AY+BX) for errors or RTs (Braver et al., 2009). Positive scores in the BSI indicate greater dominance of proactive control, negative scores indicate reactive control dominance, and near to 0 scores reflect balanced control (see Figure 1).

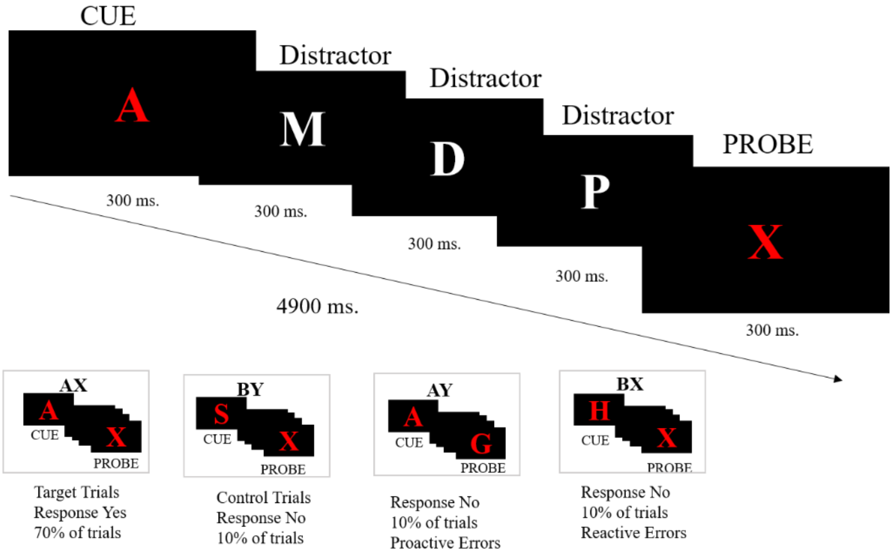

Fig. 1 AX-CPT procedure: On the top a typical trial of the task is presented, with cue and probe colored in red and three distractors in white color. The four possible conditions are presented at the bottom, AX are the target trials (a "yes" response is required, 70% of trials); BY or control trials ("no" response, 10% of trials); AY or proactive error condition ("no" response, 10% of trials) and BX or reactive error condition ("no" response, 10% of trials).

Results

Basic descriptive statistics of the 55 participants are presented in Table 1. Two participants had missing scores in the FFMQ and therefore were not included in the following analyses.

Table 4 Descriptive statistics for the main variables. The first column refers to means and standard deviations

	Score	Minimum	Maximum
FFMQ	135 (16.2)	107	178
Observing	26 (9.8)	0	40
Describing	29 (6.1)	18	40
Acting with awareness	31 (7.2)	14	48
Non-judging	28 (8.5)	10	48
Non-reactivity	21 (7.2)	0	34
Grit	4 (0.6)	3	5
PE	15 (2.88)	10	20
CI	15 (3)	8	20
AX Errors	0.16 (0.27)	0	0.97
AY Errors	0.29 (0.3)	0	1
BX Errors	0.32 (0.36)	0	1
BY Errors	0.2 (0.3)	0	1
AX RTs	510 (116)	304	895
AY RTs	665 (170)	181	1049
BX RTs	500 (167)	247	859
BY RTs	546 (142)	298	909
BSI_Errors	0.006 (0.46)	-0.89	0.79
BSI_RTs	0.15 (0.18)	-0.2	0.46
BSI_Combined	0.14 (0.19)	-0.33	0.46

Personality Measures

To test our hypothesis on the positive relationship between mindfulness and grit we performed Pearson correlation analyses between the scores of the FFMQ and the Grit Scale and its factors. Results are shown in Table 2. Additionally, we explored whether there was a relationship between age (Range = 60-82) and the trait scores. Pearson correlation analyses showed no relationship in the case of grit (r = -0.04; p = 0.78), but a negative association between age and mindfulness (r = -0.28; p = 0.04).

Table 2: Correlation matrix of the facets of both questionnaires (FFMQ and Grit Scale)

	Grit	Perseverance of Effort	Consistency of Interest
FFMQ	0.18	-0.02	0.29*
Observing	-0.01	-0.02	-0.01
Describing	0.19	0.07	0.22
Acting Awareness	0.31*	0.11	0.37**
Non-Judging	-0.07	-0.17	-0.03
Non-Reactivity	0.04	0.01	0.05

* $p < 0.05$ **$p < 0.01$, *** $p < 0.001$. Asterisks represent statistically significant correlations after controlling for multiple comparisons with the Banjamini-Hochberg method with false discovery rate at 0.25 (Benjamini & Hochberg, 1995).

Performance and the traits

Regarding cognitive control, we first tested a possible link between both traits (mindfulness and grit) and general performance. We run multiple regression analyses with accuracy in the AX-CPT as the dependent variable and mindfulness and grit scores as independent ones, while controlling for age. Results showed a negative association between general performance and grit. There was also a tendency towards better performance as a function of mindfulness (See Table 3).

Table 3. Multiple regression analyses over performance with mindfulness and grit as predictors, controlling for age.

	R^2	ΔF	*B*	*SE*	β	*P*
ACC Model	0.13	3.88				0.027
Constant			0.81	0.32		
Mindfulness			0.00	0.00	0.24	0.083
Grit			-0.15	0.06	-0.33	0.018

Mindfulness and AX-CPT

To better explore our hypothesis on the relationship between mindfulness and modes of cognitive control in older adults we run stepwise regression analyses with mindfulness as the dependent variable and errors, on the one hand, and RTs, on the other hand, of every kind of trial (AX, AY, BX and BY) as independent variables, while controlling for grit and age variables. Results showed a negative association between mindfulness scores and errors in AY trials (see Table 5). In addition, we ran Pearson correlation analyses between the FFMQ score and the BSI index based on errors and RTs. the BSI on errors showed a negative tendency supported by the findings of better performance on AY trials as a function of mindfulness (BSI Errors: $r = -0.25$, $p = 0.07$; BSI RTs: $r = 0.14$, $p = 0.31$).

Table 5: Stepwise regression analyses over mindfulness with errors on each condition of the AX-CPT as predictors, controlling for age and grit

	R^2	F	B	SE	β	p
Mindfulness Model	0.08	4.13				0.047
Constant			139.15	3.04		
AY Errors			-15.06	7.41	-0.28	0.047

Grit and AX-CPT

Finally, to test our hypothesis on the relationship between grit and modes of cognitive control in older adults we run stepwise regression analyses with grit as the dependent variable and errors, on the one hand, and RTs, on the other hand, of every kind of trial (AX, AY, BX and BY) as predictors, while controlling for mindfulness and age variables. Results showed grit to be linked to higher BY errors and lower AY errors (see Table 6). Consequently, Pearson correlation analyses between the score of grit and the BSI index on errors and RTs showed a significant relationship between grit and BSI on errors ($r = -0.39$,

$p = 0.004$). The correlation with BSI based on RTs was non-significant ($r = -0.14$, $p = 0.34$).

Table 6: Stepwise regression analyses over grit with errors on each condition of the AX-CPT as predictors, controlling for age and mindfulness

	R^2	F	B	SE	β	p
Grit Model	0.25	8.02				0.001
Constant			3.7	0.09		
BY Errors			1.2	0.3	0.67	<0.001
AY Errors			-0.82	0.3	-0.45	0.01

Discussion

While aging entails declines in cognitive control among other cognitive functions, individual differences exist in how aging affects cognition (Hedden & Gabrieli, 2004). Several are the factors that have been shown (or suggested) to be protective against age-related cognitive declines (i.e. Prakash et al., 2015; Scarmeas et al., 2004) and, in this regard, some studies have now started to investigate the possible role of mindfulness and grit traits as moderators in healthy aging (i.e., De Frias & Whyne, 2015; Rhodes & Giovannetti, 2021). Hence, the extent to which older adults with high mindfulness and high grit dispositions exhibit a different use of cognitive control might help to gain insights on how these traits foster healthy aging. Thus, the goal of the present study was to investigate the relationship between mindfulness and grit traits in older adults and their use of cognitive control modes (AX-CPT) from the dual mechanisms framework (Braver et al. 2009). Results regarding mindfulness showed it to entail a benefit in the use of reactive control and, in turn, a tendency towards better general performance. On the other hand, grit was linked to benefits in reactive control but worse general performance and, specifically,in control trials. In addition, both traits were positively correlated.

Mindfulness has been previously linked to balanced use of proactive/ reactive control modes in younger adults (Aguerre et al., 2020; Chang et al., 2018). This tendency toward balance in mindful individuals seems to be particularly related to enhanced reactive control and might be the underlying mechanism that leads to better flexibility and recovery after errors in these individuals (Aguerre et al., 2020). Interestingly, older adults exhibit a similar pattern of enhanced reactive control that has been previously reported as linked to dispositional mindfulness (Fountain-Zaragoza et al., 2016). Indeed, our results go in line with previous findings involving both younger and older adults. Specifically, while the trends towards better general accuracy and lower BSI (less proactive/more balanced control) did not reach statistical significance, regression analyses showed that there were differences in AY performance as a function of mindfulness scores. AY trials prompt “yes" responses that should be overcomed upon probe presentation by using reactive control. In this particular task, the “A” cue can be used to proactively bias response to say “yes”, which is an usually employed strategy because the occurrence of AX (target) trials is higher than the one of the rest of trials (70%). However, when the probe appears and is different from X (non-X probe; AY trials), a reactive mechanism should be triggered to detect and resolve confict by inhibiting the prompt-induced response. Enhanced rrrors in AY trials can be interpreted as the result of high reliance on proactive control and, in turn, better performance in this kind of trials represent more efficient reactive control. Performance in AY trials needs to be interpreted considering performance in BX and BY trials, because a disproporcionate tendency towards rective control would represent benefits in AY trials at the expense of performance in BX ones. Our results with older adults reveal that performance in BX trials did not differ as a function of mindfulness, which indicates a suitable use of proactive control. No differences were also observed in control trials when considering either accuracy or reaction times. The general lack of differences in RTs suggests that the benefit in AY trial are not due to trade-off causes. All in all, the present findings indicate that mindfulness is linked to a balanced use of cognitive control that results from enhanced reactive control performance, and that may lead to better general performance in these individuals.

Previous research has indicated that dispositional mindfulness and its link to the use of control modes explain part of the variance of the lack of differences in attentional performance between young and older adults (Fountain-Zaragoza et al., 2018). This is particularly important to understand if the protective effect of mindfulness against cognitive decline has to do with benefits in the particular use of control modes. Although age-related cognitive declines have been suggested to be due to difficulties in goal maintenance (Braver & West, 2008; Miller & Cohen, 2001; Paxton et al., 2008), the Goal Maintenance Deficit theory highlights the role of context processing in all its forms when it comes to aging (Braver & West, 2008; Yee et al., 2019). Previous and present findings suggest that mindfulness may be linked to the successful updating of context changes, what can help mindful older adults to flexibly adapt to changing enviroments. Future studies should more broadly investigate this pattern of control of mindfulness across ages. This could be achieved by including either two large groups of younger and older adults with differences in their mindfulness scores, or four grups of younger and older adults and high and low mindfulness. Also longitudinal studies would be very valuable to detect the possible role of cognitive modes in the mindfulness-healthy aging relationship (i.e., how young people with high mindfulness grow old). With regard to training programs to foster mindfulness and benefit healthy aging, existing results regarding control modes are not that clear (Whitmoyer et al., 2020). To our knowledge, only one study has examined the effect of 4 weeks mindfulness-based attention training as compared to an active control group and found no differencies in control performance after training (Whitmoyer et al., 2020). Similarly to the case of younger adults, where the benefits of dispositional mindfulness were not parallel to those after training (Aguerre et al., 2020; Chang et al., 2018; Incagli et al., 2020; Li et al., 2018), mindfulness in older adults should be explored in all its different forms to test whether dispositional mindfulness entails reactive mode improvements, while early stages of mindfulness practice and expert meditators show a different strategic use of control.

As for grit, higher scores in the trait were linked to reduced errors in the AY trials but more overall errors (including the baseline condition; BY). The role of reactive control was also captured by the error-based BSI, which correlated negatively with grit. The results on reactive control match those from younger participants with high grit, who have previously shown to have a "less proactive" control mode as a function of the trait score. This pattern has been interpreted as a tendency of gritty individuals to keep attentive to new information instead of driving their behavior by initial contextual cues. Remarkably, this pattern in the use of control modes was not related to enhanced cognitive performance in younger adults (Aguerre et al., under review). Another study examining the possible link between cognitive performance and grit in young adults also failed to find a positive association

(Kalia et al., 2018). In particular, Kalia et al. (2018) found that gritty people do not benefit from alerting cues as much as low grit participants. In a follow-up study, Kalia et al. (2019) found enhanced ability of gritty participants to solve difficult sudoku tasks as expense of flexibility. Taken together, the previously reviewed findings and our own results seem to indicate that high grit people do not necessarily have a beter cognitive capacity, such as Duckworth et al., (2007) has suggested. Instead, they seem to use cognitive functions in a different way paying careful attention to changes in context information, even if this information becomes interfering. Enhanced control and effort during task engagement has previously been linked to higher grit (Aguerre et al., 2021). However, while these findings are informative on the cognitive profile of gritty people, how grit foster succesful aging might rely on different (maybe non-cognitive) mechanisms (i.e. Kim & Lee, 2015; Rhodes et al., 2017; Rhodes & Giovannetti, 2021). Finally, we also found that the acting with awareness facet of mindfulness was positively related to grit in older adults. This results extend previous findings and stresses the presence of this relationship also in the elderly (Raphiphatthana et al., 2018). However, previous results leave open the question of how this relationship develops (Raphiphatthana et al., 2019) and suggest future studies to investigate the possible design of interventions of mindfulness and grit in conjuction.

Altogether, our results provide evidence for a multicomponent approach when it comes to explaining the link between dispositional mindfulness and grit and cognitive control in older adults. The fact that prior findings were replicated and generalized to a different population, as it is the elderly, gives support to the notion that the degree of traits of mindfulness and grit are linked to different uses of control modes. How this relationship is built in the development and how it prevent (or not) cognitive aging requires further research. Following this line of research would be very valuable to design evidence-based trainings that combine character education and executive training.

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Part 3: General Discussion and Conclusions

Chapter X. General Discussion and Conclusions

Positive traits are increasingly receiving attention from the scientific community due to the evidence of their implication in health and well-being (Corr & Matthews, 2020; Deneve & Copper, 1998; Sheldon & Hoon, 2007). The way we encounter the current experience, the level of mindfulness, and the goals we choose to get involved in, the amount of grit, have shown to be powerful predictors not only of well-being but also of success and life satisfaction (Brown & Ryan, 2003; Duckworth et al., 2007). In addition, the fact that their theoretical conceptualization assumes these personality traits to be inserted in how cognition is deployed to interact with the context (Bishop et al., 2004a; Duckworth et al., 2007), makes them a great opportunity to explore the interplay between the personality and cognitive neuroscience fields. Indeed, along with their positive outcomes, inquiries are moving now towards the understanding of their psychological mechanisms. Such an understanding would also help to disentangle their possible role as neuro-protective factors in aging. Towards this end, the set of studies presented in this thesis sought to elucidate the possible neurocognitive bases of these two important positive traits, mindfulness and grit, in young adults, and their evolution in the elderly.

In Study 1 (Chapter V) we examined cognitive control as a function of mindfulness trait from the Dual Mechanisms of Control perspective (Braver, 2012). Following it up, in Study 2 (Chapter VI) we explored the neural mechanisms of dispositional mindfulness by taking measures (frontal gamma, q-EEG and complexity indexes) of the DMN. Then, we moved to investigating the grit trait and in Study 3 (Chapter VII) we looked into its cognitive underpinnings on the basis of the DMC theory and the Unity and Diversity model of executive control. Next, in an attempt to shed some light into its neural mechanisms, in Study 4 (Chapter VIII) we examined neural activity (TBR and complexity indexes) as a function of grit trait. Finally, in order to explore changes in cognitive control modes potentially linked to mindfulness and grit in older adults, in Study 5 (Chapter IX) we adopted the DMC framework and examined its relationship with both traits in the elderly. Across studies we also checked the relationship between mindfulness and grit traits. The results of the present research indicate that, indeed, there seem to be a specific neurocognitive pattern underlying mindfulness and grit traits. On the one hand, dispositional mindfulness seems to be associated with a balanced proactive/reactive control modes, increased cognitive flexibility and reduced DMN activity at rest, which we interpreted as a more "present anchored" strategy of cognitive control. On the other hand, grit has been shown to be related to a less proactive tendency of control (although not better executive functions performance) and lower involvement of TBR and greater entropy during task performance, what we have interpreted as a more cautious tendency of control, together with greater effort and control over reward processes during task engagement. Finally, the balanced and cautious control strategies that are characteristics of mindfulness and grit traits respectively, were also found in older adults as a function of their scores in both traits. This pattern of results in the aging replicates our findings in young adults, suggesting that these control strategies are also playing a role in the benefits that mindfulness and grit traits seem to have in older people.

In the next sections we will draw parallels across scientific literatures addressing mindfulness, grit, and cognitive control by summarizing and discussing the empirical findings obtained across experiments in this dissertation. First, we will discuss the findings regarding dispositional mindfulness (trait) within the framework of other research on mindfulness, comparing focusing on mindfulness as a state, or as the result of training and expertise. Then, we will move to the interpretation of our findings on grit and their implications in the context of previous grit studies and possible intervention designs. We will also discuss the similarities and differences in the results of each trait and their possible relationship, and highlight the implications of our results for cognitive control research. Finally, we will draw a general conclusion derived from the current set of studies.

Cognitive and Neural Mechanisms of Mindfulness

There is compelling evidence suggesting that mindfulness has a cognitive component (i.e., Cásedas et al., 2019; Tang et al., 2015; Verhaeghen, 2021). However, the specific characteristics of this component are still under study. In addition, the question of whether the role of cognition is intrinsic to the general mindfulness construct, or whether this component changes depending on the different ways mindfulness can adopt (state, trait, prospective outcome of training, or a skill of expert meditators) remains open. While much research on this cognitive component has been conducted regarding mindfulness meditation (Tang et al., 2015), in the particular case of dispositional mindfulness only a few studies have started to point to cognitive enhancements as a function of mindfulness trait (Verhaeghen, 2021). However, developing a more precise and nuanced understanding of the neurocognitive underpinnings of dispositional mindfulness is still necessary. Towards this end, we examined the neurocognitive mechanisms of mindfulness trait in Studies 1, 2 and 5 (Chapters V, VI and IX).

A noteworthy framework to deepen in the cognitive component of mindfulness is the DMC theory, and its proposal that two different modes of control can be deployed depending on individual and situational factors: the proactive and the reactive control modes (Braver, 2012). Proactive control is implicated in goal maintenance in order to effectively prevent interference over goal-directed behavior, while reactive control is transiently employed to overcome interference when it arises (Braver, 2012). Few have been the studies taping into how control modes relate to mindfulness and those have produced mixed results when mindfulness is studied as a trait (Chang et al., 2018) or as the result of training (Incagli et al., 2020; Li et al., 2018). In this regard, results from Study 1 (Aguerre et al., 2020) and 5 replicate previous findings regarding dispositional mindfulness (Chang et al., 2018) to show that it is characterized by a more balanced (less proactive) tendency of control. These results are highly valuable for the notion that mindfulness trait is linked to balanced control, with three different experiments replicating this pattern (Aguerre et al., 2020; in preparation; Chang et al., 2018).

The AX-CPT was employed to investigate individuals' cognitive control modes in two experiments (1 and 5). This is a widely used task to measure the dynamic adjustment of control and has been shown to be highly sensitive to individual difference (Braver, 2012; Braver et al., 2009; Morales et al., 2013). Our task promoted a proactive tendency because the previous context (cues) was highly predictive (the A cue was followed by the X target in 70% of the trials); therefore the sustained maintenance of previous task information leads to high success rates, albeit leading to errors in trials where the current context (probe) ask for a (unexpected) different response (A cue, non-X probe; AY trials, 10% of the trials). Performance across conditions provides information on each participant's control mode and enables us to determine if mindfulness is linked to either a tendency towards a specific control mode or a balanced strategy of control. In addition to single trials, the BSI (Braver et al., 2009; Chiew & Braver, 2017) calculated on the relative performance on AY and BX trials (AY-BX/AY+BX) provides a measure of the individual tendency of control. Thus, a greater tendency towards proactive control is expected to increase AY errors and RTs and reduce BX ones, which is reflected in closer to 1 scores in the BSI. On the contrary, a reactive tendency increases BX errors and RTs and reduce those in AY trials that will result in closer-to -1 BSI scores. Hence, a proactive control approach to the task would probably lead to better performance at the expense of consuming more cognitive resources. Thus, young adults tend to rely more in proactive control, while older adults are more reliant on a reactive mode due to goal maintenance impairments that aging brings (Braver, 2012; Paxton et al., 2006, 2008). In both of our experiments examining the control tendency that is characteristic of mindfulness trait (Studies 1 and 5), dispositional mindfulness was linked to better performance in relation to the use of reactive control.

The balanced use of control modes employed by mindful individuals goes in line with the notion of a more present centered attention. Young adults showed no differences in BX errors regarding the level of mindfulness (which indicates that proactive control is successfully employed). Better performance in AY trials (less errors and RTs) together with slower responses to BX trials indicate a more efficient use of reactive control as a function of mindfulness trait. That is, a better reaction when the context does not match the expectation (when a non-X probe is presented) and a slowing when considering rejection of trials where the current context signals a “yes” response but the previous one should be maintained to give a “no” response (when a non-A cue is presented following by an X-probe; BX trials). This ability to overcome previous contexts and process the present one by flexibly using proactive and reactive mode was also found in a better switching performance in the cued task–switching paradigm when both control modes were available. In the same vein, the present centered attention is probably behind the fact that mindful individuals show a greater recovery after they commit an error, so they overcome interference from the bad performance in the previous trial and are able to focus on the new one and perform better. Interestingly, similar results were found in older adults. In Study 5, we demonstrated that mindful older adults show a tendency towards better general performance and a more balanced use of their cognitive control modes. Particularly, they made fewer errors in AY trials and had a tendency towards higher general accuracy, what represents 1) better context updating and 2) better baseline performance. Although they were not directly compared in our studies, it can be observed from the descriptive statistics of both experiments that older adults showed a numerically smaller BSI compared to young adults, confirming the tendency towards reactive control with aging (Munakata et al., 2012). Our results also indicate that a reactive tendency when it comes to exerting control does not necessarily link to worse performance. In fact, our results from older adults indicate that it is the flexible combination of both control modes what allows them successful performance, as it is also the case in young adults (Morales et al., 2013).

Although the results obtained on dispositional mindfulness do not totally match those found after meditation training regarding control modes (Incagli et al., 2020; Li et al., 2018), this can be due to a different strategic use of the cognitive control modes as a function of mindfulness development. Specifically, Li et al's. (2018) results indicated a proactive control enhancement (higher BSI scores based on RTs; a trend towards fewer BX errors) after a meditation intervention in naïve participants as compared to a control group. On the other hand, Incagli et al. (2020) showed a significant reduction of errors on both conflicting trials (AY and BX) in the mindfulness intervention group. In a similar stufy in older adults no differences were found after mindfulness training (Whitmoyer et al., 2020). It seems reasonable to think that dispositional mindfulness in naïve to meditation participants is linked to a more balanced, or more "present anchored", control tendency as they are characterized by more attention allocation to the present moment (Aguerre et al., 2020; Chang et al., 2018). Then, when they engage in training programs over 8 weeks, such as the MBSR, wherein both focused attention and open monitoring are trained, most likely both proactive and reactive control are improved (Incagli et al., 2020; Li et al., 2018). In fact, future studies should explore whether the degree of focused attention is linked to a benefit towards proactive control, while trainings with a greater emphasis in open monitoring fosters reactive control (Lin et al., 2021). Also, future lines of research should investigate whether expert meditators have a particular tendency in their use of control modes. Our hypothesis is that they would exhibit a pattern of control similar to the one shown by high dispositional mindfulness individuals (Chiesa et al., 2011).

This “present anchored” tendency of control found in Study 1 made us wonder whether it would be also present when individuals are not engaged in a task, which should result in lower DMN activity at rest. Mind-wandering and self-referential processes are usually associated with a resting state, which is imprinted in the brain by activity of the DMN (Raichle et al., 2001). Lower involvement in processes such as mind-wandering is associated with brain activity that is more similar from rest to task (task readiness) (Lim et al., 2018). Previous research has found lower activity in the brain patterns related to the DMN in mindfulness meditation experts (i.e., Berkovich-Ohana et al., 2012, 2014). Also, in dispositional mindfulness there are few studies showing a relationship between mindfulness trait and a brain state of “task readiness” linked to the DMN (i.e., Lim et al., 2018). Thus, we adopted Berkovich-Ohana et al.'s (2012) approach to tap into the possible link between dispositional mindfulness and an EEG signature of “task readiness”. Coherent with studies in meditators, our results from Study 2 (Chapter VI) showed brain activity that is characteristic of less involvement of mind-wandering and self-referential processes in high mindfulness individuals. Those results fit well into previous literature on the neural correlates of expert meditators and behavioral results from our previous research of a “present anchored cognitive style”.

Specifically, we focused on brain indexes of EEG that have widely been employed in individual differences studies (i.e., Doppelmayr et al., 2002; Ibáñez-Molina et al., 2014; Prat et al., 2016) and in some previous research on mindfulness meditation and expertise (Berkovich-Ohana et al., 2012; Vivot et al., 2020): namely, frontal gamma power, overall power and complexity indexes. The gamma frequency has been shown to be associated with activity in the MPFC and other self-referential processing areas of the DMN (Berkovich-Ohana et al., 2012, 2014; Mantini et al., 2007), whereas overall power allows for a more general comparison of activity from rest to task and complexity indexes give us information about the involvement during the task (Müller et al., 2003; Stam, 2005). Results from Study 2 indicated a link between mindfulness trait and reduced frontal gamma power and overall lower power at rest, but not at task. In addition, a trend towards higher entropy during task performance was present in high mindfulness individuals. These findings support the idea that mindfulness, regardless of whether it refers to a disposition, a state, a result of training or a skill of experts meditators, may be characterized by neural activity associated with lower mind-wandering, which would provide them "task readiness" and posterior task involvement, (i.e. Berkovich-Ohana et al., 2012, 2014; Lim et al., 2018; Vivot et al., 2020). While the balance of control modes may be developed in the course of different mindfulness stages in order to anchor attention to the present situation (Lin et al., 2021), it seems that the balance of control modes is accomplished in the course of the different mindfulness stages (from naïve to experts), with all the underlying changes leading to reach mind calm. This is in line with results that reveal that mindfulness (either a trait or the result of training) is characterized by reduced brain activity linked to mind-wandering and self-referential processes (i.e. Berkovich-Ohana et al., 2012, 2014; Lim et al., 2018). Deeper analyses of the DMN activity comparing all the stages of mindfulness in the same study will, however, give us a clearer understanding on the changes that mindfulness make in the brain.

Altogether, the results from this set of studies support the theoretical description of mindfulness as a more "present anchored attention" state (Bishop et al., 2004), giving credit to its cognitive component. It should be highlighted that while previous research has focused on mindfulness meditation, our studies aimed at elucidating the neurocognitive mechanisms of dispositional mindfulness, which is necessary for a complete understanding of mindfulness. To this respect, future research should investigate different stages of mindfulness. This would help to go beyond the descriptions that the contemplative field provide on the mindfulness construct and to potentially examine the intersection between the different stages of mindfulness and those aspects of it (disposition, state, training and expertise) that have been taken interchangeably in the literature. In this regard, some proposals have already envisioned how the field can advance toward a more holistic understanding of mindfulness (Lin et al., 2021) and we thoroughly recommend to follow these lines in future studies.

Cognitive and Neural Mechanisms of Grit

Another positive trait that provides an interesting scenario to investigate the interplay between personality and cognition is grit. Although in principle conceptualized as a non-cognitive trait, the tendency to engage in long term goals with enduring passion and perseverance entails a high level of self-regulation. In fact, the role of cognition in grit is also considered in models of the trait that emphasize a component of adaptability to situations , which refers to flexibility to actively adapt to changing environments (Datu et al., 2017). While the few studies that have tried to link grit to cognitive profiles have produced limited findings (Kalia et al., 2018, 2019), brain studies suggest a role of control and reward areas in grit trait (Myers et al., 2016; Nemmi et al., 2016; Wang et al., 2017, 2018). The adoption of precise frameworks on cognitive control together with continuing the brain research with different theoretically converging measures is key, in our view, to define the possible neurocognitive mechanisms of grit. With this in mind we ran Studies 3, 4 and 5 (Chapters VII, VIII and IX).

The “Unity and Diversity of Executive Functions” framework of Miyake et al. (2000) is specially suitable to approach the cognitive mechanisms of grit, as it provides a thorough differentiation of subcomponents of cognitive control that may be related to grit in different manners: namely, flexibility, working memory updating and inhibition (Friedman & Miyake, 2004; Miyake et al., 2000; Miyake & Friedman, 2012). Additionally, to get a broader picture of cognitive control in grit the DMC (Braver, 2012) theory may be especially helpful, because individual differences might rely not on the isolated components of control but in the way they are conjugated. From this perspective, we conducted Study 3 in an exploratory fashion and 5 to confirm findings in a different population. Results from Study 3 show that gritty participants do not exhibit better executive function performance. Rather, they show a less proactive (more balanced) use of the control modes. In addition, mindfulness and impulsiveness showed to account for more variability in grit than cognitive variables did. Interestingly, the pattern of less proactive (more balanced) use of cognitive control was replicated in Study 5 in older adults, again revealing that this did not result in better general performance. All in all, these results point to a specific pattern of control in gritty individuals that is somehow "cautious" and aware of the changes in context, but that does not lead to better performance, at least in the short term.

The notion that grit is not necessarily linked to enhanced cognitive performance is inherent to grit (Duckworth et al., 2007; Duckworth & Quinn, 2009; Perkins-Gough, 2013). However, there seems to be a specific cognitive profile that is characteristic of gritty people. In both studies (3 and 5) we found that gritty individuals show a less proactive control mode. In the case of older adults, and contrary to what was found in the case of mindful people (their less proactive mode had positive outcome in general performance), grit had a negative relationship with general performance and control (BY) trials, although they commited less errors in AY trials, reflecting a less proactive tendency. Those results might be indicating that gritty people do not drive their behavior by initial contextual cues, but they keep attentive to new information when giving a response that, in turn, may hinder their performance when reliance on previous contextual cues could facilitate responses. This goes in line with previous findings showing no benefits of providing alerting cues to gritty individuals (Kalia et al., 2018). Kalia et al. (2018) interpreted their findings in terms of more baseline sustained attention in gritty participants, so that they keep attentive and "on task" even in easier trials where a previous contextual cue facilitates the response. Although not our first thought, this pattern fits well with the idea of enduring perseverance towards a long-term goal, whereby even in favorable contexts effort should be maintained.

However, it is worth pointing out that even though this cognitive pattern emerged, it did not account for significant variability. Thus, Study 3 revealed that other personality variables (mindfulness and impulsiveness) were more predictive than our measured cognitive variables. This result highlights the relevance of considering other personality constructs in the expression of grit. On the one hand, the positive relationship between mindfulness and grit is particularly relevant for the present dissertation. Our results replicate previous ones with different ethnical groups (i.e. Li et al., 2018; Raphiphatthana et al., 2018, 2019; Raphiphatthana & Jose, 2020) and add to those by showing such an association also in older adults. The link between these two positive traits and the positive outcomes that both have shown to have separately, lead us to wonder whether a combined intervention of mindfulness and grit values and practices along with cognitive training (to enhance balanced cognitive control) would be more effective than previously designed mindfulness and grit trainings (i.e., Hwang, & Nam, 2021; Kabat-Zinn, 2003). On the other hand, the negative association between impulsiveness and grit matches previous findings relating grit to other self-control construct and points to the need of considering related measures in future grit studies to better understand the communalities and differences between grit and self-control related concepts (Credé, 2018; Credé et al., 2017). Taken as a whole, our results indicate a "cautious" "on task" style of control, with present focused attention that is not driven by impulsive behavior.

If this "on task" style of control is characteristic of gritty individuals, it should have EEG signatures either at rest or while performing a task. In fact, the few previous studies that explored the neural mechanisms of grit have shown an imprint on control and reward processing areas of the trait (Myers et al., 2016; Nemmi et al., 2016; Wang et al., 2017, 2018). From these findings and our own behavioral results (Study 3), we decided to examine the neural correlates of grit both at rest and while performing a learning task in Study 4. To do so, we selected a broadly employed EEG-derived index of cognitive control (the TBR, Angelidis et al. 2016) as well as complexity indexes thought to capture effort while performing a task (Stam, 2005). In addition, we included a measure of impulsiveness to better understand its similarities and differences with grit at the neural level. Our results revealed differences in brain activity only while performing the learning task. Gritty participants, particularly those with high consistency of interest facet, showed lower levels of TBR, which is thought to reflect greater cognitive control. In addition, there was a link between the facet of perseverance of effort and greater entropy while performing the task, which may be indicative of more effort and engagement in the task. Finally, impulsiveness and demographic variables did not modulate the effects at the facet level. These results fit well with our idea of gritty participants having a more "cautious" and "on task" style of control, wherein they keep control and effort along the whole task.

Our findings regarding grit, then, seem to support the idea that gritty people focuss with effort on what they do, which is in line with previous behavioral and brain data. Although suggestive, the present and previous findings should be taken with caution because some of the studies were exploratory, the effect sizes found are humble, and we employed innovative measures of brain activity in the field. Hence, future studies should replicate and extend these findings regarding mindfulness and grit. It also becomes evident from our studies that future studies should include measures of different personality traits to understand the full scope of grit. Particularly, studies combining mindfulness, self-control related constructs and other positive traits (i.e., growth-mindset) in the study of the psychological mechanisms (including or not its neurocognitive processes) of grit would be highly valuable. This is of special relevance because mindfulness has been shown to be linked to the (Big Five) trait of conscientiousness (Giluk, 2009), which shows some overlap with grit (Credé, 2018; Credé et al., 2017). These studies may be crucial for developing evidence-based grit (and others) training programs.

In the search of the cognitive basis of personality traits it is also relevant to ask oneself whether personality leads to specific cognitive styles or whether specific cognitive patterns shape personality. The answer is probably far from simple. Because some vital experiences (i.e., bilingualism; Morales et al., 2013, 2015) seem to mold cognition, it could be the case that a complex combination of genetics (partially determining personality and cognitive functions) and life experiences form personality-cognition tandems. These questions, are also relevant for the study of cognitive control. The growing body of multidisciplinary studies that include cognitive control generates new questions also for this field. Particularly, the present findings highlight the role of individual differences in cognitive control.

Finally, a word of caution should be said regarding mindfulness and grit traits. Although most results about these traits have shown their positive outcomes, there are also some studies that suggest that not all that glitters is gold. For instance in some occasions grit has been linked to more frequent suicide attempts (Anestis & Selby, 2015) and the non-judging facet of mindfulness to more criminal cognitions in people in jail (Tangney et al., 2017). In addition, some authors have argued that the adoption of a simplistic positive psychology approach may also lead to a simplistic view of suffering as a failure of self-control, which could result in obviating injustices such as racism, sexisms or poverty (Yakushko, 2018). Similarly, some authors have pointed to the risk of falling in cognitive capitalism, where the traits are fostered to meet the need of productivity, while trying to implement positive psychology (Reveley, 2013). Much research is still to be done regarding positive traits, an investigation that surely will benefit from an open but critic mind.

Conclusions

When studying the factors that influence health and well-being, some personality traits show to play an important role, and this is the case of mindfulness and grit (Brown & Ryan, 2003; Duckworth et al., 2007). The study of their underlying neurocognitive mechanisms is then crucial to understand 1) their nature; 2) their ways to produce positive outcomes; and 3) develop evidence-based programs to foster them. In this dissertation we aimed at unveiling the neurocognitive mechanisms of both traits. Our results show a particular pattern of cognition and brain activity of both traits. On the one hand, mindfulness consistently showed a tendency towards a balanced use of control modes both in young and healthy older adults, which may represent a more efficient allocation of cognitive resources together with a more "anchored to the present" attention. This intelligent resources use was also evident in a brain pattern suggestive of less mind-wandering and self-reference processes at rest. On the other hand, grit does not seem to be linked to enhanced executive functioning in the short term, but it shows a particular pattern of control modes (less proactive) suggesting a "cautious" approach to tasks both in young and healthy older adults. This cognitive pattern agrees with brain-related results that show neural signatures of control and effort during task linked to dispositional grit. These findings are especially remarkable for the fields of mindfulness and grit but also for cognitive control research. All five studies provide evidence of the individual differences that cognitive control gathers and that should be considered in the studies on cognitive control. Although mindfulness and grit show distinct neurocognitive patterns, similarities do exist and both traits have been shown to correlate. In addition, other dispositions such as impulsiveness show to be negatively related (although not totally) to the grit trait. Finally, the cognitive patterns of control were also present in older adults, which indicates that this profile is linked to the traits regardless of age and highlight the need to study the possible role of cognitive style in the positive outcomes of these traits in the old age (De Frias, 2014; De Frias & Whyne, 2015; Rhodes et al., 2017; Rhodes & Giovannetti, 2021). We believe our results open a venue for future studies on the neurocognitive mechanisms of mindfulness and grit but also in their possible relationship and the development of evidence-based programs to foster them.

Chapter XI. Resumen y Conclusiones

Una de las habilidades más fascinantes del ser humano es su capacidad para evolucionar, adaptarse y mejorarse a sí mismo, lo que en ocasiones le lleva incluso a desarrollar su más alto potencial. Estas habilidades suelen derivar en mayor auto-satisfacción, éxito y bienestar. Sin embargo, el estudio científico de las fortalezas del ser humano comenzó hace tan solo dos décadas, promovido por el nacimiento de la Psicología Positiva (Seligman y Csikszentmihalyi, 2000; Vázquez y Hervás, 2009), que pretende cubrir una necesidad ya señalada por distintos autores en el pasado (Maslow, 1954). Tradicionalmente, los esfuerzos desde la Psicología se habían dirigido fundamentalmente al estudio de las enfermedades mentales y su tratamiento, foco que en las últimas décadas se ha ampliado hacia el estudio del bienestar, dada la creciente necesidad de mejorar la condición humana en lo individual y lo colectivo. En efecto, el estudio científico de estos temas es esencial para la promoción de la salud, ya que esta comprende el estado de completo bienestar a nivel físico, mental y social, y no la mera ausencia de enfermedad (OMS, 1948). En el ámbito de la psicología positiva, varios rasgos de personalidad han tomado relevancia recientemente debido a la evidencia que muestra su relación con el bienestar; entre ellos se encuentran los rasgos de *mindfulness* y tenacidad (*grit*) (p.e., Brown y Ryan, 2003; Salles y cols., 2014).

El rasgo de *mindfulness,* o atención plena, se refiere a la tendencia a dirigir la atención a la experiencia presente en una actitud abierta y libre de juicio (Bishop y cols., 2004; Kabat-Zinn, 2003). La frecuencia con que las personas entran en el estado de atención presente difiere de forma natural entre individuos. Mientras muchas personas se sienten abrumadas por pensamientos sobre el pasado o el futuro, otras tienden a estar abiertas a lo que ocurre a su alrededor. La capacidad de ser conscientes del entorno permite a estos individuos adaptarse de forma flexible a él, lo que conlleva varios beneficios (Brown y Ryan, 2003). Además, esta tendencia a estar presente puede cultivarse con la meditación (Chiesa y Malinowski, 2011). Entre los beneficios que se han asociado al *mindfulness* se encuentran una mejor salud mental (Grossman y cols., 2004; Tomlinson y cols., 2018), habilidad cognitiva más eficiente (Cásedas y cols., 2019; Verhaeghen, 2021) o mejores relaciones en la comunidad y el trabajo (Good y cols., 2016; Mesmer-magnus y cols., 2017).

Por otro lado, el rasgo de *grit* designa la inclinación a involucrarse en retos a largo plazo con tenacidad y pasión continuas (Duckworth y cols., 2007). Este rasgo es característico de personas que persiguen sus sueños a pesar de los reveses. No se llegaría al monte Everest, por ejemplo, si no fuese con *grit*, tampoco se sacaría una oposición o se completaría un doctorado. La idea detrás del rasgo de personalidad de *grit* es que la consecución de un éxito no es la mera expresión de un talento o habilidad, sino que depende del esfuerzo continuado que se hace para conseguirlo y de la pasión, y el propósito, que lleve a continuar.

Este rasgo de personalidad ha mostrado predecir el éxito académico, como terminar el instituto (Duckworth et al., 2007), el éxito profesional, como conseguir altas posiciones en una compañía (Eskreis-Winkler et al., 2014; Mueller et al., 2017), e incluso el éxito personal, como tener una larga y feliz relación de pareja o mayor satisfacción con la vida (Duckworth et al., 2007; Vainio & Daukantaitė, 2016). A pesar de que estos rasgos han despertado la curiosidad de la comunidad científica, la mayoría de la investigación hasta el momento ha proporcionado evidencia de sus efectos y no tanto de sus mecanismos. El estudio de los mecanismos, psicológicos en general y neurocognitivos en particular, de estos rasgos es crucial tanto para comprender la naturaleza de los mismos como para futuros estudios que pretendan diseñar programas basados en la evidencia para su desarrollo.

Una de las características más llamativa de las definiciones de los rasgos de *mindfulness* y *grit* es el papel fundamental que juega en ellas la auto-regulación, una habilidad que conlleva el uso de capacidades cognitivas básicas como el control cognitivo. Esta particularidad hace a los rasgos de *mindfulness* y *grit* un campo de estudio especialmente pertinente para entender la interacción entre la personalidad y los mecanismos neurocognitivos subyacentes. Por ejemplo, el mantenerse en el presente conlleva la acción voluntaria de re-localizar los recursos atencionales cuando estos divagan; por otro lado, el involucrarse en un reto a largo plazo conlleva inhibir conscientemente otras acciones más placenteras en pos de continuar las acciones que llevan al objetivo. El control cognitivo es precisamente la capacidad que nos permite dirigir nuestro comportamiento de forma voluntaria, en contraposición a actuar de forma automática. De esta manera, el objetivo principal de esta tesis ha sido indagar en los posibles mecanismos neurocognitivos de los rasgos de *mindfulness* y *grit*, donde nos preguntamos si estos rasgos están ligados a una manera particular de usar el control cognitivo (y sus bases neurales). Con tal fin hemos adoptado dos de los marcos teóricos de control cognitivo más influyentes en la actualidad; el modelo de "Unidad y Diversidad" de las funciones ejecutivas propuesto por Miyake y cols., (2000) y la teoría de "Mecanismos Duales de Control" de Braver (2012). El modelo de "Unidad y Diversidad" es especialmente adecuado para investigar diferencias individuales en control cognitivo porque describe con precisión los componentes de esta función: flexibilidad, actualización en la memoria de trabajo e inhibición. Además, proporciona tareas experimentales para medir cada uno de ellos. Estos tres subprocesos son separables (diversos) pero comparten cierto solapamiento (unitarios), haciendo posible investigar la posibilidad de que algún componente esté especialmente relacionado con un rasgo. Por su parte, la teoría de "Mecanismos Duales de Control" propone que hay diversos estilos en los que las funciones de control cognitivo pueden ser combinadas: el modo proactivo y el modo reactivo. Descrito de forma simple, el control proactivo es aquel que permite mantener la información relevante de la tarea que se quiere llevar a cabo y así prevenir interferencias. Los procesos de interferencia o conflicto surgen habitualmente tanto de nuestro pensamiento como del entorno, y el modo de control proactivo actúa como un sesgo en la atención, la percepción y la acción dirigido por el objetivo, lo que frecuentemente permite anticipar y evitar el conflicto. Por el contrario, el control reactivo supone la reactivación momentánea de la información relevante para la tarea en el momento en el que un conflicto aparece, permitiendo su resolución. Este modo de control se pone en funcionamiento únicamente ante la presencia de un evento altamente interferente, lo que exige su detección y resolución. Aunque todo el mundo podría exhibir ambos modos de control, hay personas que tienden a un modo más que a otro y otras que mantienen un uso equilibrado de ambos. Esto puede evaluarse con la tarea AX-CPT (Braver, 2012; Braver y cols., 2009). Por ejemplo, ante la intención de realizar una acción simple como ir a comprar después del trabajo se podría utilizar cualquiera de los modos de control. Una persona con tendencia proactiva mantendría la intención activa en la memoria durante toda la jornada de trabajo, lo que le permitiría prevenir la interferencia cuando una compañera la invitara a tomar algo tras acabar la jornada laboral, siendo capaz de rechazar la invitación. En cambio, una persona que usara su control reactivo, mantendría libre sus recursos cognitivos durante toda la jornada y solo ante el conflicto de la invitación reactivaría la intención de comprar y rechazaría la propuesta de tomar algo. Mientras que el control proactivo suele estar relacionado con mejor rendimiento, esto es a expensas de consumir más recursos cognitivos (Amer y cols., 2016). Así, es el correcto ajuste entre ambos tipos de control el que permite un comportamiento más adaptativo (Burgess y Braver, 2010; Munakata y cols., 2012).

En el Estudio 1 usamos dos tareas para determinar los modos de control, la AX-CPT y una tarea de cambio con clave, en participantes que diferían en su rasgo de *mindfulness* medido a través de los cuestionarios MAAS y FFMQ (Baer y cols., 2006; Brown y Ryan, 2003). La idea era conocer si los participantes con altas puntuaciones en los cuestionarios de *mindfulness* mostraban un uso particular del control cognitivo. Nuestros resultados mostraron que estos participantes hacían un uso más equilibrado del control, que parece ligado a una atención más eficiente y anclada en el presente. Es decir, los participantes con alto *mindfulness* combinaban su control proactivo y reactivo de la forma más conveniente para realizar la tarea, eran capaces de prepararse y estar atentos al contexto cuando los ensayos lo requerían, pero, además, destacaban especialmente en su capacidad para reaccionar rápido cuando surgía el conflicto. Además, los participantes con alto *mindfulness* mostraron mayor flexibilidad para cambiar de tarea y para recuperarse tras haber cometido un error (Aguerre y cols., 2020; estos resultados también están disponibles en un artículo de divulgación en castellano; Aguerre, 2021). Esta evidencia nos llevó a plantearnos si el control equilibrado y la "atención más anclada en el presente" que las personas con alto *mindfulness* mostraron tener durante la realización de una tarea, serían también característicos de estas personas en estado de reposo, es decir, cuando no están realizando ninguna tarea concreta. Específicamente, la divagación mental ha mostrado estar relacionada con mayor actividad en diversas áreas del cerebro que conforman la Red de Modo por Defecto, y que puede ser captada a través de varios índices neurales (actividad gamma frontal, EEG cuantitativo e índices de complejidad) (Berkovich-Ohana y cols., 2012). Así, en el Estudio 2 medimos esta actividad a través de electroencefalograma (EEG) para ver si difería en función del nivel de *mindfulness* de los participantes. Lo que encontramos fue precisamente que las personas con alto *mindfulness* mostraban patrones cerebrales más similares en reposo y en tarea que los participantes con bajo *mindfulness*, patrones de menor implicación en procesos de divagación mental y auto-referencia. Estos resultados van en la línea de una "atención más anclada en el presente" incluso en reposo.

En el Estudio 3 nos centramos en el rasgo de *grit*, con el objetivo de explorar sus posibles mecanismos cognitivos. Para ello empleamos las tareas sugeridas por el modelo de Miyake y cols., (2000), junto con la AX-CPT, ampliamente usada en la investigación guiada por la teoría de los Mecanismos Duales de Control (Braver y cols., 2009), y medimos otros rasgos de personalidad (*mindfulness* e impulsividad, a través de cuestionarios) para ver su relación con *grit* (medido con el cuestionario diseñado por Duckworth y Quinn, 2009). Los resultados de este estudio mostraron que el rasgo de *grit* parece no estar relacionado con un mejor rendimiento cognitivo, pero sí con un uso particular del control cognitivo, que muestra ser menos proactivo. Ante ensayos en los que las personas con bajo *grit* suelen responder rápido y acertadamente debido a que el contexto previo había sesgado la respuesta correcta (control proactivo), las personas con alto *grit* emplean más tiempo y comenten más fallos ya que consideran (erróneamente) el conflicto que el nuevo contexto trae. Hemos denominado a este estilo "precavido", en el que se prefiere prestar atención a cada estímulo incluso cuando esto no supone una ventaja para el rendimiento en la tarea actual. Además, este estudio mostró que las personas con más *grit* suelen tener también más *mindfulness* y menos impulsividad (Raphiphatthana y cols., 2018). Estos resultados nos llevaron a preguntarnos sobre los posibles mecanismos neurales del *grit*. En el Estudio 4 seleccionamos índices neurales empleados para captar diferencias individuales a través de EEG (theta-beta ratio frontal e índices de complejidad) con el fin de medir patrones de activación cerebral de las personas con alto *grit* en estado de reposo y durante la realización de una tarea. Los resultados mostraron que, en línea con un estilo "precavido" de control, los participantes con alto *grit* tenían una actividad cerebral ligada a mayor control cognitivo (menor theta-beta ratio frontal) y esfuerzo (mayor entropía) durante la realización de una tarea cognitiva (Aguerre y cols., 2021).

Dados los resultados previos, y por último, quisimos indagar en la posibilidad de que estos estilos de control ligados al *mindfulness* y al *grit* en adultos jóvenes pudiesen estar también presentes durante el envejecimiento no patológico, lo que podría ayudarnos a entender por qué estos rasgos parecen ser beneficiosos para los adultos mayores (De Frias y Whyne, 2015; Rhodes y

Giovannetti, 2021). En el Estudio 5 medimos los niveles de *mindfulness* y *grit* (a través de cuestionarios) de adultos mayores, junto con sus puntuaciones en la AX-CPT (Braver y cols., 2009). Los resultados de este estudio replicaron la evidencia previa con adultos jóvenes. Por un lado, mostraron una tendencia de control equilibrado, buen ajuste entre control proactivo y reactivo, ligada a adultos mayores con alto *mindfulness*, que podría estar indicando un uso más eficiente de sus recursos cognitivos. Por otro lado, mostraron una tendencia más "precavida" y menos proactiva en los mayores con alto *grit*, la cual no está ligada a un mejor rendimiento. Además, comprobamos que ambos rasgos estaban ligeramente relacionados entre ellos también en esta población.

En su conjunto, la evidencia proporcionada por los estudios incluidos en esta tesis permite conocer algunos de los mecanismos neurocognitivos subyacentes a los rasgos de *mindfulness* y *grit*. Por un lado, el *mindfulness* ha mostrado estar relacionado con un modo de control más equilibrado y una atención más anclada en el presente (tanto en tarea como en reposo), que parecen estar ligados a una mayor flexibilidad, tanto en jóvenes como en adultos mayores. Por otro lado, las personas, jóvenes y mayores, con alto *grit* parecen usar un estilo de control más "precavido", empleando control y esfuerzo en las tareas que realizan, aunque no por ello obtengan mejor rendimiento. Aunque estos hallazgos son solo un primer paso hacia una comprensión más exhaustiva de los mecanismos que subyacen a los rasgos de *mindfulness* y *grit*, consideramos que son especialmente valiosos porque abren una línea de investigación para futuros estudios en la intersección entre la personalidad y la neurociencia cognitiva. Además, el conocimiento preciso de los mecanismos de estos rasgos puede ser crucial para el desarrollo de programas de entrenamiento para mejorarlos (Hwang y Nam, 2021; Tang, 2011).

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