Mindfulness and enhanced executive control:

From training to trait

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Mindfulness and Enhanced Executive Control: From Training to Trait

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To all who wander

(on purpose, by accident, or otherwise).

.

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Es menos tópico que cierto decir que el doctorado es, entre otras cosas, una suerte de laberinto recorrido a ciegas donde nunca sabes cuál será el siguiente obstáculo que encontrarás. Aunque muchas veces estos obstáculos tienen un carácter meramente práctico o técnico, otras tantas su naturaleza se percibe, desde la ingenuidad característica del estudiante de doctorado, como amenaza existencial. Por suerte, a distintas alturas del laberinto se va uno encontrando con otros individuos —por lo general tan perdidos como él— con los que compartir un tramo del camino, intercambiar tribulaciones y anhelos y, aún más importante, echar incontables cervezas. Algunas de estas personas se quedarán solo unas pocas jornadas, antes de continuar el camino por sus propias galerías. Otras compartirán trechos más largos. Las hay incluso que estuvieron ahí ya antes de entrar, y que seguirán tras el final. Llegando ahora a ese final, es momento de echar la vista atrás y dar las gracias a tod@s l@s que habéis hecho este camino más transitable, ameno, y enriquecedor…

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***

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TABLE OF CONTENTS

ABSTRACTS

Abstract

From mastering a new skill, to planning our finances, to navigating the complex and dynamic world of interpersonal relationships, we oftentimes face situations in which relying on reactive or automatic behavior would lead us astray. Such situations, instead, require us to apply top-down, voluntary control of our attention and actions. This critical cognitive ability, which comprises the functions of *inhibitory control*, *working memory*, and *cognitive flexibility,* is commonly referred to as *executive control*. *Mindfulness*, in turn, is the name given to a family of mental training regimes intended to foster the regulation of attentional and emotional processes (*mindfulness training*), as well as to the psychological faculty that these practices develop (*mindfulness trait*). Could the cultivation of mindfulness help us strengthen our executive control? This dissertation was proposed with the aim to shed light onto whether or not, to what extent, and by which mechanisms the construct of mindfulness (training and trait) is linked to enhanced executive control.

Three studies along with a broad review and conceptual analysis of the state of the evidence in the field were conducted to address this overarching question. These include (a) a meta-analysis of randomized controlled trials testing the effectiveness of mindfulness training in enhancing executive control; (b) a highly-powered individual differences investigation examining the attentional and executive control basis of mindfulness trait using a novel *ANTI-Vea* task; and, (c) a multi-sample study investigating the interrelationships between self-reported trait mindfulness, external distraction (i.e., executive control of attention), and internal distraction (i.e., mind-wandering). Finally, the main results from these studies are discussed in the light of (d) an extensive meta-review and theoretical analysis of the state of the art of the target literature, which culminates in the proposal of a novel mechanistic account of the relationship between mindfulness and executive control.

The empirical and theoretical analysis conducted throughout this dissertation indicates that, based on available evidence, it can be asserted with moderate confidence that mindfulness is linked to enhanced executive control performance. This effect would be circumscribed to the domains of inhibitory control and working memory, while no relationship was revealed for cognitive flexibility. In terms of magnitude, the effect is expected to be rather small under most circumstances. In addition, available evidence suggests that mindfulness brings about this salutary cognitive effect not by enhancing executive control capacity in itself, but by enabling a more efficient use of it, possibly by causal routes that include downregulation of both affective reactivity and unintended mind-wandering as core mechanisms. The dissertation concludes with a discussion of potentially fruitful avenues for future meta-analytical and empirical research at the intersection of mindfulness, mind-wandering, and executive control.

Resumen

Desde el aprendizaje de una nueva habilidad o la planificación nuestras finanzas, hasta el manejo del dinámico y complejo mundo de las relaciones interpersonales, a menudo nos enfrentamos a situaciones en las que dejarnos llevar por comportamientos reactivos o automáticos nos llevaría por mal camino. Situaciones que, por el contrario, requieren de un control “top-down”, o voluntario, de nuestra atención y comportamiento. Esta importante habilidad cognitiva, que comprende las funciones de *control inhibitorio*, *memoria de trabajo*, y *flexibilidad cognitiva*, se conoce comúnmente como *control ejecutivo*. *Mindfulness*, por su parte, es el nombre que recibe una familia de regímenes de entrenamiento mental destinados a fomentar la regulación de los procesos atencionales y emocionales (*mindfulness* como *entrenamiento*), así como la facultad psicológica que estas prácticas desarrollan (*mindfulness* como *rasgo*). ¿Podría el cultivo del mindfulness ayudarnos a fortalecer nuestro control ejecutivo? La presente tesis doctoral fue propuesta con el objetivo de dilucidar si, hasta qué punto, y a través de qué mecanismos, el constructo de mindfulness (como entrenamiento y como rasgo) está ligado a un mayor control ejecutivo.

Para abordar esta pregunta se llevaron a cabo tres estudios junto con una amplia revisión y análisis conceptual del campo del estudio. Estos incluyen (a) un estudio metaanalítico de ensayos controlados aleatorizados testando la eficacia del entrenamiento en mindfulness en la mejora del control ejecutivo; (b) un estudio de diferencias individuales que examina las bases atencionales y ejecutivas del mindfulness rasgo empleando la novedosa tarea *ANTI-Vea*; y, (c) un estudio multi-muestra que explora las interrelaciones entre medidas autoreportadas de mindfulness rasgo, distracción externa (i.e., control ejecutivo atencional), y distracción interna (i.e., divagación mental o “mind-wandering”). Finalmente, los resultados principales de estos

estudios se discuten a la luz de (d) una extensa meta-revisión y análisis conceptual del estado del arte de la literatura objetivo, que culmina en una propuesta teórica original sobre los mecanismos subyacentes a la relación entre mindfulness y control ejecutivo.

El análisis empírico y teórico desarrollado en esta tesis sugiere que, en base a la literatura disponible hasta la fecha, existe moderada evidencia a favor de una relación positiva entre mindfulness y rendimiento ejecutivo. Este efecto se circunscribiría específicamente a los dominios de control inhibitorio y memoria de trabajo, no así a la flexibilidad cognitiva. En términos de magnitud, es esperable que el efecto sea relativamente pequeño en la mayoría de circunstancias. La evidencia disponible sugiere, además, que el mindfulness no trae consigo este saludable efecto cognitivo mejorando la capacidad de control ejecutivo, sino permitiendo una mayor eficiencia en el uso del mismo, posiblemente a través de rutas causales que incluyen la regulación de la reactividad afectiva y el mind-wandering involuntario como mecanismos principales. La tesis concluye con una discusión acerca de potenciales futuras líneas de investigación empírica y metaanalítica sobre mindfulness, mind-wandering, y control ejecutivo.

CHAPTER I: INTRODUCTION

What is mindfulness?

Origins and overview

Mindfulness is nowadays a highly popular term. Largely integrated into institutional settings as diverse as the healthcare system, the educational system, the workplace, or the military, no doubt that mindfulness has found a place in the everyday language of our modern societies (Creswell, 2017; Kabat-Zinn, 2017; Van Dam et al., 2018). However, this word by no means represents a recent concept. On the contrary, "mindfulness" is an English translation of the ancient Pali[1] word *sati*, which, as agreed upon by most scholars, originally connoted aspects related to *awareness*, *attentiveness*, and *remembering*. Particularly, in the traditional Buddhist texts *sati* alluded to a psychological faculty by which one continuously remembers to pay attention to and be aware of what is occurring within and around them (i.e., sensory, affective, and cognitive experience), moment by moment; a faculty that could be cultivated by engaging in certain kinds of *meditation* practice (Desbordes et al., 2015; Siegel et al., 2009).

Within contemporary academic and clinical contexts, the definition of mindfulness is slightly different from that found in ancient texts. While it retains the emphasis on the attentiveness to and awareness of present-moment, immediate experience, it also usually encompasses the ability to approach such experience with non-judgement and acceptance (Siegel et al., 2009; Tang et al., 2015). In addition, the term mindfulness is nowadays commonly used to refer to the specific meditation-based mental training regimes that cultivate the above-mentioned psychological faculty of mindfulness (Kabat-Zinn, 2003; Lutz et al., 2008). As will be further detailed in the next sections of this introduction, these are the two most common current meanings of the term mindfulness:

[1] Pali is the language in which the early Buddhist scriptures were recorded.

a type of meditation-based practice (*mindfulness training*), and the particular psychological faculty or disposition that it develops (*dispositional mindfulness* or *mindfulness trait*).

The scientific interest on the topic of mindfulness (regarding both training and trait) has grown exponentially over the last two decades, mirroring the number of individuals that regularly engage in some sort of mindfulness-related meditation practice. This is a burgeoning field of study, within which more than 4,000 studies were published only in 2021. While providing a thorough overview of this rich and diverse research area is beyond the aims of this introduction, an infographic summary covering various key bibliometric indices and trends in the field over the past century can be found in **Fig. 1**. In addition, interested readers are directed to the **Appendix**, where they can find a succinct review of the book *Altered traits* (Goleman & Davidson, 2017) which does offer an narrative summary of findings in this field, while also describes its origins, historical development, and prospects for the future (Cásedas, 2021).

Mindfulness as training

As outlined above, the term "mindfulness" can be used to refer to various types of meditation-based mental training regimes. Characterizing what "meditation" means also comes with inherent challenges, and a fully agreed upon definition is still lacking (Matko & Sedlmeier, 2019). However, most authors would broadly agree to regard it as a set of practices intended to regulate attentional and emotional processes to ultimately foster the cultivation of insight and well-being (Dahl et al., 2015; Lutz et al., 2008). Under this general framework, mindfulness meditation would simply be a specific family of meditation practices (for an influential taxonomy of meditation families and practices, see Dahl et al., 2015). Particularly, within research settings, mindfulness meditation is most commonly operationalized as comprised by the practices of *focused attention* and *open monitoring*

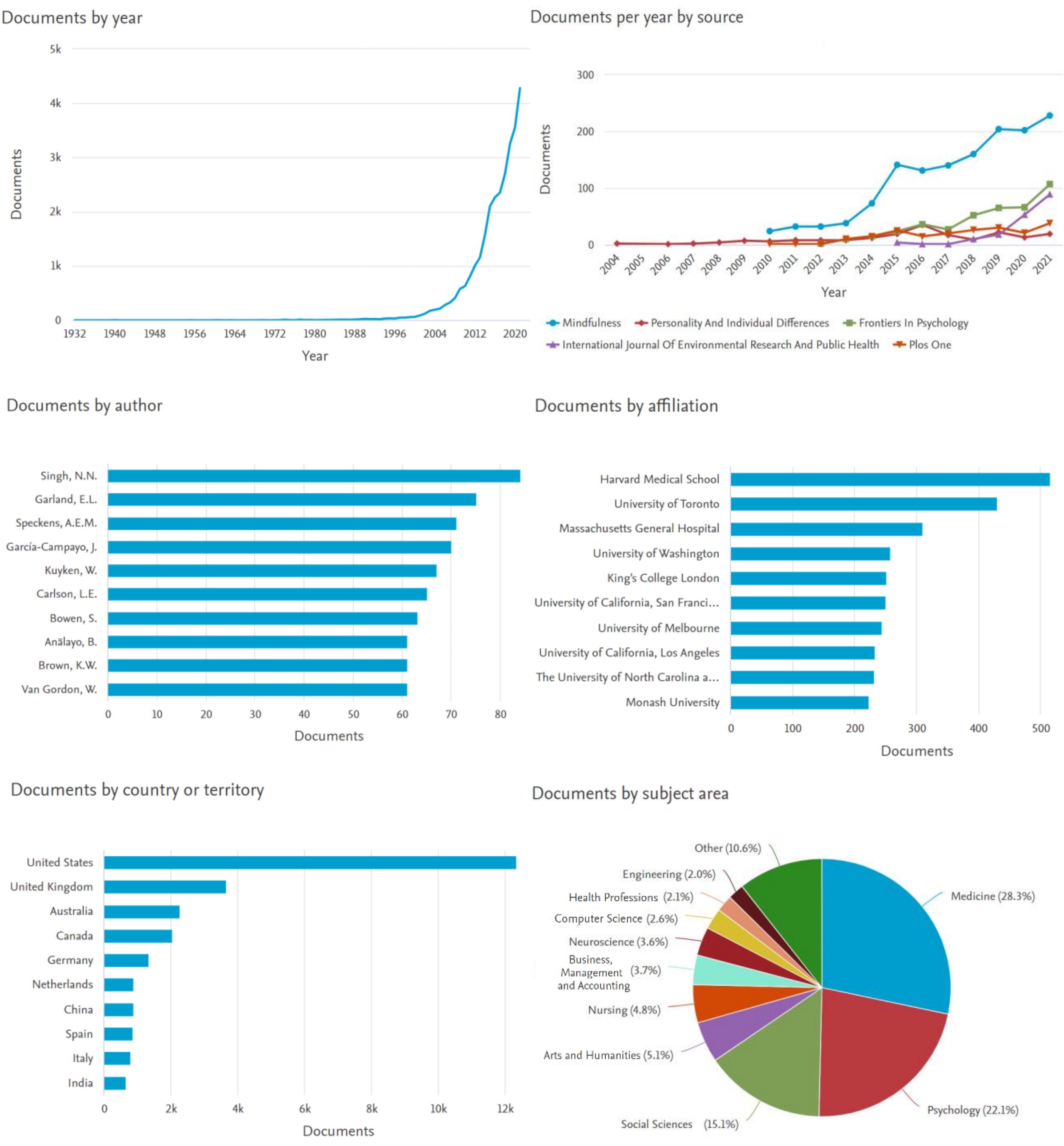

Fig. 1 Infographic summary with key bibliometric indices of the field of mindfulness research. The term "mindful*" was introduced in title, abstract, and keywords in the Scopus search engine (year range: 1921-2021). The number of publications is provided by year, journal, author, affiliation, country, and subject area.

(Lutz et al., 2008; Malinowski, 2013; Tang et al., 2015). These meditation styles are taught in most Buddhist traditions (yet some may emphasize one over the other), and are also a core component of contemporary mindfulness-based programs such as the Mindfulness-Based Stress Reduction (Kabat-zinn, 2003) or the Mindfulness-Based Cognitive Therapy (Kuyken et al., 2010).

Focused attention is commonly learnt during the initial stages of mindfulness meditation practice. During focused attention meditation, the practitioner directs and sustains their attention onto any given object, most commonly the sensations of one's breath. At the same time, the exercise requires the meditator to monitor the content of experience, so as to detect whenever the mind wanders away from the anchor of attention. When the distraction is detected, the instruction is to non-judgmentally disengage attention from it, and to restore it to the chosen object. By repeatedly going through this cycle, focused attention meditation is believed to cultivate meta-awareness, equanimity, and various attention-regulative skills, including the stability of sustained attention, as well as the capacity to monitor, disengage, and reorient attention away from distraction (Lutz et al., 2008; Malinowski, 2013). As the practice advances, the mind wanders less often, distraction is more readily detected, and the ability to sustain attention becomes gradually effortless (Lutz et al., 2008). While sometimes maintained as primary technique even in advanced stages (Wallace, 1999), focused attention is more often used to stabilize the mind and prepare the meditator for the subsequent practice of open monitoring meditation (Laukkonen & Slagter, 2021; Lutz et al., 2008).

As focused attention progresses, the well-trained monitoring skill becomes the key aspect of the practice in the transition to open monitoring. During open monitoring meditation, thus, the aim is to simply remain in the monitoring state, without focusing in any particular object but rather allowing whatever arises in experience to come and go (being sensations, feelings, or thoughts) from an accepting and non-judging stance (Lutz et al., 2008). In the initial stages of open monitoring meditation, the practitioner may require to invest more effort not to be “caught up” by specific elements of the content of experience (i.e., not to become cognitively fused with them, as opposed to being meta-aware of them). However, as the practice stabilizes, it becomes progressively effortless to simply appraise experience as a whole, as if the phenomenal background (e.g., the emotional tone, the quality of attention) would have been brought to the forefront of experience. By repeated practice, open monitoring meditation allegedly leads the practitioner to an increasingly acute, but less emotionally reactive, meta-awareness of their inner mental processes (Laukkonen & Slagter, 2021; Lutz et al., 2008).

Mindfulness as trait

As it has just been described, mindfulness training is theorized to engage and cultivate psychological qualities that are both cognitive (e.g., attention, awareness) and affective (e.g., non-judgement, acceptance) in nature. Closely mirroring this two-dimensional depiction, most contemporary conceptualizations of trait mindfulness generally consider it a dispositional (yet not fixed) psychological tendency to (a) attend to present-moment experience while (b) having an attitude of acceptance toward it (Bishop et al., 2004; Lindsay & Creswell, 2017; Rau & Williams, 2016)[2]. These two factors have been referred to as the “*what*” (attention monitoring) and the “*how*” (accepting attitude) of mindfulness (Baer, 2019). Trait mindfulness can be considered a psychological faculty that is both innate and modifiable. It is innate, since it is present in every individual to a greater or lesser extent. Yet it is also modifiable, given that engagement in mindfulness training has been shown to enhance it (for meta-analyses, see Goldberg et al., 2018;

[2] While this is the most common view of mindfulness as a psychological construct, note that the definitional issue is not exempt of contentious debate in this case either. See Grossman (2011) and Van Dam et al. (2018) for critical discussions on the topic.

Quaglia et al., 2016). **Fig. 2** provides a schematic representation of the process by which repeated mindfulness practice is theorized to produce enduring changes at the trait level.

The psychological faculty of mindfulness is most commonly assessed by means of self-report scales (Baer, 2019). This methodological particularity is coupled with both limitations and strengths. On the one hand, self-reports are subject to certain idiosyncratic biases, mostly due to its subjective nature (Grossman, 2011; Quigley et al., 2017). For instance, the interpretation of self-report items might vary depending on the specific population in which they are administered (something which has occasionally been documented when comparing samples of participants with and without meditation experience; Grossman, 2011; Rau & Williams, 2016). On the other hand, questionnaires are the best available research tool for the assessment of individual differences, an important domain of inquiry complementary to that of group differences (e.g., comparing participants having received mindfulness meditation training vs. meditation-naïve participants). In addition, self-reports are a highly convenient and efficient methodology, and have shown to be capable of valid and reliable psychological assessment as long as they are well constructed and administered in their intended populations (Baer, 2019; Hersen, 2004).

Various self-report measurements of dispositional mindfulness have been developed, out of which the two more widely used are the Mindfulness Attention Awareness Scale (MAAS; Brown & Ryan, 2003) and the Five Facets Mindfulness Questionnaire (FFMQ; Baer et al., 2006). Of them, the MAAS has been object of particularly strong criticism (see Grossman, 2011). While it is particularly brief and convenient, the MAAS presents a unidimensional structure that only taps into perceived prevalence of attentional lapses (an important, yet likely not sufficient, feature to characterize mindfulness). On the contrary, the FFMQ was developed by conducting a series of factor analyses on the items of several previous scales of mindfulness, an

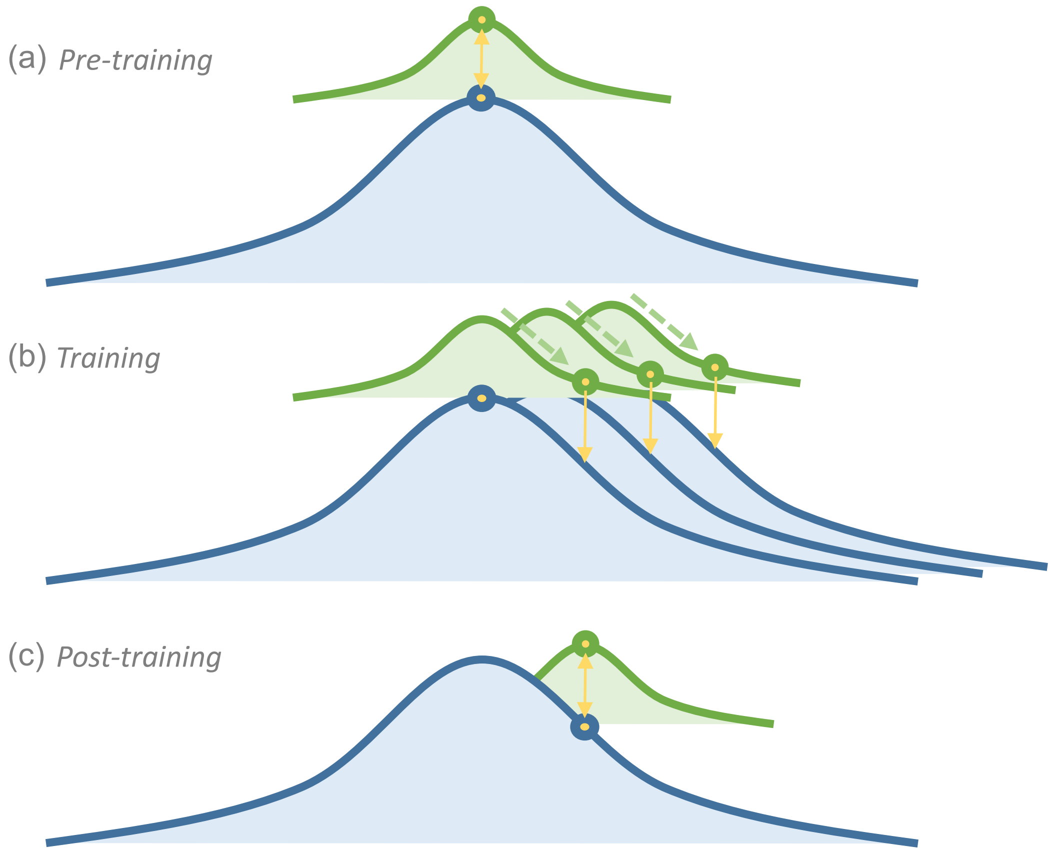

Fig. 2 Schematic representation of the process by which repeated mindfulness practice is theorized to produce enduring changes at the trait level. **(a)** Representation of the level of trait mindfulness for a hypothetical individual prior to engage in meditation practice. The blue curve represents the Gaussian distribution of inter-individual variation in trait mindfulness (with values further to the right indicating higher trait mindfulness). The yellow dot represents the individual within the curve. The green curve represents the Gaussian distribution of intra-individual variation in trait mindfulness (which is expected to change, at least to a certain extent, in response to the individual's contingencies, including meditation practice). **(b)** Engagement with meditation practice repeatedly produces high levels of "state" mindfulness (i.e., the level of mindfulness achieved transiently during and immediately after the meditation session). **(c)** If repeated meditation practice is sustained in time for sufficiently long, state-like changes are hypothesized to crystalize in a trait-like manner (see Goleman & Davidson, 2017; Kiken et al., 2015, Wheeler et al., 2017).

approach that qualified it to be representative of a rich set of aspects integral to mindfulness. By assessing *Oserving* (“noticing or attending to internal and external experiences”), *Describing* (“labeling internal experiences with words”), *Acting with awareness* (“attending to one’s activities of the moment [as] contrasted with behaving mechanically while attention is focused elsewhere”), *Non-judging* (“taking a non-evaluative stance toward thoughts and feelings”, and *Non-reactivity* (“the tendency to allow thoughts and feelings to come and go, without getting caught up in or carried away by them”; all quotes in Baer et al., 2008, p. 330), the FFMQ is arguably the most comprehensive assessment of dispositional mindfulness to date[3].

This and the previous sections have provided a succinct overview of the ancient and modern meaning of the concept of mindfulness, including a brief description of the construct both as a type of training and as psychological trait. In the sections to come, a similarly concise introduction will provided for the construct of executive control.

What is executive control?

Executive functions model

We humans have evolved in highly complex and ever-changing physical and social environments. Even though most of our behavioral repertoire has been automatized through the course of our collective and individual learning history (i.e., both phylogenetically and ontogenetically), we are oftentimes confronted with novel situations for which relying on reactive, instinctive, or automatic behavior would be maladaptive.

[3] In terms of the "what" vs. "how" classification mentioned above, Observe has been proposed to purely measure the former, while Non-judging and Non-reactivity would purely capture the latter. In turn, Acting with awareness is proposed to partly tap into both domains, while Describe would not be related to any of them (Lindsay & Creswell, 2017).

Executive control, also referred to as *executive functioning* or *cognitive control*, is regarded as the key cognitive system that allows us to respond flexibly and effectively in such situations, enabling us to adjust our actions in a “top-down” (or goal-directed) as opposed to “bottom-up” (or stimulus-driven) manner (Cohen, 2017; Diamond, 2013). At the neural level, this system has been shown to be primarily (yet not exclusively) instantiated in the prefrontal cortex (Andrés et al., 2016; Miyake et al., 2000). While automatic behavior is not always necessarily maladaptive (given that, even though inflexible, it entails faster responding), executive control is the basis of self-regulation, and has been found to be essential in a wide range of relevant aspects of life. To consider some examples, it has been linked to increased mental health (Penadés et al., 2007), physical health (Will Crescioni et al., 2011), marital satisfaction (Eakin et al., 2004), job success (Bailey, 2007), or civic behavior (Denson et al., 2011), to name a few.

Beyond this broad conceptualization, there have been numerous more specific theoretical approximations to the construct of executive control (Baddeley, 1992; Cohen, 2017; Miyake et al., 2000; Morton et al., 2011; Norman & Shallice, 1986; Posner & Petersen, 1990). While early models considered it a unitary multipurpose control system (e.g., the *central executive* in Baddeley, 1992; or the *Supervisory Attentional System* in Norman & Shallice, 1986), over time there seems to be increasing agreement in conceiving it, rather, as a collection of related yet relatively independent executive functions. Even though the specific characterization of this cognitive construct is far from being a solved scientific issue, at present, perhaps the most widely adopted “fractionated” perspective is the so-called *unity and diversity framework* of executive functions. Initially developed by Miyake and colleagues (Miyake et al., 2000; Miyake & Friedman, 2012; see also Lehto et al., 2003) and further popularized by Diamond (2013), this framework acknowledges the idiosyncratic nature of executive control (“unity”), while also distinguishes three clearly separable executive functions as being part of it (“diversity”):

working memory, *inhibition*, and *shifting* (also referred to as *cognitive flexibility*; Diamond, 2013)[4].

The function of working memory involves both the capacity of holding information "online" in spite of interference while, crucially, being able to manipulate and update it. In essence, working memory is necessary to make sense of anything that unfolds over time, as that requires holding in mind what happened earlier and relating it to what will come next (Diamond, 2013). A prototypical example of a laboratory task assessing working memory is the Backward Digit Span, in which participants have to hold in memory a string of numbers while also using that information to rehearse the same numbers in inverse order (Grégoire & Van der Linden, 1997). In turn, inhibition concerns one's capacity to deliberately withhold automatic, impulsive, or prepotent responses to guide one's behavior in a goal-directed manner. Note that this definition closely resembles the general conceptualization of executive control offered at the beginning of this section; in line with this, inhibition has been reported as the executive function that account best for the general, superordinate factor of executive control (Miyake & Friedman, 2012). Classical assessments of inhibition are the Go/NoGo (Curry, 1984) and the Flanker (Eriksen & Eriksen, 1974) tasks, which tap into response inhibition and attentional inhibition (also called executive attention), respectively. Finally, cognitive flexibility involves the ability to efficiently adapt our mental set to match the changing demands of the environment, including shifting between multiple tasks. According to Diamond (2013), this is the function that ultimately allows us to change our perspective when needed and to think "out of the

[4] Note that while the views from Miyake et al. (2000) and Diamond (2013) are highly similar, there are also subtle differences between them. In regards to working memory, the former is specifically concerned with its updating component, while the latter considers the construct broadly. As for cognitive flexibility, Miyake and colleagues are only concerned with the capacity to shift between tasks, while Diamond also considers other aspects including verbal and category fluency. In this dissertation, we adhere to the broader, more comprehensive framework proposed by Diamond (2013).

box". A prototypical example of cognitive flexibility assessment is the Trail Making Test (part B), where the participant has to follow an alphanumeric sequence alternating continuously between attending to numbers or to letters (Reitan, 1958).

Working memory, inhibition, and cognitive flexibility, in turn, are proposed to be the basis of other higher-order cognitive abilities including reasoning, problem-solving, and planning (Diamond, 2013; Rueda, 2018). While these vital processes are not the focus of this dissertation, the fact that they are built upon the three basic executive functions further underscores the importance of developing means to nurture the precious mental resource we refer to as executive control.

Attentional networks model

A second neurocognitive framework for executive control, distinct from yet overlapping with the model of executive functions just described, is the highly influential Posner and Petersen's *attentional networks model* (Petersen & Posner, 2012; Posner & Petersen, 1990; see also Raz & Buhle, 2006). This model postulates, and has spurred the generation of a great amount of evidence to support, that human attention is the result of the function of three distinct neurocognitive systems. These systems include the *executive control network*—which largely maps onto the executive functions system presented in the above section—, along with the *orienting network* and the *alertness network* (for a schematic representation of the connection between the executive functions and attentional networks models, see **Fig. 3**). The three networks have been shown to be independent from each other (both functionally and neuroanatomically), although they can and do interact in most everyday life activities. Under Posner and Petersen (2012)'s view, the executive control network is implemented mainly in the dorsolateral prefrontal and anterior cingulate cortices, and enables flexible monitoring and control of attention in favor of goal-directed

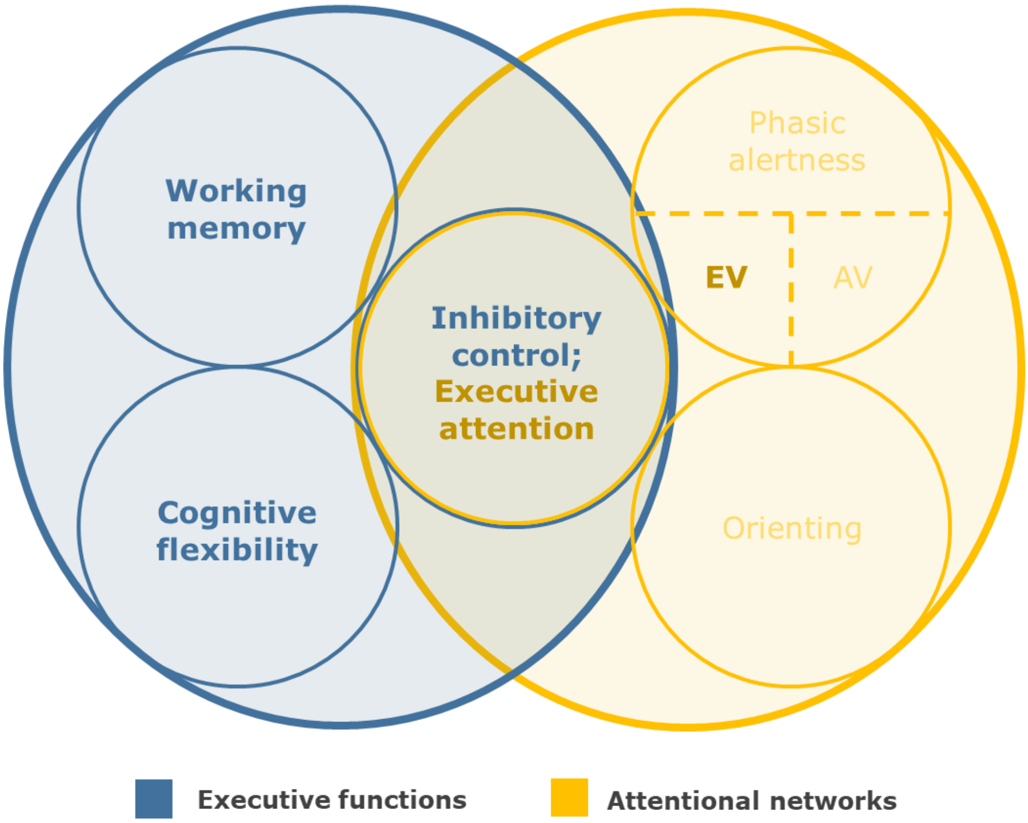

Fig. 3 Schematic depiction of the two executive-related cognitive taxonomies we adhere to in this dissertation. The processes postulated by the executive functions framework (Diamond, 2013; Miyake et al., 2000) and by the attentional networks framework (Petersen & Posner, 2012; Posner & Petersen, 1990) are represented in blue and yellow, respectively. Note that both schemes overlap, given that the executive control network in Posner and Petersen's model implements the function of executive attention, which is synonymous with inhibitory control at the attentional level. Functions considered to represent aspects of executive control are boldfaced. EV = Executive vigilance; AV = Arousal vigilance.

behavior (i.e., executive attention). The orienting network, in turn, extends over various cortical and subcortical brain regions including the frontal eye fields, the temporoparietal junction, or the superior colliculus. This system is in charge of prioritizing sensory input by selecting relevant modalities or locations to attend to. Finally, the alertness network comprises the locus coeruleus and the frontoparietal cortex, primarily in the right hemisphere, and underpins the functions of phasic alertness (i.e., the capacity for transient increases in arousal in response to singular events) and tonic alertness or vigilance (i.e., the capacity for sustaining attention in a prolonged manner).

While the attentional networks model originally considered vigilance as a unitary process, recent empirical and theoretical advances suggest that there may indeed be two dissociable aspects to it (Luna et al., 2018; 2022). Traditionally, vigilance has been defined as the capacity to detect rare but critical events sustained over time. This function is assessed with tasks such as the Sustained Attention to Response Task (SART), where participants are continuously presented with digits between 0 and 9 and are required to emit a response in all but one case (i.e., the rare event, usually the digit 3) in which they must withhold the response (Robertson et al., 1997). However, the capacity to sustain attention over time arguably involves other aspects beyond being able to accurately detect infrequent targets. Particularly, in the clinical neuropsychology literature the term usually encompasses a more basic, arousal component not related to target detection (Oken et al., 2006). This function is assessed with tasks such as the Psychomotor Vigilance Task (PVT), which requires participants merely to respond as fast as possible when a countdown, which appears in intervals between 2 and 10 seconds, is presented (Lim & Dinges, 2008). Note that these two components of vigilance are clearly distinguishable from each other: While in the former case the vigilance decrement phenomenon (i.e., the deterioration of performance as a function of time on task) is observed as a progressive decrease in target detection, in the latter case this is observed as a progressive increment in both mean reaction time and reaction time variability. These two functions have been labelled as *executive vigilance* and *arousal vigilance*, respectively (Luna et al., 2018).

The attentional networks, including vigilance in its executive and arousal manifestations, can be assessed with the *Attentional Network Tests for Interactions and Vigilance – executive and arousal components* (*ANTI-Vea*; Luna et al., 2018; 2021). The ANTI-Vea is an upgraded version of the classic ANT, the task that pioneered the assessment of the attentional networks. Using an arrows flanker paradigm (Eriksen & Eriksen, 1974) that incorporates spatial cues and warning signals, the ANT allowed to measure executive attention, orienting, and phasic alertness (Fan et al., 2002). However, it was not well suited to assess the vigilance decrement. On the contrary, and as noted above, the ANTI-Vea incorporates two novel types of trials resembling those from SART- and the PVT-like tasks, thus allowing for the assessment of both the executive and arousal components of vigilance. Additionally, and as it is the case for other versions of the task (e.g., ANTI; Callejas et al., 2004), it allows for a more independent measurement of the attentional networks as compared to the original ANT, and can also evaluate their interactions. In sum, the ANTI-vea is one of the most complete attentional assessments available nowadays; and one which—importantly in the context of this dissertation—taps into two separate executive processes, namely executive attention and executive vigilance.

The role of mind-wandering

In the previous sections, we have highlighted the importance of executive control in various adaptive cognitive operations, including the inhibition of external distraction (e.g., inhibition of distracting arrows during a flanker paradigm). But what if distraction comes *from the inside*, instead? We are all familiar with the experience by which, while attempting to pay attention to a lecture, we notice that our mind is completely focused elsewhere—from memories of past events to anticipations of situations yet to come. This is one common example of *mind-wandering*, also known as *stimulus-independent* or *task-unrelated thought*, which can be generally defined as the cognitive process by which we engage in thoughts unrelated to the current demands of the external environment (Schooler et al., 2011; Smallwood & Schooler, 2015). Mind-wandering is a ubiquitous mental phenomenon, estimated to occupy between 20% and 50% of our waking hours

(Killingsworth & Gilbert, 2010; Seli, Beaty, et al., 2018). At the neural level, mind-wandering is mainly the result of activity in the *default mode network*, a large-scale network extending over medial frontoparietal regions of the brain (most notably the medial prefrontal and the posterior cingulate cortices; Andrews-Hanna et al., 2014)[5]. While mind-wandering has been linked to various positive outcomes when displayed in the right situations (e.g., Franklin et al., 2013; Gable et al., 2019), it is broadly acknowledge that mind-wandering episodes in inappropriate contexts can and do markedly impair performance in tasks that demand attentional resources (for a meta-analysis, see Randall et al., 2014).

Several theoretical proposals have been formulated to explain why the mind wanders (McVay & Kane, 2010; Smallwood, 2013; Smallwood & Schooler, 2006; Thomson et al., 2015). Interestingly, and while they differ in various key tenets, in all of them executive control is postulated to play an important role. Smallwood and Schooler (2006) provided the seminal account that would spur this research field, getting the study of the wandering mind at the forefront of mainstream psychological science. According to these authors, mind-wandering occurs when a personally relevant goal (e.g., an ongoing unresolved personal problem) activates a shift of executive control away from the primary task, leading to superficial representations of the external environment and performance errors. Under this view, therefore, mind-wandering paradoxically reflects itself an executive process by which we engage, often unintentionally, in a sort of problem-solving mode related to personal concerns to the detriment of the task at hand (Smallwood &

[5] While this has traditionally been the dominant view regarding the neural basis of mind-wandering, note that a considerable amount of work also implicates executive-related brain areas as being relevant to it (for a meta-analysis, see Fox et al., 2015). This may be related to a recent theoretical characterization of *intentional* and *unintentional* mind-wandering as two distinct phenomena; although more research is needed in this regard, the former has been proposed to reflect a more executive process, being thus a better candidate to recruit executive-related brain regions (Seli, Risko, Smilek, et al., 2016).

Schooler, 2006). In contrast, McVay and Kane (2010) proposed that mind-wandering does not require executive resources but, instead, reflects an executive control failure. Under this view, the endogenous *ignition* (i.e., the process by which a specific thought emerges in consciousness; Dehaene & Changeux, 2011) that occurs during mind-wandering is also instantiated by the individual's personal current concerns. However, it is an executive control failure that allows the intrusion of the mind-wandering episode to take over, thus leading to impoverished performance in the primary task (McVay & Kane, 2010). These two accounts have sometimes been referred to as the *Control X Concerns* and *Control failure X Concerns*, respectively.

More recently, Smallwood (2013) formulated the *process-occurrence framework* of mind-wandering in trying to integrate both previous perspectives. According to this framework, it is critical to specify whether a given explanation of mind-wandering refers to *why* it happens (i.e., what are the events that control the *occurrence* of the experience) or to *how* it happens (i.e., what are the *processes* that ensure the continuity of the experience once initiated). Following this logic, it is argued that Smallwood and Schooler (2006) postulate that executive control is required for the maintenance of mind-wandering (i.e., process) while McVay and Kane (2010) theorize that an executive control failure is needed to initiate the mind-wandering episode (i.e., occurrence), being both views, therefore, not necessarily incompatible but rather complementary.

Finally, and also building upon the two initial theoretical models, Thomson et al. (2015) proposed the *resource-control account*, a relevant framework in the context of sustained attention research. According to the resource-control theory, executive control is needed to allocate the attentional resources to the task at hand, thus preventing them to go to mind-wandering (which is understood as the mind's default state). Over time-on-task, executive control progressively wanes, which translates into more resources being directed to mind-wandering, and therefore into increased performance costs (Thomson et al., 2015). Importantly, and as noted before, the resource-control account is only concerned with why mind-wandering progressively increases (and performance decreases) *over time-on-task*; however, and unlike the other three theories, it remains agnostic about why mind-wandering happens in the first place (beyond stating that it is the default state of the individual).

As shown, the specific characterization of the relationship between mind-wandering and executive control is dependent on the theoretical framework adopted. Nonetheless, all models agree to consider mind-wandering as antithetical to executive control *at the functional level*. In other words, in all cases the occurrence of mind-wandering is conceptualized as detrimental for performance in tasks that require the exertion of executive control. In addition, the three accounts that address why mind-wandering happens in the first place (and not only why it increases over time-on-task; Thomson et al., 2015) agree to consider the activation of personally relevant goals and concerns as a critical mechanism for the initiation of the mind-wandering episode (McVay & Kane, 2010; Smallwood, 2013; Smallwood & Schooler, 2006).

* * *

Having described the main theoretical constituents of this PhD dissertation, namely mindfulness and executive control—including its relationship to mind-wandering—the following chapter will introduce readers with the general and specific aims of our work, along with a brief overview of the research conducted to achieve them.

CHAPTER II: AIMS AND OVERVIEW OF RESEARCH

Aims and overview of research

The preceding chapter introduced the constructs of mindfulness (both training and trait) and executive control (including its relationship to mind-wandering), describing the processes and elements they comprise according to some of the most firmly stablished scientific models available to date. In this chapter, we will concisely address the theoretical and empirical background for a potential link between mindfulness and executive control (see **Chapters III** to **V** for more in-depth discussions) and, on that basis, we will delineate the general and specific aims pursued by the present PhD dissertation.

As introduced in the section above, mindfulness meditation is theorized to repeatedly engage several (executive) attentional functions (via focused attention practice) and to enhance one's capacity to be meta-aware of and uncouple from mind-wandering (via focused attention and open monitoring practice). Considering that specific attentional functions can be trained by regular repetition of tasks recruiting those functions (i.e., *brain network training*; Tang & Posner, 2009, 2014), and given the deleterious impact of mind-wandering on executive processes, mindfulness meditation training has been regarded as a potential means for the enhancement of executive control (e.g., Lindsay & Creswell, 2017; Malinowski, 2013). In addition, some authors postulate that mindfulness meditation is a type of *brain state training* that could impact cognition also indirectly, mainly by producing parasympathetic dominance in the autonomic nervous system (Malinowski & Shalamanova, 2017; Tang & Posner, 2009, 2014). Complementarily, if we assume that mindfulness training develops the psychological faculty of mindfulness (**Fig 2**; see also Goleman & Davidson, 2017; Kiken et al., 2015; Wheeler et al., 2017), high levels of mindfulness trait (being it innate or cultivated) could be hypothesized to be linked to similar outcomes to those resulting from mindfulness training, including improved executive control.

These arguments, along with the results of several seminal studies, led to the common claim that mindfulness, particularly as a type of training, was indeed linked to enhanced executive control (e.g., Malinowski, 2013; Tang et al., 2015; Teper et al., 2013). However, and as will be further discussed in the following chapters, by the time this PhD project was conceived the state of the evidence in this regard was arguably inconclusive, mainly due to the various methodological limitations that pervaded the early mindfulness literature (Van Dam et al., 2018). On this basis, the present dissertation was proposed with the general aim of *deepening the scientific understanding of the relationship between mindfulness and executive control-related processes* in adult population, in terms of both the existence and magnitude of the purported association, as well as the mechanisms that could potentially explain it. The achievement of this general aim was implemented in three empirical studies (see **Table 1** for a comparison chart) as well as in the overarching conceptual analysis provided in the **General Discussion**. Each of these four sections aimed to attain several more specific aims, as described next.

Table 1

Studies Comparison Chart

	Design	Mindfulness	Executive control assessment	Executive control context
Study I	Experimental	Training	Cognitive-behavioral (objective)	Laboratory task
Study II	Correlational	Trait	Cognitive-behavioral (objective)	Laboratory task
Study III	Correlational	Trait	Questionnaire (subjective)	Daily life

Note. Design and methodological features of the three studies included in this PhD dissertation.

In **Study I** (**Chapter III**) we conducted a systematic review and meta-analysis of studies testing the effectiveness of mindfulness training in enhancing executive control. Specifically, we meta-analysed studies that trained participants in either focused attention or open monitoring (or both) types of meditation, and that assessed pre- to post-training changes in at least one executive control function (i.e., working memory, inhibitory control, or cognitive flexibility). In addition, we evaluated the potential impact of methodological and publication biases in the reviewed literature. Importantly, only randomized controlled trials (RCTs) were included in the study. By adopting an exclusively experimental approach (i.e., RCT), this work aimed to achieve one of the most relevant specific aims of the dissertation, namely: *to stablish a causal link between the practice of mindfulness meditation and the enhancement of executive control*. This study has been published in *Mindfulness* (Cásedas et al., 2020a), for which there is also a popular science version published in *Ciencia Cognitiva* both in English (Cásedas et al., 2020b) and Spanish (Cásedas et al., 2020c).

Having observed a causal link between mindfulness training and enhanced executive control (Cásedas et al., 2020a), in **Study II** (**Chapter IV**) we adopted an individual differences research approach. Particularly, we set out to investigate the attentional and vigilance correlates of trait mindfulness by using the online version of the ANTI-Vea task and the FFMQ, respectively. This methodological approach proved to be highly efficient to recruit a large sample of participants. This was a key aspect of the study, given the observation that most previous similar research used samples sizes likely underpowered to detect effects expected to be small in magnitude. Moreover, the use of the ANTI-Vea allowed us to measure a constellation of (transient and sustained) attention processes, including both executive attention and executive vigilance. The main specific aim of this study was, therefore, *to stablish a correlational link between trait mindfulness, the attentional networks, and sustained attention, with a particular focus on both executive* *attention and executive vigilance*. Additionally, the use of the FFMQ allowed us to explore which specific aspects of mindfulness (i.e., which facets), if any, were of special relevance in their relation to executive control. The analysis plan and hypotheses of this study were preregistered at the Open Science Framework (https://osf.io/gb6c7/), and its results have been published in *Mindfulness* (Cásedas, Cebolla, et al., 2022).

In **Study III** (**Chapter V**), we conducted a multi-sample individual differences investigation on the relationship between mindfulness trait, subjective executive attention, and subjective mind-wandering. This study was motivated by our increasing interest in mind-wandering as a potentially highly relevant process to take into account in the relationship between mindfulness and executive control. In particular, we addressed the relationship between FFMQ scores and (1) self-reported ability for attentional control of *external distraction*, and (2) self-reported susceptibility to engage in mind-wandering (i.e., *internal distraction*). In light of recent discussions highlighting the importance of assessing *intentionality* in the study of mind-wandering, we set out to assess both intentional and unintentional types mind-wandering by using the Mind-Wandering Deliberate and Spontaneous (MW-D/MW-S) scales (Carriere et al., 2013). Given that there is currently no available version of this instrument in our language, the first specific aim of this study was *to develop and validate the Spanish version of the MW-D/MW-S scales.* As for its second specific aim, by using a multiple linear regression approach we set out *to explore whether or not, and to what extent, attentional control and mind-wandering were uniquely linked to the facets of mindfulness.* Given that internal and external distraction are known to be partially overlapping processes, a combined regression analysis allowed us to assess the relative importance of each of them in their relationship to mindfulness. The manuscript of this study is currently under review in *Mindfulness* (Cásedas, Torres-marín, et al., 2022).

Finally, in the **General Discussion** (**Chapter VI**) we place our findings in the broader context of the mindfulness, executive control, and cognitive training literatures. By integrating empirical and theoretical insights from these fields, we aim *to comprehensively address the empirical question of whether or not mindfulness (training and trait) is linked to enhanced executive control, and to discuss potential mechanistic pathways explaining the relationship.* To this end, we provide a non-systematic umbrella review of the available meta-analyses of experimental, quasi-experimental, and correlational studies addressing the relationship between mindfulness and executive control in adults (of which the **Study I** of this dissertation was the first to be published), and propose a tentative theoretical model that emphasizes the primary role of affect and mind-wandering in the executive control gains observed after training in mindfulness meditation. To conclude, we present some preliminary results from an in-progress meta-analysis on the impact of mindfulness training on mind-wandering as a first step in testing the model, and provide directions for future research to continue testing it.

CHAPTER III: STUDY I

Does Mindfulness Meditation Training Enhance Executive Control? A Systematic Review and Meta-Analysis of Randomized Controlled Trials in Adults.

The content of this chapter has been published as:

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Abstract

Objectives: Over the last years, mindfulness meditation has been claimed to be effective in enhancing several cognitive domains, including executive control. However, these claims have been mostly based on findings pertaining to case-control and cross-sectional studies, which are by nature unable to reveal causal relationships. Aiming to address this issue, we set out to conduct the first quantitative assessment of the literature concerning mindfulness meditation as an enhancer for executive control considering only randomized controlled studies. **Methods:** We conducted a systematic review and meta-analysis covering experimental studies testing the effect of mindfulness meditation training on at least one executive control function (working memory, inhibitory control, or cognitive flexibility) in adult samples. Four databases were examined, resulting in the identification of 822 candidate references. After a systematic filtering process, a set of 16 studies was retained for evaluation, of which 13 could be included in a subsequent meta-analysis. **Results:** We found an average effect size of $g = 0.34$ [0.16, 0.51], indicating a small-to-medium effect of mindfulness meditation training in enhancing executive control. Effect sizes for individual functions were $g = 0.42$ [0.10, 0.74] for working memory, $g = 0.42$ [0.20, 0.63] for inhibitory control, and $g = 0.09$ [−0.13, 0.31] for cognitive flexibility. Funnel plot asymmetry analysis revealed no evidence of publication bias. **Conclusions:** Taken together, our findings provide preliminary and moderate yet positive evidence supporting the enhancing effects of mindfulness meditation on executive control. Shortcomings of included studies and considerations for future empirical and meta-analytical research are discussed.

Introduction

The scientific interest in mindfulness meditation has grown exponentially over the last decades (Tang, 2017; Van Dam et al., 2018). In recent years, studies have reported beneficial effects of mindfulness meditation on outcomes pertaining to a variety of domains, including mental and physical health (Grossman et al., 2004), brain and cognitive function (Tang et al., 2015), and interpersonal functioning (Mcgill el al., 2016). In parallel, several mindfulness-based programs are currently being integrated into a number of institutional settings including the healthcare system (Demarzo et al., 2015), the educational system (Sibinga et al., 2016), the workplace (Good et al., 2016), and the military (Johnson et al., 2014).

It is broadly acknowledged that there are two styles of mindfulness meditation practice: focused attention (FA) and open monitoring (OM) (Lutz et al., 2008; Malinowski 2013; Tang et al., 2015). In FA meditation, the practitioner sustains the attentional focus on a chosen object (most commonly one's breath) and returns it to this anchor each time the mind wanders. Accordingly, it is theorized that FA develops three attentional control processes, along with their underpinning neural networks: (a) the monitoring faculty that remains vigilant to mind-wandering while attention is sustained to the anchor (alerting network), (b) the ability to detect mind-wandering (salience network) and to disengage from it (executive network), and (c) the ability to redirect the focus to the anchor (orienting network) (Lutz et al., 2008; Malinowski, 2013). Some proficiency in FA meditation is required to transition to OM practice, in which the aim is to remain solely in the monitoring state maintaining an open, nonreactive attention to all arising and passing mental events. OM would further develop the practitioner's meta-awareness of inner mental processes, including mind-wandering (Lutz et al., 2008).

Attentional processes can be enhanced by regular repetition of tasks that involve specific attention networks (Posner et al., 2015). On the other hand, it is well documented that mind-wandering can substantially compromise available attentional and executive control resources, especially when needed to be sustained over prolonged periods of time (Thomson et al., 2015). By systematically strengthening the aforementioned neurocognitive networks (via FA), as well as by increasing one's capacity to be aware of and disengage from mind-wandering (via FA and OM), mindfulness meditation has been proposed as a potential means for cognitive enhancement (e.g, Lindsay & Creswell, 2017; Lutz et al., 2008; Malinowski, 2013). Under this proposal, mindfulness meditation training would enhance (executive) attention processes both by increasing available resources and by allowing for more efficient use of them. Even though these explanations remain largely speculative, empirical evidence supporting the cognitive enhancing effect of mindfulness meditation has indeed started to emerge regarding various cognitive functions which include—yet are not limited to—the executive control domain (Chiesa et al., 2011; Gallant, 2016; Lao et al., 2016).

Executive control is a central piece of human cognitive architecture. Also referred to as executive functioning or cognitive control, executive control encompasses a family of top-down cognitive processes that scaffolds human goal-directed behavior and self-regulation. Research has shown that executive control is relevant for mental and physical health (Penadés et al., 2007; Will Crescioni et al., 2011), academic and professional success (Bailey, 2007; Borella et al., 2010), or simply to enjoy a better quality of life (Brown and Landgraf, 2010). To consider some examples, better executive control has been linked to healthier eating (Calvo et al., 2014), better math and reading competence in school (Checa et al., 2008), better marital satisfaction (Eakin et al., 2004), and more prosocial behavior (Broidy et al., 2003). In turn, dysfunction of this system either due to aging, stroke, attention-deficit/hyperactivity disorder, or else—may hinder leading an independent life (Chan et al., 2008). As research shows, developing strategies and tools capable to strengthen executive control entails a highly relevant societal challenge to take on.

There have been various formulations of executive control, ranging from views considering it as a unitary multipurpose control system to fractionated models conceiving it as a collection of relatively independent executive functions (for a review, see Morton et al., 2011). Among fractionated perspectives, there is general agreement in differentiating three core executive functions: working memory, inhibitory control, and cognitive flexibility (Diamond, 2013; Miyake et al., 2000).

The present study follows the conceptual framework and definitions proposed by Diamond (2013). According to Diamond (2013), working memory involves holding information for processing while simultaneously being able to manipulate it (e.g., maintaining task-relevant information and relating it to long-term memory content in order to solve a particular problem). Examples of tasks tapping into working memory are the Backward Digit Span (that requires to hold in memory a series of numbers while rehearsing them in inverse order) or the N-Back (where the subject is presented with a sequence of stimuli, having to indicate when the current stimulus matches the one shown *n* presentations earlier in the sequence).

Inhibitory control involves being able to control one's behavior, attention, thoughts and/or emotions in order to override a strong internal predisposition or external lure in benefit of longer-term goals. The Stroop test (where the subject is required to respond to the color of the ink of words while inhibiting attending to its meaning in order to avoid the more automatic word naming response) and the Go/No-Go task (that requires the subject to repeatedly respond by pressing a button, but to inhibit that habitual response when certain rare stimuli are presented) are two popular examples of tasks tapping into different aspects of inhibitory control.

Cognitive flexibility is defined as the ability to change our mental set to efficiently adapt to the demands of the environment. It is typically measured by means of tasks such as the Trail Making Test (where the subject is required to continuously switch between responding to numbers and letters) or the Wisconsin Card Sorting Task (that requires the subject to flexibly switch response strategies based on experimenter's feedback on participants' performance). Other higher-order executive-related processes such as planning, reasoning or problem solving would be built upon the three core executive functions (Diamond, 2013).

To date, three systematic reviews have assessed the effect of mindfulness meditation over executive control in adult population (Chiesa et al., 2011; Gallant, 2016; Lao et al., 2016). Chiesa et al. (2011) evaluated the effects of several mindfulness-related practices (including Zen meditation, Vipassana retreats, or Mindfulness-Based Stress Reduction programs, among others) on a wide range of cognitive functions. Regarding executive control, the authors concluded that mindfulness training may be effective in enhancing executive attention and response inhibition (aspects of inhibitory control), verbal fluency (an aspect of cognitive flexibility), and working memory at different stages of training. Lao et al. (2016) conducted a similar review but focused on standardized Mindfulness-Based Stress Reduction (MBSR) and Mindfulness-Based Cognitive Therapy (MBCT) programs, and found preliminary evidence for working memory and cognitive flexibility (but found no evidence for executive attention, while the evidence for response inhibition was mixed). Lastly, Gallant (2016) included mainly standardized mindfulness-based programs (such as MBSR or MBCT) but also other meditation practices (such as Vipassana or Shambala meditations), and narrowed the focus of the systematic review to just executive functioning. Gallant, in contrast, found inhibitory control to be the most consistently improved executive function by mindfulness meditation training, with more variable outcomes for working memory and cognitive flexibility.

Even though these findings may seem somewhat inconsistent, the discrepancies can arguably be attributed to two reasons. First, the reviews operationalized mindfulness meditation differently. Consequently, to an extent, each of them included studies evaluating different types of programs and meditations. This conceptual divergence likely affected their results and conclusions. Second, each review followed different taxonomies of cognition and executive control, thus seeming discrepancies may be partly just a terminological issue. To bring one example, Lao et al. (2016) concluded that "studies did not support […] executive function improvements. We found preliminary evidence for improvements in working memory and […] cognitive flexibility" (p. 109). These authors conceptualized working memory as a memory sub-function, while cognitive flexibility was not subsumed by any broader cognitive category. Such cognitive classification differs from the one followed by Gallant (2016), for whom executive functioning comprises inhibition (inhibitory control), updating (working memory), and shifting (cognitive flexibility). When taking into account these divergences, previous research appears to provide initial evidence for an enhancing effect of mindfulness meditation over executive control—even if such effect is still to be characterized in terms of both the particularities of the practices that bring it about and the specific cognitive sub-domains involved.

These preliminary findings of the positive effects of mindfulness meditation training in executive control outcomes (as well as in other cognitive and non-cognitive domains) are nonetheless paralleled by significant concerns that scholars from within and outside the field have raised about the methodological rigor behind much of extant evidence (e.g., Coronado-Montoya et al., 2016; Isbel & Summers, 2017; Van Dam et al., 2018). One of the main limitations in the mindfulness literature refers to an overabundance of research methodologies that are unable to reveal causal relationships, such as the use of case-control and cross-sectional designs. High-standard methodologies such as randomized controlled trials (RCTs) have been rather scarce in the literature until recently (Creswell, 2017). Accordingly, the above mentioned systematic reviews were largely based on non-experimental (i.e., non-RCT) studies. Moreover, none of them conducted a meta-analysis, likely because the inclusion of different study designs hindered the quantitative synthesis of the results. This circumstance underscores the need for a systematic and meta-analytic assessment of the literature circumscribed to only experimental studies, so as to validate—or otherwise update—our current understanding of the field.

On the basis of the above considerations, the aim of the present systematic review and meta-analysis was to evaluate the effectiveness of mindfulness meditation (i.e., FA and OM practices) in enhancing executive control (i.e., working memory, inhibitory control, and cognitive flexibility) in adult population by—importantly—assessing RCTs exclusively. In addition, we also set out to assess whether findings in our review were likely to be overestimated by methodological biases in included studies (Higgins et al., 2011) and/or by publication bias (Sterne et al., 2011).

Methods

Search Procedure

The systematic review was conducted by following the PRISMA statement (Moher et al., 2009; see Supplementary Materials for a PRISMA checklist). We examined the databases Web of Science, PsycINFO, PubMed and Cochrane Library in search of eligible studies, entering the following syntax: "(mindfulness OR "integrative body-mind training" OR meditat* OR MBSR OR MBCT OR IBMT OR MBRP OR MBRE OR "focused attention" OR "open monitoring" OR "body scan" OR zazen OR zen OR vipassana OR samatha OR "acceptance and commitment") AND ((executive OR cognition OR "cognitive function" OR prefrontal) OR (inhibition OR inhibitory OR "self-control" OR ("selective attention" OR "focused attention" OR cingulate)) OR ("working memory" OR updating OR monitoring)

OR (flexibility OR shifting OR switching)))". The search was conducted on September 2017. It was limited to articles in English, Spanish or French, published any time.

A set of 822 registers was obtained, from which we conducted a systematic filtering process (see **Fig. 1**). First, we removed 342 duplicates. Thereafter, inclusion criteria C1 to C5 (see *Selection criteria* below) were applied while screening the title and abstract of the remaining papers. Papers not clearly violating at least one criterion were retained for full-text examination. On a later stage, the first author (LC) and the second author (VP) independently examined the remaining set of 57 papers while applying the inclusion criteria. When necessary, we contacted the authors of the studies for paper retrieval and/or further clarification of its content. Inter-rater disagreements regarding the inclusion of studies were solved through discussion. In case of persistent disagreement, the fourth author (JL) was brought into the discussion until consensus was achieved. A set of 16 studies was retained after full search procedure (Ainsworth et al., 2013; Allen et al., 2012; Greenberg et al., 2013; Josefsson et al., 2014; Mallya & Fiocco, 2016; Mitchell et al., 2017; Moynihan et al., 2013; Mrazek et al., 2013; Prätzlich et al., 2016; Sahdra et al., 2011; Schoenberg et al., 2014; Tang et al., 2007; Tsai and Chou, 2016; Valls-Serrano et al., 2016; Wetherell et al., 2017; Zeidan et al., 2010).

Selection Criteria

Studies needed to satisfy the five following criteria to be included in this review. (C1) The article is a peer-reviewed research report. Narrative and systematic reviews, doctoral dissertations, posters, registered study protocols, commentaries, books and book chapters, essays and other theoretical accounts were therefore excluded. (C2) The study includes mindfulness mediation training as part of the intervention and assesses executive control as outcome according to the definitions provided in section below (see *Operational*

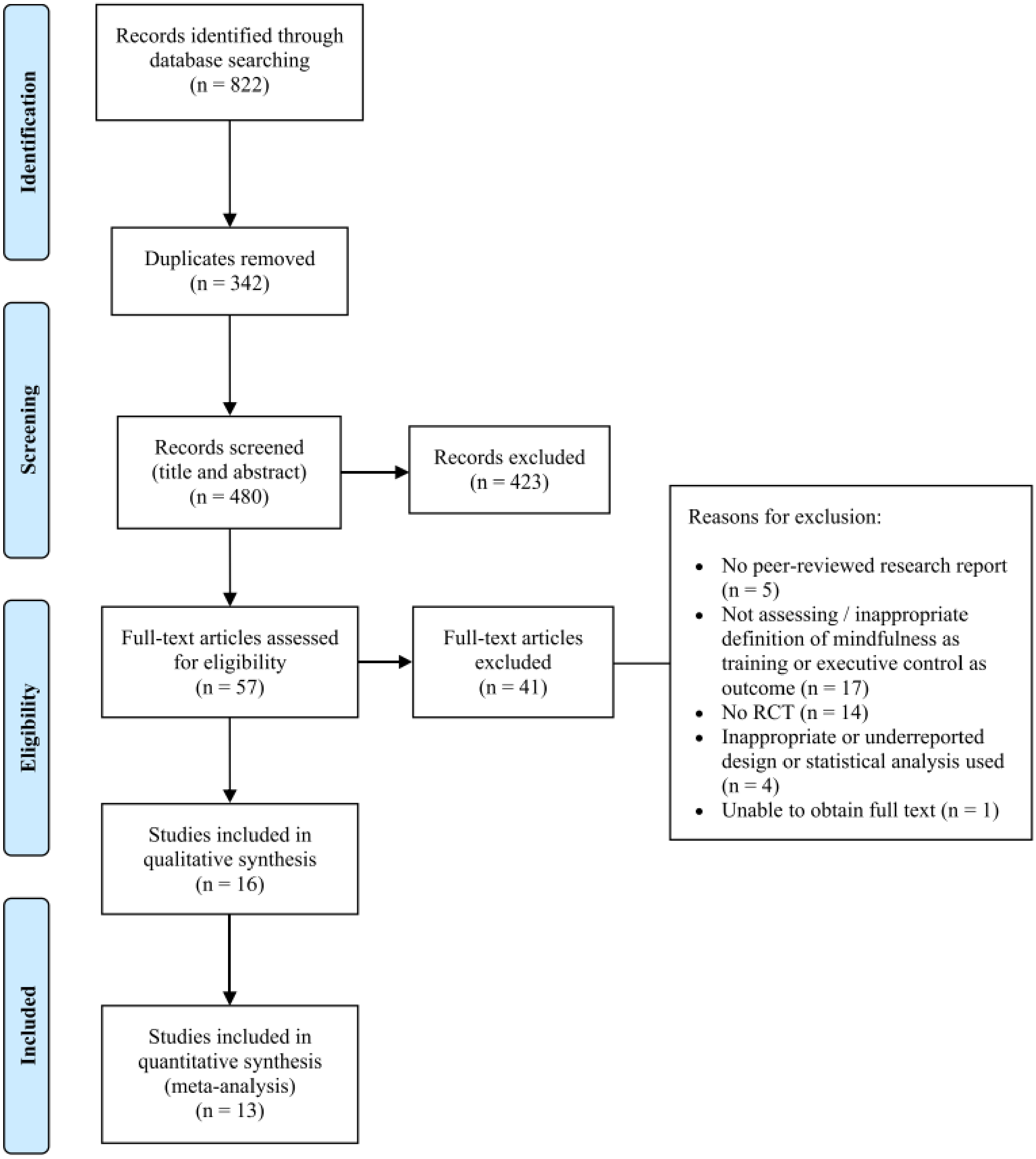

Fig. 1 PRISMA flowchart of study selection process

definitions). (C3) The study is a controlled trial with randomization of participants to experimental (receiving meditation training) and control group (not receiving meditation training). (C4) Study participants are adults (i.e., aged ≥ 18 years). (C5) Descriptions of experimental design, statistical analyses and results of the study are complete and clearly described. Statistical analyses assess pre- to post-intervention differences in the experimental as compared to the control group (i.e., analysis of interaction between time of assessment [pre- and post-intervention] and group [experimental and control group] is addressed). Studies analyzing solely post-intervention differences were therefore excluded. In case of incompleteness or ambiguity, we contacted the first author of the study for further clarification. Studies for which clarification was not provided were excluded.

Operational Definitions

Mindfulness Meditation Training

We defined mindfulness meditation training as any training regime in which participants are taught one or both formal practices broadly recognized as mindfulness meditation (i.e., FA and/or OM meditation). Given that we aimed, to the extent possible, at evaluating the effects of mindfulness meditation free from ancillary factors (see Isbel & Summers, 2017), at least one of the included mindfulness practices should be purely cognitive and, thus, not involve physical exercise or vocalization (interventions exclusively based on yoga or mantra repetition were therefore excluded). Lastly, the training regime should be sustained in time for more than one session (one-day brief laboratory inductions were therefore excluded).

Executive Control Assessment

Executive control assessments must include at least one neuropsychological test or computerized cognitive task involving reaction time or response accuracy measurement (studies using solely self- or other-report measures, or only physiological, neurophysiological or neuroimaging assessments were therefore excluded). Moreover, they must assess specifically either working memory, inhibitory control or cognitive flexibility as defined by Diamond (2013). General measures that conflate several sub-processes (such as, e.g., the Symbol Digit Modalities Test, where participants presumably deploy working memory and set switching as well as other cognitive processes such as fine motor skills) were therefore excluded.

Data Extraction

We extracted the following information from each of the included studies: mean age of the sample being tested, sample size, duration of the intervention provided, total approximate dosage of the intervention (in minutes), population assessed (healthy or clinical), name of the intervention (when provided), control group used, and categorization of control group as active or passive (see **Table 1**). The first author extracted the data, and any queries were clarified with the second and fourth authors. Subsequently, we extracted from each study the data needed to calculate an effect size estimate (see *Data analyses* for details). In three studies, data of interest were only depicted graphically (i.e., were not reported numerically). In those instances, we used the online software WebPlotDigitizer (Version 4.1; Rohatgi, 2018) to extract the underlying numerical data from bar plots. WebPlotDigitizer has been shown as a valid and reliable tool (Drevon et al,. 2017). When data were not available (either numerically or graphically) we contacted the corresponding authors of the study via e-mail for data retrieval. When no reply was obtained, we contacted all other authors. Unfortunately, for three of the included studies either requested data were not available, or a reply was not obtained from any of its authors. Therefore, only 13 of the 16 studies included in the systematic review could also be included in subsequent meta-analyses.

Risk of Bias Assessment

Methodological quality of included studies was assessed by means of the Cochrane Collaboration’s tool for assessing risk of bias (Higgins et al., 2011). The tool evaluates six potential sources of bias: (a) selection bias (whether randomization was adequately performed and allocation of participants to experimental/control group adequately concealed); (b) performance bias (whether participants and personnel providing the intervention were blind to study hypothesis); (c) detection bias (whether outcome assessors where blinded to study hypothesis); (d) attrition bias (whether amount, nature or handling of incomplete outcome data was adequately addressed); (e) reporting bias (whether selective outcome reporting was found); and (f) other bias (whether the study appears to be at risk of other biases not previously evaluated). The Cochrane Collaboration's tool diagnoses studies at *high* or *low risk of bias* for each of the aforementioned domains. Alternatively, if studies fail to provide enough information to assess their quality they are evaluated as *unclear risk of bias*. We used RevMan (version 5.3; Cochrane Collaboration, 2014) software to code information of each of the studies included and to generate graphical summaries of their individual and combined risk of bias (see **Fig. 2** and **3**).

Data Analyses

Effect Size and Variance

We conducted a meta-analysis in order to estimate the weighted averaged effect size found in our pool of included studies. To this end, Hedges' *g* was chosen as effect size estimate for each individual study. Hedges's *g* is a weighted version of Cohen's *d* that allows for unbiased estimation when sample sizes are small (Borenstein et al., 2009). Given that all included studies used a pretest-posttest control group experimental design, we followed the procedure for effect size estimation recommended by Morris (2008). Thus, Hedges' *g* is defined as follows:

$$g = C_P \left[\frac{(M_{post,T} - M_{pre,T}) - (M_{post,C} - M_{pre,C})}{SD_{pre}} \right]$$

where $M_{post,T}$, $M_{pre,T}$, $M_{post,C}$ and $M_{pre,C}$ are the post-intervention and pre-intervention mean scores for the treatment group and control group, respectively. In turn, SD_{pre} is the pooled standard deviation of the pre-intervention scores, defined as follows:

$$SD_{pre} = \sqrt{\frac{(n_T - 1)\ SD^2_{pre,T} + (n_C - 1)\ SD^2_{pre,C}}{n_T + n_C - 2}}$$

where n_T, n_C, $SD_{pre,T}$ and $SD_{pre,C}$ are the number of participants and the standard deviations of the scores at pre-intervention for treatment and control group, respectively. Lastly, C_P is a correction for bias defined as follows:

$$C_P = 1 - \frac{3}{4\ (n_T + n_C - 2) - 1}$$

In turn, the variance of Hedges' *g* is defined as follows:

$$V_g = 2\ (C_P^2)\ (1 - r)\ \left(\frac{n_T + n_C}{n_T\ n_C}\right) \left(\frac{n_T + n_C - 2}{n_T + n_C - 4}\right) \left(1 + \frac{g^2}{2\ (1 - r)\ \left(\frac{n_T + n_C}{n_T\ n_C}\right)}\right) - g^2$$

where *r* is the correlation between pre-test and post-test scores. As this statistic was not reported in any of the studies under consideration, we conducted our analyses assuming *r* = 0.5 in all cases. However, to ascertain the robustness of the results under this assumption, we conducted sensitivity analyses also imputing *r* = 0.25 and *r* = 0.75 in the calculations. In both cases, we obtained virtually identical results than those for *r* = 0.5. For the sake of simplicity, we only report the results of the latter.

Aggregates

Some of the included studies contributed effect sizes for more than one outcome of interest. In those instances, we calculated aggregated effect sizes so that each study ultimately had one overall effect size to contribute to subsequent meta-analyses. The rationale for this approach is described in detail in Borenstein et al. (2009). In short, calculation of aggregates deals with the problematic practice of treating outcomes coming from the same study as if they were independent, therefore assigning more relative weight to these studies and improperly estimating the precision of its effect. The procedure followed to compute a single aggregated effect size, $\bar{g}$, from two individual outcomes is defined as follows:

$$\bar{g} = \frac{1}{2}(g_1 + g_2)$$

where g_1 and g_2 are the individual effect sizes. In turn, the variance of the aggregated effect size is defined as follows:

$$V_{\bar{g}} = \frac{1}{4}\left(V_{g_1} + V_{g_2} + 2r\sqrt{V_{g_1}}\sqrt{V_{g_2}}\right)$$

where V_{g_1} and V_{g_2} are the variances of g_1 and g_2, respectively, and r is the correlation between the two outcomes. In absence of the value of this correlation, it was set as 0.5 as proposed by Wampold et al. (1997). Some studies contributed three or four outcomes to our meta-analyses. Equations used to calculate aggregates in those instances are detailed in Borenstein et al. (2009).

To confirm the robustness of the results we also conducted a multi-level meta-analysis including all the individual effect sizes, adding a random intercept at the study level to account for dependencies among effect sizes. The results of this analysis were virtually identical to those of the overall univariate meta-analysis with aggregate effect sizes (see *Meta-analysis* section below). For the sake of simplicity, we only report the results of the latter.

Meta-Analysis

Four univariate meta-analyses were conducted: one to obtain the overall summary effect for all included studies, and one per each individual executive function (i.e., working memory, inhibitory control, and cognitive flexibility). Random-effect models were fitted in all cases (Cumming, 2013). Additionally, we conducted an Egger's regression test for funnel plot asymmetry to evaluate the potential presence of publication bias within the literature reviewed. Funnel plots depict effect estimates against their standard error. Given that precision in estimating an effect will increase as the sample size increases (and thus the standard error decreases), results from small studies will spread largely whereas those from large studies will collapse closer to the mean effect estimate. In the absence of bias, results should distribute symmetrically around the mean effect estimate. However, publication bias will usually induce asymmetry in the distribution of effect sizes, as small studies with negative results will be more likely to be missing. Egger's regression test statistically evaluates the degree of asymmetry of the distribution (Egger et al., 1997).

We used the metaphor package for R (Viechtbauer, 2010) to conduct all meta-analytic procedures and to generate corresponding figures (forest plot and funnel plot, see

Fig. 4 and **5**). As proposed by Cohen (1992), we interpreted effect sizes of 0.2, 0.5 and 0.8 as small, medium and large, respectively.

Results

Qualitative Results

The present systematic review included 16 studies sampling a total of 1,112 participants. In most cases, participants were novices to the practice of mindfulness meditation, when not completely meditation-naive. In one study, though, a certain level of experience was required for participation (i.e., having completed prior to recruitment at least three 5- to 10-day meditation retreats; Sahdra et al., 2011), and four studies did not provide information regarding previous experience with meditation (Moynihan et al., 2013; Mrazek et al., 2013; Schoenberg et al., 2014; Valls-Serrano et al., 2016). The studies assessed participants from the entire adult life-span (mean ages ranging from 20.3 to 73.4 years) and primarily evaluated the effect of mindfulness meditation in healthy participants (only four studies addressed clinical populations). The use of active/passive control group was evenly distributed among studies (eight studies used the former, seven used the latter, and one used both). A summary of these and other main characteristics of included studies is provided in **Table 1**. In total, 32 outcomes were assessed throughout the studies. Of them, 15 reported a statistically significant effect favoring the mindfulness meditation training program over the control intervention. No significant effects were reported for the remaining 17 outcomes. A summary of the assessments used as well as the main findings across the studies can be found in **Table 2**.

The Cochrane Collaboration tool suggested that included studies are, overall, at low risk in regard to attrition and reporting bias. However, risk regarding selection, performance, and detection bias remains largely unknown, given that most studies failed to report sufficient information to evaluate them. Summaries of individual and combined risk of bias are provided in **Figs. 2** and **3**.

Quantitative Results

As mentioned above, we were able to obtain enough information to estimate an effect size for 13 of the 16 studies, which were therefore included in subsequent meta-analyses. The overall weighted mean effect size reported in these studies was g = 0.34, 95% CI [0.16, 0.51], z = 3.76, p < .001, indicating a small-to-medium effect favoring mindfulness training over control interventions in enhancing executive control. A forest plot with individual effect sizes as well as the weighted mean is depicted in **Fig. 4**. The test for heterogeneity failed to reach statistical significance $Q_{(12)}$ = 17.18, p = .143, I^2 = 33.27%, 95% CI [0, 72.31]. A funnel plot representing individual effects against their standard error is depicted in **Fig. 5**. Egger's regression test for funnel plot asymmetry was far from statistical significance, z = 0.40, p = .686, indicating that the result of the meta-analysis is unlikely to be overestimated by publication bias.

Effect size estimates for each individual executive function were as follows: g = 0.42, 95% CI [0.10, 0.74], z = 2.60, p = .009 for working memory; g = 0.42, 95% CI [0.20, 0.63], z = 3.83, p < .001 for inhibitory control; and g = 0.09, 95% CI [-0.13, 0.31], z = 0.80, p = .423 for cognitive flexibility. These results indicate small-to-medium effect sizes for working memory and inhibitory control, and no significant effect for cognitive flexibility. Respectively, the results for heterogeneity tests were $Q_{(3)}$ = 2.66, p = .446, I^2 = 0%, 95% CI [0, 94.70]; $Q_{(8)}$ = 9, p = .342, I^2 = 18.33%, 95% CI [0, 74.74]; and $Q_{(4)}$ = 4.28, p = .369, I^2 = 0%, 95% CI [0, 92.46].

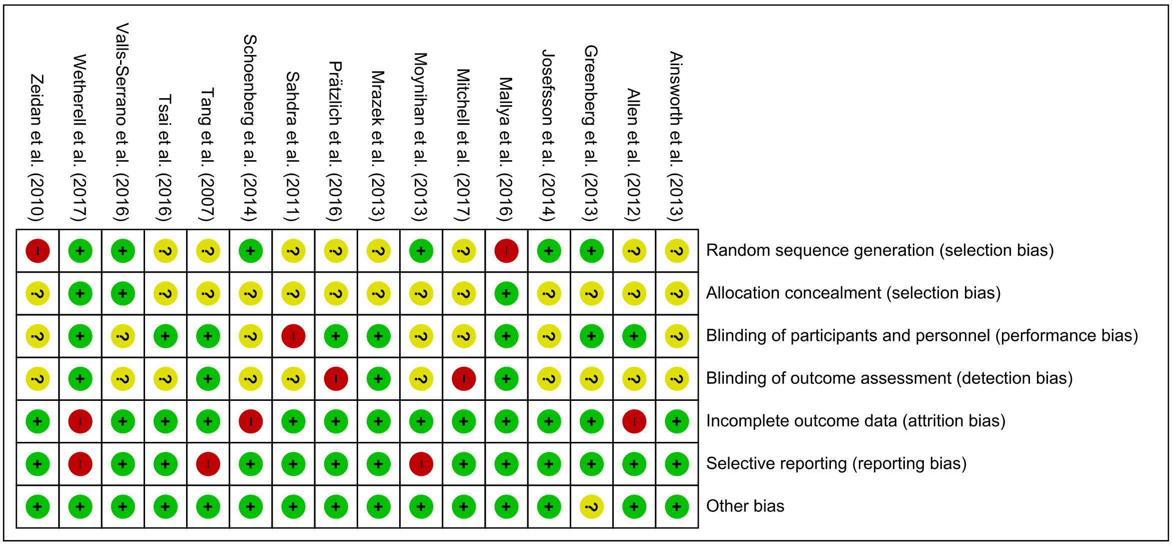

Fig. 2 Risk of bias summary

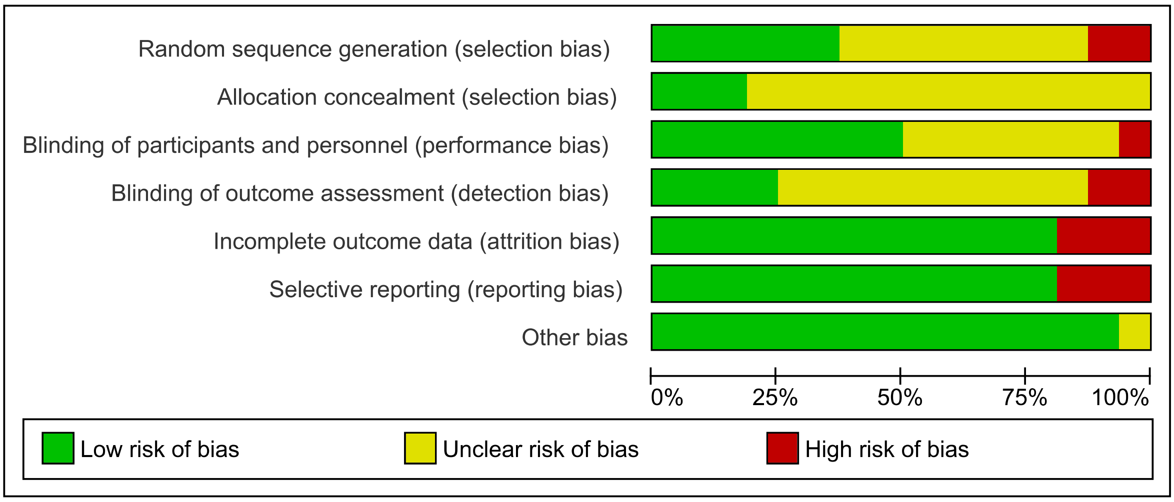

Fig. 3 Risk of bias graph

Table 1

Characteristics of Included Studies

Study	Mean age	Sample size	Duration of intervention	Dosage (minutes)	Population	Intervention	Control group	Active control
Ainsworth et al. (2013)	20.3	73	3 x 1h sessions (plus 10min daily home practice during 8 days)	260	Healthy	Other (FA) Other (OM)	Relaxation	Yes
Allen et al. (2012)	26.5	38	6 weekly 2h sessions (plus 20min daily home practice)	1560	Healthy	Other	SRL	Yes
Greenberg et al. (2013)	26	65	7 weekly 2h sessions and half a day retreat (plus 20min daily home practice)	2180	Healthy	MBCT	Wait-list	No
Josefsson et al. (2014)	48.1	104	2 x 45min weekly sessions, for 4 weeks	360	Healthy	Other	Relaxation Wait-list	Yes No
Mallya et al. (2016)	69.2	97	8 weekly 2.5h sessions (plus 30min daily home practice)	2880	Healthy	MBSR	R&R	Yes
Mitchell et al. (2017)	38.6	20	8 weekly 2.5h sessions (plus 5 to 15min daily home practice)	1760	ADHD	MAPs for ADHD	Wait-list	No
Moynihan et al. (2013)	73.4	208	8 weekly 2h sessions and 7h retreat	1380	Healthy	MBSR	Wait-list	No
Mrazek et al. (2013)	20.8	48	4 x 45min sessions, for 2 weeks (plus 10min daily home practice)	500	Healthy	Other	Nutrition program	Yes
Prätzlich et al. (2016)	28.6	59	3 x 20min sessions	60	Healthy	Other (FA-HE) Other (FA-LE)	SM-HE SM-LE Silence	Yes Yes Yes
Sahdra et al. (2011)	48	59	7h a day for three months	38200	Healthy	Other	Wait-list	No

Table 1 *(continued)*
Characteristics of Included Studies

Study	Mean age	Sample size	Duration of intervention	Dosage (minutes)	Population	Intervention	Control group	Active control
Schoenberg et al. (2014)	36.8	44	12 weekly 3h sessions (plus 30 to 45min daily home practice)	5310	ADHD	MBCT	Wait-list	No
Tang et al. (2007)	21.8	80	5 x 20min sessions	100	Healthy	IBMT	Relaxation	Yes
Tsai et al. (2016)	20	40	12 weekly 50min sessions	600	Healthy	Other	Wait-list	No
Valls-Serrano et al. (2016)	33.1	32	8 weekly 40min sessions	320	Substance abuse	Other	TAU only	No
Wetherell et al. (2017)	71.9	96	8 weekly 90min sessions	720	Depression/anxiety	MBSR	Health education	Yes
Zeidan et al. (2010)	22.5	49	4 x 20min sessions	80	Healthy	Other	Book listening	Yes

Note. Intervention: FA = Focused Attention; OM = Open Monitoring; HE = High Expectations; LE = Low Expectations; MBCT = Mindfulness-Based Cognitive Therapy; MBSR = Mindfulness-Based Stress Reduction; MAPs = Mindful Awareness Practices; IBMT = Integrative Body-Mind Training; GMT = Goal Management Training.
Control group: SRL = Shared Reading and Listening; R&R = Reading and relaxation; SM = Sham Meditation; TAU = Treatment As Usual.

Table 2

Assessments Used and Main Findings Across Included Studies

Study	Assessment			Main findings
	WM	IC	CF	
Ainsworth et al. (2013)	-	ANT	-	Both experimental groups (FA and OM) improved executive attention after intervention as compared to relaxation group.
Allen et al. (2012)	-	EAT Stroop	-	Both groups improved stop accuracy after intervention in the EAT. Mindfulness group reduced Stroop conflict after intervention as compared to active control group.
Greenberg et al. (2013)	-	-	*Vertical boxes* and *Faces* paradigms	Improved backwards inhibition rendering improved switching performance after intervention in MBCT group relative to wait-list group.
Josefsson et al. (2014)	-	Stroop	-	No significant differences found in Stroop performance pre- to post-intervention when comparing the experimental group to neither to the active nor to the passive control group.
Mallya et al. (2016)	-	-	TMT COWAT	No significant differences were found pre- to post-intervention between MBI and control group in neither TMT nor COWAT.
Mitchell et al. (2017)	BDS	ANT CPT	TMT	No significant differences were found pre- to post-intervention between experimental and wait-list control group in any of the four tasks.
Moynihan et al. (2013)	-	-	TMT	Improvement in TMT B/A ratio in MBSR group relative to wait-list control group immediately after the intervention, but no differences found three nor 24 weeks after the intervention.
Mrazek et al. (2013)	OSPAN	-	-	Improvement in OSPAN after intervention in mindfulness group relative to reading group.
Prätzlich et al. (2016)	-	Stroop	RWT 5-Point test	Reduced Stroop interference after intervention in groups primed with positive expectations, both mindfulness meditation and sham meditation. Improvement in verbal fluency (RWT) only in mindfulness mediation high expectations group. No pre-to-post differences among groups were found for figural fluency (5-point test).
Sahdra et al. (2011)	-	RIT	-	Improvement in RIT score for experimental group, but not for wait-list group, both immediately after intervention and at 5-months follow-up.

Table 2 *(continued)*
Assessments Used and Main Findings Across Included Studies

Study	Assessment			Main findings
	WM	IC	CF	
Schoenberg et al. (2014)	-	CPT-X	-	Improvement after intervention in CPT-X in MBCT group but not in wait-list control group.
Tang et al. (2007)	-	ANT	-	Improved executive attention network efficiency after intervention in IBMT group as compared to relaxation control group.
Tsai et al. (2016) [a]	-	ANT	-	Improvement after intervention in executive attention in mindfulness group as compared to wait-list control group.
Valls-Serrano et al. (2016)	Letter-Number Sequence	Stroop	-	Intervention improved performance in Letter-Number Sequence in experimental relative to control group. No differences were found regarding Stroop test.
Wetherell et al. (2017)	-	Stroop	Verbal Fluency Test	No differential effect of intervention among groups group was found in any of the measures.
Zeidan et al. (2010)	BDS n-back	-	COWAT	Improvement after intervention in COWAT and n-back task scores in mindfulness group as compared to book listening group. No significant effect found for backward DS.

Note. In accordance to the definitions in this review, extracted ANT scores refer only to the *executive attention network.*
WM = Working Memory; IC = Inhibitory Control; CF = Cognitive Flexibility.
WM: BDS = Backward Digit Span; OSPAN = Operation Span.
IC: ANT = Attention Networks Test; EAT = Error Awareness Task; CPT = Continuous Performance Test; RIT = Response Inhibition Task.
CF: FP = TMT = Trail Making Test; COWAT = Controlled Oral Word Association Test; RWT = Regensburger Wortflüssigkeitstest.

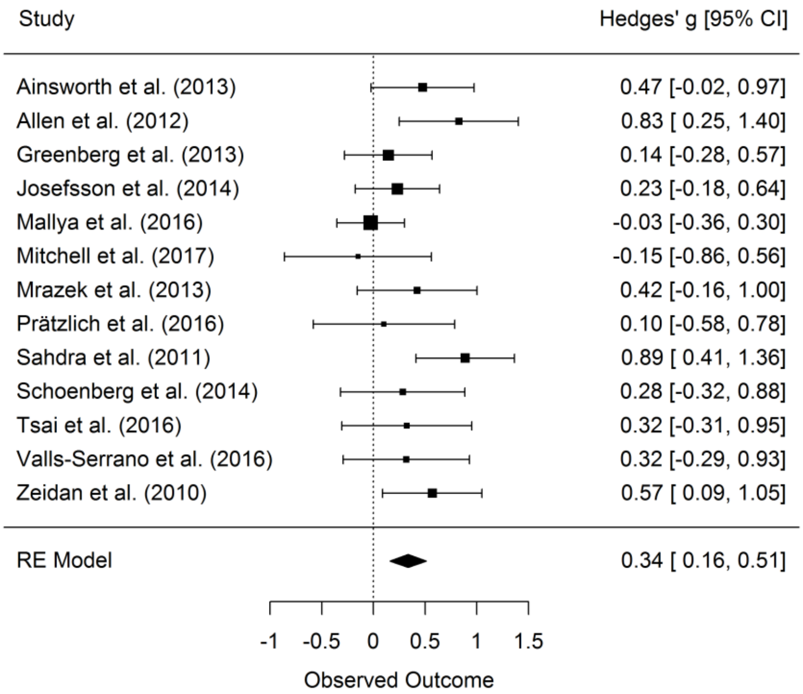

Fig. 4 Forest plot of studies included in overall meta-analysis

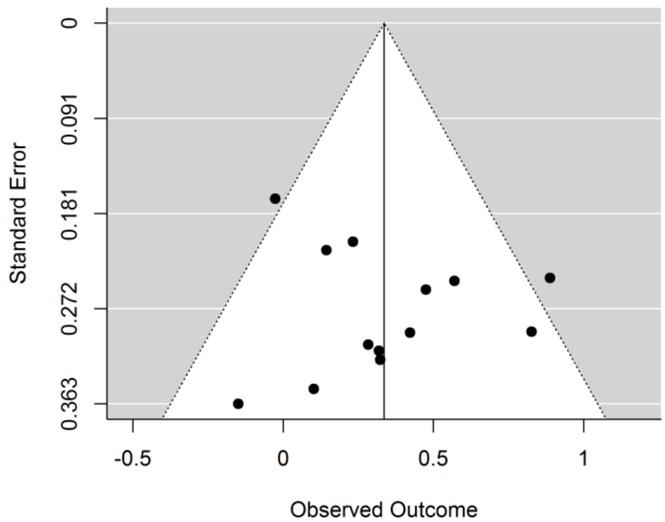

Fig. 5 Funnel plot of studies included in overall meta-analysis

Discussion

The aim of the present systematic review and meta-analysis was to assess the effectiveness of mindfulness meditation as a cognitive enhancer for executive control. Our literature-search strategy allowed us to identify 16 randomized controlled studies conducted in adults, of which 13 could be included in a subsequent meta-analysis. Across these studies, the effectiveness of mindfulness meditation (i.e., FA and OM meditation practices) in enhancing working memory, inhibitory control, and/or cognitive flexibility was assessed by means of neuropsychological tests and/or computerized cognitive tasks. Additionally, we assessed the methodological quality of the included studies and examined the possibility of publication bias in the literature reviewed.

Our findings indicate that mindfulness meditation exerts a small-to-medium effect in enhancing executive control (g = 0.34); with small-to-medium effect sizes for working memory (g = 0.42) and inhibitory control (g = 0.42), and no significant effect for cognitive flexibility (g = 0.09). Moreover, these effects seem to be consistent given the relatively small, non-significant heterogeneity found for each of them (especially in regards to each individual executive function). Furthermore, in light of the results of the funnel plot asymmetry analysis, the effects are not likely to be overestimated by publication biases. This pattern of findings, alongside the fact that they are obtained based on randomized controlled studies, suggests that mindfulness meditation training might indeed be effective in enhancing executive control.

The findings partially align with those from previous systematic reviews (Chiesa et al., 2011; Gallant, 2016; Lao et al., 2016). Our results indicate that mindfulness meditation may be effective in enhancing working memory, as suggested by Chiesa et al. (2011) and Lao et al. (2016). Gallant (2016), in contrast, concluded that mindfulness meditation does not improve working memory in itself. In this author's view, working memory improvements would be driven by an indirect effect, namely by reductions in mind-wandering. As previously discussed, this is indeed a plausible mechanism underlying improvements in working memory following mindfulness meditation training. However, in or view, the "indirect" nature of the effect does not deny its existence. In fact, the three studies reviewed by Gallant reported working memory to be improved as a consequence of mindfulness meditation training (Jha et al., 2010; Mrazek et al., 2013; Zeidan et al., 2010).

A similar picture is found for inhibitory control, for which two previous reviews seem to align with ours (Chiesa et al., 2011; Gallant, 2016) while one differs (Lao et al., 2016). The opposite pattern is seen regarding cognitive flexibility, with conclusions by Gallant (2016) more in line with ours, in contrast to those by Chiesa et al. (2011) and Lao et al. (2016). In these cases, differences in results seem to be based on conceptual discrepancies. As anticipated in the Introduction, different conceptualizations of mindfulness meditation may lead to different search algorithms and study selection criteria, and therefore to different sets of studies included. For instance, one researcher may define mindfulness training as comprised by only standardized mindfulness-based programs such as MBSR or MBCT, while another might also include Vipassana and other types of traditional meditation practice. The same applies to executive control. Following different cognitive taxonomies may render different sets of studies included. As an example, one researcher may consider executive attention to be part of inhibitory control, while another might consider it a separate attentional function. Ultimately, conceptual divergences—which are to an extent inherent to the study of psychological and cognitive constructs—may lead to different results and conclusions.

There is also a methodological reason potentially explaining differences between our results and those from previous reviews. In contrast to previous research, our study includes a meta-analysis. Findings obtained by meta-analyzing a set of studies can substantially differ from those rendered by simply "vote-counting" positive and null results in the same set of studies (Siddaway et al., 2019). For instance, a meta-analysis may find a significant positive effect when combining a set of non-significant findings coming from underpowered studies. One strength of our approach is to more accurately provide evidence in terms of the existence (or lack thereof) of an effect of mindfulness meditation in enhancing executive control, while additionally estimating the magnitude of such effect.

With that all being said, the results of our meta-analysis must be interpreted with caution due to at least two reasons. First, the risk of selection, performance, and detection bias in included studies is largely unknown. This is due to the fact that most studies failed to report sufficient information as for us to make informed judgments in this regard. In particular, details on how randomization and participants' allocation to groups were performed (selection bias) and regarding the blinding of participants, instructors, and outcome assessors (performance and detection biases) were largely underreported. Empirical research has shown that bias in randomized controlled trials is associated with overestimated intervention effects (Higgins et al., 2019). For instance, interventions not reporting to use double-blinding have been shown to be associated with overestimated intervention effects by 18%, on average, as compared to those reporting it (Pildal et al., 2007). This circumstance, added to the fact that a small proportion of items per study were at high risk of bias, calls for prudence when interpreting the size of the effects found in the meta-analysis. Moreover, it underscores the value of thorough reporting practices in future empirical research, especially when also considering that three of our 16 studies (i.e., more than 18%) could not be meta-analyzed due to the scarcity of reported statistical information.

The second reason for caution interpreting our findings relates to the small set of studies that we were able to include, which may not afford sufficient statistical power for our tests to detect existing heterogeneity, both overall and, especially, within each executive function. This limitation may also affect the test for funnel plot asymmetry and, therefore, the inferred unlikelihood of publication bias in the literature reviewed. The small number of included studies also prevented us from conducting moderator analyses to investigate whether effect sizes were related to any study-level independent variable. In fact, it is recommended to have no less than 30 studies to conduct such analysis, and, in some cases, even 60 studies would not be adequate to perform them (Lau, 2006). Given the value of revealing distinctive patterns of effectiveness depending on variations in the interventions provided (e.g., duration), or in populations assessed (e.g., young versus older adults), future meta-analyses must consider this approach once more studies are available.

Importantly, readers must also be careful when interpreting the seeming different effect found for cognitive flexibility as compared to working memory and inhibitory control. Two aspects are worth discussing in this regard. First, even though these meta-analyses suggest that such differences may exist in the population, we cannot be certain that these divergences are not reflecting just sampling variation. This is especially true considering the limited number of studies contributing to the meta-analyses for working memory and cognitive flexibility (four and five, respectively). Although the estimate for cognitive flexibility did not reach statistical significance, the upper bound of its confidence interval falls at g = 0.31, indicating that the true population effect might actually be closer to the estimates for working memory and inhibitory control than it seems *prima facie*. Second, a closer look at the tests used to assess each executive function reveals that cognitive flexibility was measured by means of paper-based neuropsychological tests in all but one case. In contrast, working memory and inhibitory control were more consistently assessed by means of computerized cognitive tasks. As has been previously discussed (Mak et al., 2018), it is possible that paper-based neuropsychological tests and computerized cognitive tasks are not equally sensitive. Computerized tasks allow measuring reaction times down to the millisecond, likely being more sensitive than paper-based assessments which are usually based on accuracy scores. If this is true, the smaller effect found for cognitive flexibility as compared to working memory and inhibitory control could be partially driven by an artifact. Once again, as the number of experimental studies on the topic grows, larger meta-analyses will be needed to evaluate the presence of this differential effect, ideally conducting moderator analysis to reveal potential confounds derived from the type of assessments used (computerized vs. paper-based tasks).

It is worth mentioning that only two of the studies under consideration in the systematic review reported being registered trials, none of which could be included in the meta-analysis. Several meta-research studies show that effect sizes tend to be substantially smaller in registered trials (Kaplan & Irvin, 2015; Papageorgiou et al., 2018), possibly due to selective reporting and other biases in unregistered research that artificially inflate effect sizes (Kerr, 1998; Simmons et al., 2011). Ideally, future RCTs conducted in this topic should adhere to preregistered protocols and analysis plans, to ensure that their results are free from these sources of bias.

Another aspect that may inform future directions in the field stems from the small number of clinical studies that we were able to include. Four studies conducted in clinical populations were included in the systematic review, of which only three could be meta-analyzed. As a consequence, we were not able to investigate the differential effects of mindfulness meditation in clinical as compared to healthy populations, let alone to compare different clinical populations with each other. This is unfortunate, especially given that executive control is compromised in a wide range of psychological and psychiatric disorders from attention-deficit/hyperactivity disorder or addiction to depression or schizophrenia (for reviews, see Diamond, 2013; Royall et al., 2002). More experimental studies in this area are needed. In turn, ascertaining to what extent mindfulness meditation is effective in enhancing executive control in such populations, as well as investigating whether or not and how much this improvement translates into symptom amelioration or remission, entails a highly relevant research challenge that we encourage future meta-analytical studies to take on.

In summary, this systematic and meta-analytic review provides preliminary and moderate yet positive evidence supporting the enhancing effects of mindfulness meditation in executive control. We hope that the current meta-analysis will pave the way to future experimental studies further evaluating this subject. Importantly, these studies must consider upgrading current reporting standards regarding methods used and results obtained, so as to facilitate cumulative science. As in any other scientific field, only a cooperative endeavor will render the most valuable outcomes. In turn, as the field continues to grow, we hope that future meta-analytic research will be able to afford a more comprehensive account of the effectiveness of mindfulness meditation by revealing not only to what extent it enhances executive control but, also, under what specific circumstances, and for which particular populations, it does so.

Supplementary Materials

SUPPLEMENTARY MATERIAL S1: PRISMA checklist

Part 1:

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3-7
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	7-9
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	No protocol
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	8-9
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	7, 9
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	7
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	7-12, Fig 1
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7-8
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	8-9
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	9-10
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	10-11
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	11-12

Part 2:

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	9-10
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	9, Fig 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	13, Tables 1 and 2
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	13, Figs 2 and 3
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	14, Fig 4
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	14, Fig 4
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	14, Figs 2, 3, 5
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	15
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16-19
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	15-19
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	19

CHAPTER IV: STUDY II

Individual Differences in Dispositional Mindfulness Predict Attentional Networks and Vigilance Performance

The content of this chapter has been published as:

Cásedas, L., Cebolla, A., & Lupiáñez, J. (2022). Individual differences in dispositional mindfulness predict attentional networks and vigilance performance. *Mindfulness*, *13*, 967–981. https://doi.org/10.1007/s12671-022-01850-6.

Abstract

Objectives: Research addressing the relationship between dispositional mindfulness and objective attention performance remains inconclusive, partly because previous studies used sample sizes possibly leading to underpowered designs. Here, we examined this relationship in a large sample using the ANTI-Vea: a novel cognitive-behavioral task that simultaneously assesses the classic attentional networks—phasic alertness, orienting, executive control—and both the executive and arousal components of vigilance. **Methods:** Two hundred nineteen meditation-naïve participants completed the study. Correlational analyses using Kendall's Tau were performed between FFMQ scores and ANTI-Vea outcomes. Additional subsidiary correlations were performed between the FFMQ and two self-report measures assessing subjective attentional control and mind-wandering. Internal consistency reliability indices were estimated for all measured used to aid the interpretation of the correlational results. Benjamini-Hochberg was applied to control the Type I error rate. **Results:** Higher non-reactivity predicted overall faster reaction times and higher accuracy in attentional networks trials. Higher non-reactivity, as well as higher FFMQ total score, predicted faster reaction time and fewer lapses in arousal vigilance trials, the latter also being negatively associated with describe scores. The magnitude of the correlations ranged from τ_b = .103 to τ_b = .119. We found no association between FFMQ scores and executive control or executive vigilance. **Conclusions:** Our results indicate that dispositional mindfulness is linked to improved global attentional and arousal vigilance performance, being non-reactivity to inner experience the key facet driving the association. The absence of association to executive processes is discussed based on the high cognitive demands of the ANTI-Vea task. **Pretrial Registration:** Open Science Framework, https://osf.io/gb6c7.

Introduction

Attention is one of the core components of the construct of mindfulness in virtually all theoretical and psychometric models proposed to date (Baer, 2019; Brown & Ryan, 2003; Bishop et al., 2004; Hölzel et al., 2011; Lutz et al., 2008; Malinowski, 2013). Although different conceptualizations of dispositional mindfulness emphasize different particular aspects, most of them generally conceive it as a trait-like (yet modifiable) tendency to (1) attend to present moment experience while (2) having an attitude of acceptance towards it. These two aspects have been termed as the "what" (attentional monitoring) and "how" (accepting attitude) of mindfulness (Baer, 2019). Apart from some exceptions (see, e.g., Levinson et al., 2014), dispositional mindfulness is most commonly assessed through self-report measures, such as the Mindfulness Attention Awareness Scale (MAAS; Brown & Ryan, 2003) and the Five Facets Mindfulness Questionnaire (FFMQ; Baer et al., 2006).

While essential to mindfulness, attention is not a simple nor a single neurocognitive process but rather a complex collection of them (Hommel et al., 2019). In fact, a host of theoretical proposals within Cognitive Psychology and Neuroscience has been advanced in trying to explain such complexity. Among them, one highly integrative and widely renowned proposal is Posner and Petersen's (1990) Attentional Networks model. The attentional networks model divides human attention into three differentiable, yet interdependent, neurocognitive systems: alertness, orienting, and executive control. The alertness network is composed of the locus coeruleus and the right frontoparietal cortex, and underpins the functions of phasic alertness (i.e., the capacity to increase arousal momentarily in response to a sudden event) and tonic alertness or vigilance (i.e., the capacity to sustain attention for a prolonged period). In turn, the orienting subsystem is implemented in the pulvinar nuclei of the thalamus, the superior colliculus, the frontal eye fields, and the posterior parietal cortex, and is responsible for the allocation of attention towards potentially relevant locations or sensory modalities. Finally, the executive control network extends mainly over the dorsolateral prefrontal and anterior cingulate cortices, and enables flexible monitoring and control of attention in the adaptation of behavior to long-term goals (Petersen & Posner, 2012; Posner & Petersen, 1990).

While also part of the alertness network in Posner and Petersen's model, the capacity to sustain attention during extended periods—vigilance—has its own theoretical entity and explanatory models. There are two classic, competing explanations of the vigilance decrement phenomenon: the resources-depletion (or overload) account and the mindlessness (or underload) account. While the former understands the attentional system as a limited pool of resources that are depleted over time, the latter posits that monotonous, repetitive tasks (such as those assessing vigilance) are understimulating and lead to attention disengagement from task-relevant stimuli (Fortenbaugh et al., 2017). Recently, an alternative theoretical proposal, known as the resource-control account of sustained attention, has been developed to encompass the results predicted by both previous models (Thomson et al., 2015). Under this framework, available resources do decline, but not because they are depleted. Instead, they are increasingly redirected from external stimuli to mind-wandering (which is understood as the mind's default state), while it is executive control, needed to redirect and maintain resources onto the relevant task, the function that wanes over time. Finally, an even more recent account argues the aforementioned progressive decay of executive control to be driven by motivational factors, while also proposes arousal as a key variable in sustaining attention, so that too high or too low arousal levels would lead to suboptimal vigilance performance (Esterman & Rothlein, 2019).

Considering these theoretical perspectives, dispositional mindfulness may be related to the functioning of the attentional networks and vigilance in at least three different ways. First, the attention monitoring quality of dispositional mindfulness is known to involve the voluntary engagement, disengagement, and reengagement of awareness with the multiple elements of experience (Lutz et al., 2008). Arguably, this entails a primarily executive process highly related to executive control. Second, the characteristic “present moment” quality of mindful attention is juxtaposed with the perceptual decoupling that occurs during mind-wandering. As a result, higher levels of dispositional mindfulness may facilitate sustaining attention to external stimuli during extended periods of time, i.e., vigilance (possibly in parallel to an increased efficiency of the executive control network; Thomson et al., 2015). Finally, the accepting and non-reactive attitude towards inner experience involved in dispositional mindfulness may enable an individual to deploy attentional resources more efficiently in contexts involving stress, fatigue, or any other feature that is linked to negative affectivity. Although speculative, this may in turn relate to executive control and vigilance functioning, given that engagement in both of these processes is well known to result aversive in itself (Kurzban, 2016).

Several cognitive-behavioral tasks have been devised to assess attentional networks and vigilance performance. Regarding the attentional networks, these include the pioneer and widely used Attentional Networks Test (ANT; Fan et al., 2002), as well as posterior modifications such as the ANT for Interactions (ANTI; Callejas et al., 2004). Using an arrows flanker paradigm (Eriksen & Eriksen, 1974) that incorporates spatial cues and warning signals, these tasks are well suited to simultaneously evaluate executive control, orienting, and phasic alertness (i.e., the classic attentional networks). However, they are not suitable to evaluate tonic alertness (i.e., vigilance). To assess vigilance, other specific tasks have been developed, in which participants are classically required to remain attentive to detect critical events during extended periods. These assessments include, among others, the Sustained Attention to Response Task (SART; Robertson et al., 1997), the Continuous Performance Test (CPT; Conners, 2000), or the Psychomotor Vigilance Task (PVT; Lim & Dinges, 2008).

Excitingly, a novel experimental task has been developed in recent years to evaluate both the attentional networks and vigilance, simultaneously: the ANT for Interactions and Vigilance—executive and arousal components (ANTI-Vea; Luna et al., 2018). This comprehensive experimental assessment, moreover, is built upon the theoretical assumption that vigilance itself may not be a unitary function, but could be comprised of two distinct processes (Oken et al., 2006). While the first process would involve the capacity to maintain an executive control set for target selection of critical events over time (as assessed, e.g., in the ANTI-V, SART, or CPT), the second process would entail the maintenance of a level of arousal that allows quick response to the environment without exerting much control (as assessed in the PVT). In considering this distinction, the ANTI-Vea thus assesses phasic alertness, orienting, and executive control, while simultaneously tapping into both executive vigilance (EV) and arousal vigilance (AV). Furthermore, the task provides two additional measures indexing global attentional performance (i.e., average processing speed and accuracy across all attentional networks conditions). Successfully validated for both laboratory and online testing (Luna et al., 2021), the ANTI-Vea is arguably one of the most comprehensive assessments of the human attention system to date.

Notwithstanding the fundamental role that attentional processes may play in the psychological construct of mindfulness, little research has examined the relationship between objective (sustained) attentional performance (as measured using ANT-related or vigilance tasks) and dispositional mindfulness (as measured by self-report, most commonly the MAAS or FFMQ). This contrasts with research conducted on the relationship between attention and mindfulness training, for which there is a larger body of published literature (while delving into the state-of-the-art of the mindfulness training literature is beyond the scope of the present introduction, we direct interested readers to the recent meta-analyses by Whitfield et al., 2021; Zainal & Newman, 2021. To our knowledge, there are only 13 published studies tackling the relationship of dispositional mindfulness with attentional networks and vigilance performance; and their results show little consistency. This is especially noticeable regarding the classic attentional networks, for which higher self-reported dispositional mindfulness has been linked to improved executive control (Ainsworth et al., 2013; Tsai & Chou, 2016); to enhanced phasic alertness and reduced orienting (Di Francesco et al., 2017); to enhanced orienting (Isbel & Mahar, 2015); and to none of the attentional networks or only interactions among them (Jaiswal et al., 2018; Sørensen et al., 2018; Wittmann et al., 2014). Regarding vigilance, previous research has found several positive associations between task performance and dispositional mindfulness (Cheyne et al., 2006; Josefsson & Broberg, 2011; Lara et al., 2014; Rice & Liu, 2017; Schmertz et al., 2009). However, effect sizes differed substantially among studies (from Pearson's r = .13 to r = .51) and null findings were also reported in nearly all of them (Josefsson et al., 2011; Lara et al., 2014; Rice & Liu, 2017; Schmertz et al., 2009). Moreover, one study did not find any association at all (Rahl et al., 2017).

Also of note, most previous studies were relatively small. Excluding one unusually large study (N = 504; Cheyne et al., 2006), the average sample size throughout them is 80 participants. While this is already a meritorious sample that may lead to reasonable statistical power in other types of study designs, it may arguably not be sufficient for individual differences (i.e., correlational) research (Schönbrodt & Perugini, 2013). This holds especially true considering that most statistically significant findings were found within the small-to-medium size range, i.e., around r = .20 (Ainsworth et al., 2013; Cheyne et al., 2006; Di Francesco et al., 2017; Josefsson & Broberg, 2011; Rice & Liu, 2017). In fact, assuming a correlation of .20 (and setting alpha at .05) the statistical power achieved with a sample of 80 participants is .43 (Faul et al., 2009). Given that low power renders both low probability of observing effects that do exist (i.e., high probability of Type II errors) and high probability for observed significant effects to be false positives (Forstmeier et al., 2017), this may be one critical factor explaining the aforementioned pattern of mixed results.

Based on the above considerations, we conducted the present preregistered study aiming to examine the existence and strength of the relationship between dispositional mindfulness and objective attentional (i.e., phasic alertness, orienting, and executive control) and vigilance performance, while testing a sufficiently powered sample of participants. Particularly, we set out to correlate scores on FFMQ with objective performance in the ANTI-Vea. As described in greater detail in the preregistration, we hypothesized higher dispositional mindfulness to predict better executive control, executive vigilance, and global attentional performance (i.e., overall faster processing speed and/or lower error rate), while no hypotheses were formulated regarding phasic alertness, orienting, or arousal vigilance. As a subsidiary goal, we set out to explore the relationship between dispositional mindfulness scores and two self-report measures of attention, namely the Attentional Control Scale (ACS; Derryberry & Reed, 2002) and the Mind-Wandering Deliberate and Spontaneous scales (MW-D and MW-S; Carriere et al., 2013).

Methods

Participants

G*Power 3.1 (Faul et al., 2009) was used to estimate the sample size needed given our study design. We expected some of the effects under investigation to be around r = .20, as found in several previous studies correlating self-reported dispositional mindfulness and cognitive-behavioral tasks assessing attentional networks or vigilance (e.g., Ainsworth et al., 2013; Cheyne et al., 2006; Di Francesco et al., 2017; Josefsson & Broberg, 2011; Rice & Liu, 2017). In order to detect a two-tailed Pearson correlation of

.20, setting the significance level at .05 and the statistical power at .80, the estimated sample size needed in our study was 193 participants. Based on this a priori calculation, we aimed at testing a sample of at least 200 subjects.

Participants were invited using the institutional e-mail distribution lists of the University of Granada and participated in exchange of course credit (in case they were undergraduate Psychology students) or monetary compensation (in case they were students from other programs or university staff). Three hundred forty seven participants completed the full set of self-report measures and provided valid cognitive-behavioral performance data. Of them, those who met a prespecified, exhaustive set of eleven selection criteria were included in the analysis. We devised these criteria aiming to (1) standardize the sample and remove confounding variables that could potentially affect our data (C1-9) and (2) control for artifacts derived from a biased interpretation of self-report items (C10-11). The selection criteria and number of participants qualifying for exclusion in each case are provided in **Fig. 1**. A total of 219 participants (aged between 18 and 34 years; mean age = 23.37; SD = 3.64; 68.49% female) met all criteria and were included in the study.

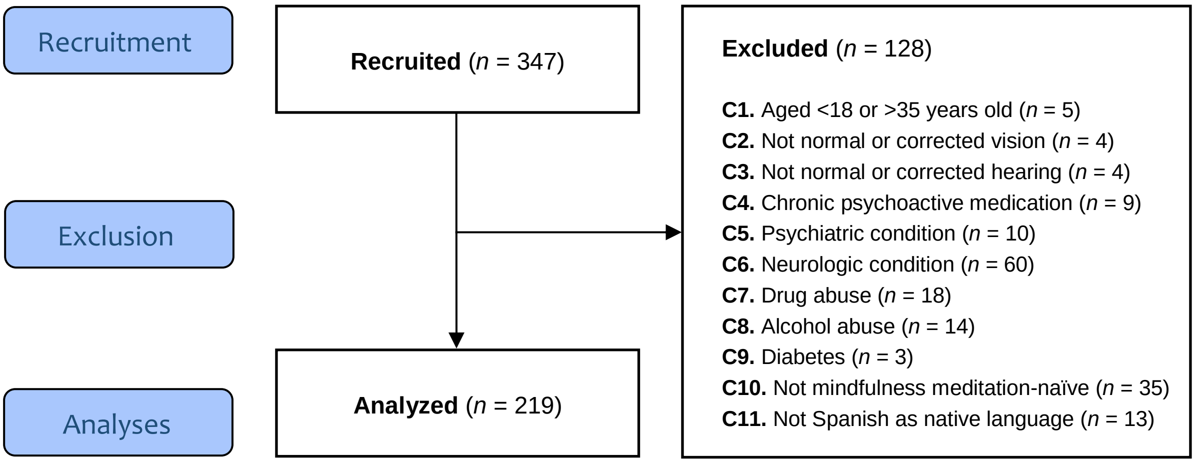

Fig. 1 Participant's flow diagram and selection criteria including number of subjects qualifying for exclusion in each case. Note that a proportion of participants qualified for exclusion by more than one criteria, reason why the sum of *n* by criteria surpass the 128 participants excluded

Procedure

Participants were reached through e-mail. By following a link, they could access the first part of the study that consisted of an online survey hosted on LimeSurvey (http://www.limesurvey.org). Once accessed, and prior to starting the experimental procedure, participants received basic information about the study and gave informed consent. Next, they were presented with an eligibility battery comprised of sociodemographic, health-related, and lifestyle questions. Next, participants completed the FFMQ (Cebolla et al., 2012), the ACS (Derryberry & Reed, 2002), as well as the MW-D and MW-S (Carriere et al., 2013) scales. By the end of the survey, participants were invited to follow another link to the webpage hosting the ANTI-Vea (https://www.ugr.es/~neurocog/ANTI/).

At the ANTI-Vea webpage, and before beginning with the task, participants were encouraged to reduce any possible distractions from then onwards. A message also warned them that the task would be displayed full-screen and that it was important to perform the entire procedure with no interruptions. Additionally, they were asked to configure the computer's sound level at 75%, use no headphones, and turn off the sound and vibration function on their mobile phone. They were also encouraged to keep the phone out of reach until the end of the task. Moreover, they were asked to turn off any entertainment device, such as television, radio, or music players. Immediately before starting the ANTI-Vea, participants were invited to take a break if it was needed for any particular reason and were encouraged to remain seated thereafter until completion of the task.

The ANTI-Vea comprises three types of trials: ANTI (measuring the attentional networks; 60%), EV (measuring executive vigilance; 20%), and AV (measuring arousal vigilance; 20%). In ANTI trials, participants performed a flanker task that was sometimes preceded by a warning tone and or a visual cue (or both), in order to assess phasic alertness (no tone minus tone condition), orienting (invalid minus valid cue condition), and executive control (incongruent minus congruent condition). In EV trials, the target (central arrow) was upwardly or downwardly displaced, and participants had to detect this minor change. In AV trials, a red millisecond countdown was presented, which participants were instructed to stop as fast as possible. For a schematic representation of the ANTI-Vea task procedure in each trial type, see **Fig. 2** (a detailed description of the procedure is provided in Supplementary Material S1). The ANTI-Vea started with a practice phase, in which instructions were given so that participants could gradually familiarize themselves with each type of trial. Next, six blocks of 80 randomized trials each (48 ANTI, 16 EV, and 16 AV) were presented, without any break, as the actual experimental task. Participants were encouraged to respond as quickly and accurately as possible while keeping their eyes on the fixation cross until the finalization of the task.

Measures

Five Facets Mindfulness Questionnaire

Our primary self-report measure was the Spanish version of the FFMQ (Cebolla et al., 2012), a 39-item scale assessing five component factors of mindfulness. (1) Observing (hereafter referred to as Observe) regards attending to and noticing internal and external experiences such as sensations, emotions, and thoughts. (2) Describing (Describe) refers to labeling internal experiences, especially emotions, with words. (3) Acting with awareness (Actaware) is defined as the capacity to being focused on present-moment activities as opposed to behaving reflexively or getting distracted. (4) Non-judging of inner experience (Nonjudge) refers to adopting a non-evaluative attitude toward thoughts and feelings. And (5) non-reactivity to inner experience (Nonreact) regards experiencing thoughts and feelings without reflexively responding nor being caught up by them. FFMQ items are rated on a 5-point Likert scale ranging from one (“never or very rarely true”) to five (“very often or always true”). In our study, the reliability of the instrument was similar to that found in previous research, yielding estimates of internal consistency (*α* for Cronbach's alpha and *ω* for McDonald's omega) as follows: for Observe, *α* = .68, *ω* = .69; for Describe, *α* = .91, *ω* = .92; for Actaware, *α* = .88, *ω* = .88; for Nonjudge, *α* = .90, *ω* = .90; for Nonreact, *α* = .76, *ω* = .77; and for the Total score, *α* = .85, *ω* = .86. The items of the Spanish version of the FFMQ are provided as Supplementary Material S2.

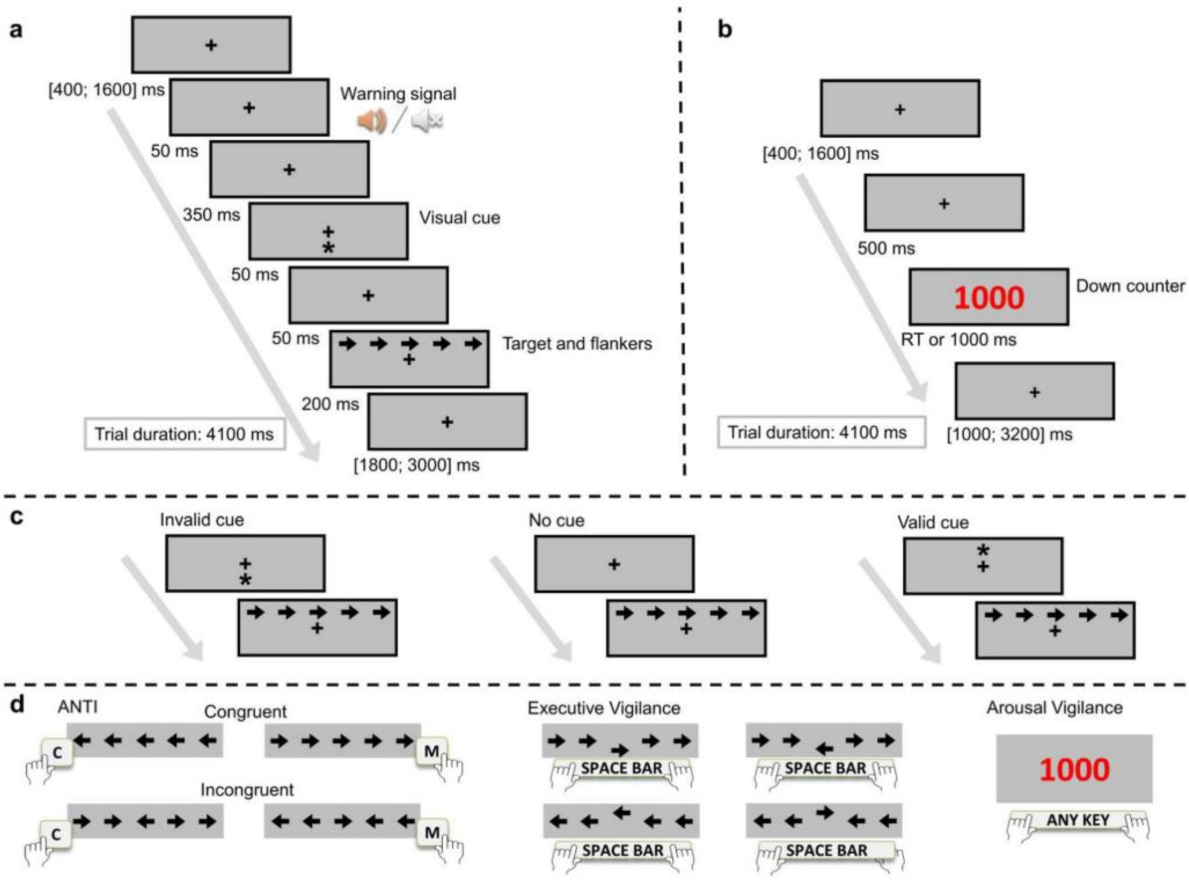

Fig. 2 Visual representation of the ANTI-Vea task procedure. (**a**) Stimuli sequence for ANTI and EV trials, during which participants had either to respond to the direction pointed by the central arrow or to detect its vertical displacement, respectively. (**b**) Stimuli sequence for AV trials, during which participants had to stop the red countdown as fast as possible. (**c**) Examples of the three visual cue conditions for the assessment of the orienting network. (**d**) Correct responses for each type of trial

Attentional Control Scale

Participants additionally completed the Spanish translation of the ACS (Derryberry & Reed, 2002). The ACS comprises 20 items assessing general everyday attentional control ability. Items are rated on a 4-point Likert scale from one (“almost never”) to four (“always”). In the present study, the internal consistency of the instrument was α = .84, ω = 0.84. The items of the Spanish translation of the ACS are provided as Supplementary Material S3.

Mind-Wandering Deliberate and Spontaneous Scales

As the last self-report measure, participants completed the Spanish translation of the MW-D and MW-S (Carriere et al., 2013). The MW-D and MW-S comprise four items each and assess everyday tendencies to engage in task-unrelated thought or mind-wandering either voluntarily or involuntarily, respectively (Carriere et al., 2013). Items are scored on a 7-point Likert scale from one (“rarely”) to seven (“a lot”) except for the third item of the MW-S (1 = “almost never” to 7 = “almost always”) and the third item of the MW-D (1 = “not at all true” to 7 = “very true”). In our study, the MW-D and MW-S yielded internal consistency estimates of α = .86, ω = .86, and α = .80, ω = .80, respectively. The items of the Spanish translation of the MW-D and MW-S scales are provided as Supplementary Material S4.

ANTI-Vea Task

Cognitive-behavioral attentional and vigilance data were collected using the online version of the ANTI-Vea (Luna et al., 2018), which is available for free use in multiple languages at https://www.ugr.es/~neurocog/ANTI/. The stimuli characteristics for each trial type are depicted in **Fig. 2** (further technical specifications are provided in Supplementary Material S1). The ANTI-Vea has recently been validated for both in-lab and online testing (Luna et al., 2021). As demonstrated by Luna et al. (2021), there are no substantial differences between the data collected by each version of the task. Moreover, in both cases, the ANTI-

Vea: (1) demonstrated to be at least as reliable as previous versions of the task such as the classic ANT for the assessment of the attentional networks; while (2) demonstrated high reliability for assessing the executive and arousal components of vigilance. The reliability of the ANTI-Vea in the present study was also estimated by computing split-half internal consistency estimates based on our collected data.

Data Analyses

ANTI-Vea Analysis

Following standard analysis of the ANTI-Vea task (Luna et al., 2020), reaction time (RT) analysis in ANTI trials excluded incorrect responses or trials with RT below 200 ms or above 1500 ms. Data from participants with an error rate larger than 25% or with extreme average RT (±2.5 standard deviations [SD] from the group mean) in ANTI trials were also excluded. Additionally, we removed participants with extremely low hit rate or extremely high lapse rate (±2.5 SD from the group mean), as such rates were interpreted not as just poor performance but as indicative of participants not being actually engaged in the task. Lastly, one participant was excluded for which 80 trials were not registered due to technical reasons. Since it has been previously shown that four blocks are sufficient to reliably measure the attentional networks and to detect decrements changes in sustained attention (Román-Caballero et al., 2021), participants were included in the analysis if they had performed the task at least until the end of the fourth experimental block (out of the total sample of 219 participants, 202 [92.2%] performed the task at least until end the fifth experimental block, and 191 [87.2%] completed the full ANTI-Vea procedure).

Once the data were preprocessed, separate analyses were conducted for ANTI, EV, and AV trials. For ANTI trials, we computed: (1) the mean RT and percentage of errors (as global indices of attentional performance); and the efficiency indices for (2) phasic alertness (no tone minus tone, in no cue trials), (3) orienting (invalid minus valid trials), and (4) executive control (incongruent minus congruent trials) using both RTs and percentage of errors. For EV trials, we computed the following measures: (1) hits (correctly identified vertically displaced target); (2) false alarms (non-displaced target assessed as being vertically displaced); (3) A' (sensitivity); and (4) B'' (response bias). For each of them, we obtained both overall indices and decrement slope indices. The overall indices are average measures throughout the task. In turn, the decrement slope indices are measures of the extent of change over time. In particular, to obtain the decrement slopes we calculated the slope of the regression line for each participant across the six blocks of trials in each vigilance measure. Lastly, regarding AV trials, we computed both overall indices and decrement slopes for (1) mean RT, (2) SD of RTs, and (3) percentage of lapses (defined as the percentage of AV trials with responses >600 ms or with no response).

Correlational Analysis

Correlational analyses were conducted (1) between FFMQ and the indices computed from ANTI, EV, and AV trials, and (2) between FFMQ and the ACS, MW-D, and MW-S scales. First, the assumption of normality was tested by using Shapiro-Wilk (Shapiro et al., 1968). Given that virtually none of the pairs of variables of interest were bivariate normally distributed, we used Kendall's Tau for analysis, as it is considered the most robust correlation coefficient in cases of non-parametric data (Croux & Dehon, 2010). Note that the interpretation of Kendall's Tau magnitude differs from that of Pearson's *r.* While values of .10, .30, and .50 are commonly considered as small, medium, and large Pearson correlations, the equivalent values for Kendall correlation are .07, .20, and .35, respectively (for a table of conversion among correlation coefficients, see Gilpin, 1993).

One-tailed correlations were applied to contrasts for which we had preregistered directional hypotheses (i.e., regarding executive control, executive vigilance, and global attentional performance). In particular, we applied one-tailed tests for positive correlations to variables indexing good performance (hits and A') or that decrease over time in task (hits slope, A' slope, FA slope); conversely, we applied one-tailed tests for negative correlations to variables indexing poor performance (interference control effect, FAs, overall RT, overall percentage of errors) or that increase over time in task (B'' slope). Two-tailed correlations were conducted for all remaining contrasts. In addition, the set of correlations as conducted applying two-tailed tests to all contrasts is provided as Supplementary Information. Alpha (significance level) was set at .05. Finally, Benjamini-Hochberg correction for multiple comparisons was applied (Benjamini & Hochberg, 1995) setting the FDR at .20 (McDonald, 2014). We used JASP 0.13.1 (JASP Team, 2020) to conduct the correlations and Jamovi 1.6.23 (Jamovi Project, 2021) to generate the corresponding scatter plots.

Reliability Analysis

To aid the interpretation of our correlational results, we considered recent discussions highlighting the criticality of assessing measurement reliability when conducting individual differences research (e.g., Dang et al., 2020; Parsons et al., 2019). As any observed correlation is constrained by the reliability of the measures used to obtain it, so that $\text{Sample correlation} = \text{"True" correlation} \times \sqrt{\text{Reliability (x)} \times \text{Reliability (y)}}$ (Dang et al., 2020), without reliability estimates it is not possible to ascertain whether the size of a given correlation reflects the actual shared variance or is rather a byproduct of measurement error. We thus computed internal consistency indices for all measured used. For self-report assessments, we obtained both Cronbach's alpha and McDonald's omega coefficients (Peters, 2014). Regarding the ANTI-Vea, we computed 10,000-iterations permutation-based split-half reliability indices with Spearman-Brown correction, for both overall and decrement slope assessments. The rationale of the split-half reliability method has been described by Parsons et al. (2019), while its procedure as applied to the ANTI-Vea task has been detailed by Luna et al. (2021). The analysis was conducted in RStudio

2021.09 (RStudio Team, 2021). The script used was adapted from the original version by Luna et al. (2021) and is available at the Open Science Framework (https://osf.io/374rs/).

Results

Attentional Networks and Vigilance

Descriptive statistics and split-half reliability indices for ANTI, EV, and AV outcomes are provided in **Table 1**. As shown, the task yielded indices in line with those reported by Luna et al. (2021) regarding both the attentional and vigilance measurements and their reliability estimates. Additional analyses were conducted to be certain that our EV and AV indices were appropriately assessing the vigilance decrement phenomenon. As detailed in Supplementary Material S5, a series of repeated measures ANOVAs confirmed that all the EV and AV measures were sensitive to detect performance changes across time on task. Our main research outcomes are summarized in **Table 2**, where correlations between FFMQ scores and ANTI, EV, and AV outcomes are reported. For the sake of simplicity, herein we only report *p*-values of significant findings. *P*-values obtained for all significant and non-significant comparisons performed between FFMQ scores and ANTI, EV, and AV outcomes are provided as Supplementary Material S6.

The reliability of the ANTI outcomes ranged from r_{SB} = .22 to r_{SB} = .99, with the global indices of attention demonstrating higher reliability (r_{SB} = .91 to r_{SB} = .99) than the efficiency scores (r_{SB} = .22 to r_{SB} = .64; see **Table 1**). We found seven correlations between FFMQ and attentional networks outcomes, of which two remained significant after Benjamini-Hochberg correction for multiple comparisons (see **Table 2**). In particular, scores on Nonreact facet were negatively associated to overall RTs, $\tau_b = -.118$, $p = .006$, and percentage of errors, $\tau_b = -.118$, $p = .006$, in ANTI trials (see also **Fig. 3**). In line with our hypotheses, these results indicate that participants reporting higher dispositional mindfulness—particularly those less predisposed to react reflexively to negative thoughts and emotions—showed better global attentional performance as indexed by faster and more accurate responses to the task.

Table 1

Descriptive Statistics and Split-Half Reliability Indices (Spearman-Brown corrected) of ANTI-Vea Outcomes

	M	*SD*	r_{SB}
Attentional Networks			
RT Overall	629	85	.99
% Errors Overall	6.01	4.51	.91
RT Alerting	43	41	.45
% Errors Alerting	1.30	4.56	.24
RT Orienting	45	27	.40
% Errors Orienting	0.14	3.71	.22
RT Control	38	28	.64
% Errors Control	0.01	3.71	.51
Executive Vigilance			
% Hits	80.40	12.83	.91
% Hits Slope	−1.79	3.22	.58
% FAs	6.84	6.04	.78
% FAs Slope	−0.37	2.16	.21
A’	.93	.04	.84
A’ Slope	−.004	.01	.45
B’’	.41	.43	.80
B’’ Slope	.05	.16	.06
Arousal Vigilance			
RT Mean	490	55	.96
RT Mean Slope	5.44	10.74	.65
% Lapses	9.49	12.79	.96
% Lapses Slope	1.54	3.14	.81
SD of RT	78.27	26.71	.71
SD of RT Slope	4.03	9.59	.65

Note. M = Mean; SD = Standard deviation; r_{SB} = Split-half reliability (Spearman-Brown corrected); RT = Reaction time; FA = False alarm.

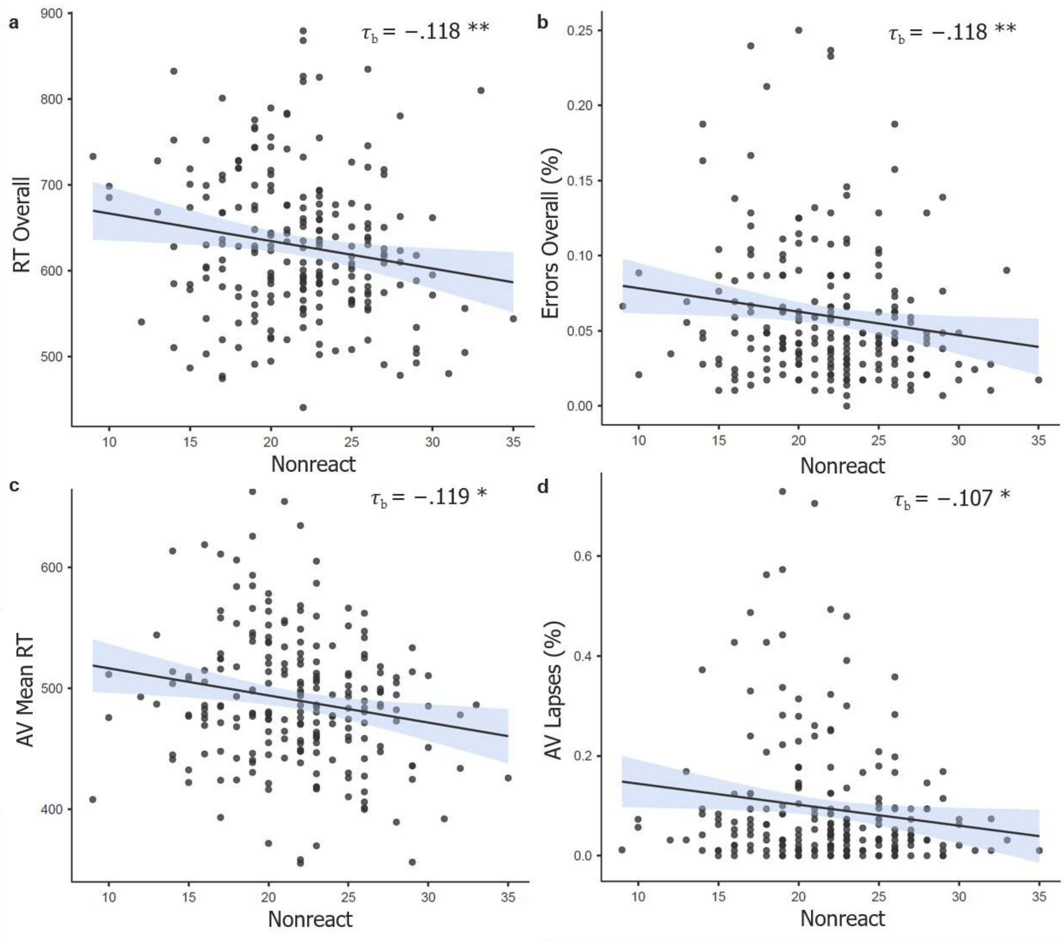

Fig. 3 Main correlational results of the study. Scatter plot and correlation between Nonreact score and (**a**) mean RT across ANTI trials; (**b**) mean error rate across ANTI trials; (**c**) RT in AV trials; and (**d**) lapses rate in AV trials. Correlations estimated using Kendall's Tau coefficient. Reported *p*-values are after applying Benjamini-Hochberg procedure. Shading represents standard errors. $N = 219$

Concerning EV outcomes, reliability estimates ranged from $r_{SB} = .06$ to $r_{SB} = .91$, with overall indices showing higher reliability ($r_{SB} = .78$ to $r_{SB} = .91$) than decrement slope scores ($r_{SB} = .06$ to $r_{SB} = .58$; see **Table 1**). Of the correlations performed, two of them were initially found to be significant. However, none of them were maintained as true positives after performing Benjamini-Hochberg correction for multiple comparisons (see **Table 2**).

In contrast, five correlations were found between AV and FFMQ scores, all of which remained significant after correcting for multiple comparisons (see **Table 2**). Split-half reliability ranged from r_{SB} = .65 to r_{SB} = .96 for AV outcomes. As for EV, overall indices demonstrated higher reliability (r_{SB} = .71 to r_{SB} = .96) than decrement slope scores (r_{SB} = .65 to r_{SB} = .81; see **Table 1**). Correlational results showed that scores on Describe facet were negatively associated with number of lapses, $\tau_b = -.111$, $p = .019$, while scores on Nonreact were negatively associated with both mean RT in AV trials, $\tau_b = -.119$, $p = .011$, and percentage of lapses, $\tau_b = -.107$, $p = .026$ (see also **Fig. 3**). Moreover, total FFMQ scores also correlated negatively with mean RT in AV trials, $\tau_b = -.103$, $p = .025$, and number of lapses, $\tau_b = -.103$, $p = .027$. These results indicate that participants with higher self-reported dispositional mindfulness showed improved arousal vigilance as indexed by faster responses and fewer lapses (i.e., missed targets) in AV trials.

As shown in Supplementary Material S7, the results applying two-tailed tests to the full set of correlations were virtually identical to those reported above. As the only exception, the two correlations between Nonreact and the global attentional indices, albeit also declared significant, did not held after correction for multiple comparisons when bidirectional testing was applied.

Finally, and in addition to our planned comparisons, a series of post hoc correlational analyses were conducted to further scrutiny the relationship between dispositional mindfulness and attentional performance. In particular, we examined the relationship between attentional performance and dispositional mindfulness at the first half (i.e., blocks 1-3) and the second half (i.e., blocks 4-6) of the task, separately. The rationale for this analysis was to investigate potential changes in attentional networks performance in relation to mindfulness trait as a function of time on task. Note that while the AV and EV measures can capture such a potential change during time on task by means of the decrement slopes, this is not the case for the attentional networks indices. The results from these exploratory analyses along with a narrative overview and interpretation of them is provided as Supplementary Material S8.

Table 2

Kendall's Tau Correlations Between Five Facets Mindfulness Questionnaire and Attentional Networks, Executive Vigilance, and Arousal Vigilance Outcomes

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
Attentional Networks						
RT Overall	−.055	−.014	−.016	−.029	−.118**	−.078#
% Errors Overall	.010	−.054	.005	−.012	−.118**	−.078#
RT Alerting	−.035	.025	.095#	−.014	−.020	.011
% Errors Alerting	−.031	−.026	.101#	.011	−.029	.017
RT Orienting	−.002	.012	−.035	−.040	.104#	−.008
% Errors Orienting	−.020	−.041	−.062	−.077	−.023	−.075
RT Control	−.014	−.024	.083	.006	−.025	.012
% Errors Control	−.001	−.009	.058	.031	.054	.044
Executive Vigilance						
% Hits	−.066	.049	.013	−.009	.010	.012
% Hits Slope	.008	−.013	−.026	.041	−.033	.006
% FAs	.011	.033	−.022	−.018	−.027	−.019
% FAs Slope	−.027	−.030	.046	.029	−.005	.020
A'	−.090	.025	−.007	−.008	.025	−.002
A' Slope	.007	.004	−.012	.027	.016	.002
B''	.045	−.032	.017	.013	.019	.026
B'' Slope	−.042	.023	−.058	−.078#	−.044	−.096#
Arousal Vigilance						
RT Mean	.052	−.091	−.033	−.060	−.119*	−.103*
RT Mean Slope	.043	.034	.015	−.010	−.059	.005
% Lapses	.034	−.111*	.010	−.059	−.107*	−.103*
% Lapses Slope	.026	−.042	−.008	−.082	−.058	−.070
SD of RT	.018	−.039	.034	−.022	−.079	−.043
SD of RT Slope	.001	−.031	−.004	−.046	−.062	−.049

Note. $N = 219$. RT = Reaction time. FA = False alarm. SD = Standard deviation. Number sign (#) indicates correlations declared significant ($p < .05$) prior to Benjamini-Hochberg procedure. Asterisks (*) indicate correlations held significant after Benjamini-Hochberg procedure.

* $p < .05$; ** $p < .01$.

Self-Reported Attentional Control and Mind-Wandering

Secondary research outcomes are summarized in **Table 3**, where correlations between FFMQ and ACS, MW-D, and MW-S scores are reported. After correction for multiple comparisons, we found that FFMQ total score correlated positively with ACS, $\tau_b = .336$, $p < .001$, and negatively with MW-S, $\tau_b = -.264$, $p < .001$ (while it was not related to MW-D, $\tau_b = -.013$, $p = .781$). These results indicate that participants with higher dispositional mindfulness reported having a greater everyday attentional control ability and a reduced inclination to engage spontaneously in mind-wandering (while showed no different propensity to mind-wander voluntarily). For correlations between specific FFMQ facets and self-reported attentional control and mind-wandering see **Table 3**. *P*-values obtained for all comparisons performed between FFMQ scores, ACS, and MW questionnaires are provided as Supplementary Material S9.

Table 3

Kendall's Tau Correlations Between Five Facets Mindfulness Questionnaire and ACS, MW-S, and MW-D.

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
ACS	.004	.197***	.366***	.193***	.163***	.336***
MW-D	.149**	−.013	−.137**	−.039	.075	−.013
MW-S	.184***	−.111*	−.434***	−.247***	−.091	−.264***

Note. $N = 219$. ACS = Attentional Control Scale. MW-S = Mind-Wandering Spontaneous. MW-D = Mind-Wandering Deliberate. Asterisks (*) indicate correlations held significant after Benjamini-Hochberg procedure.

* $p < .05$; ** $p < .01$; *** $p < .001$.

Discussion

The present study aimed to examine the existence and strength of the relationship between dispositional mindfulness and a variety of objective measures of attention and vigilance. To this end, FFMQ scores were correlated with attentional performance in a novel cognitive-behavioral assessment: the ANTI-Vea. As an additional aim, we also explored the relationships between dispositional mindfulness and two subjective attention-related measures (ACS and MW-D/MW-S). In order to buffer the influence of Type I and Type II error rates, we tested a large sample of participants (N = 219) and corrected for multiple comparisons using the Benjamini-Hochberg procedure. For all measures, reliability coefficients were computed to aid in the interpretation of our results.

As expected, our analyses revealed an association between global attentional performance and dispositional mindfulness. Particularly, higher Nonreact scores predicted faster RT and reduced error rate in ANTI trials. Contrary to expectations, however, we did not find an association between dispositional mindfulness and executive vigilance. Instead, we found such a relationship with arousal vigilance, so that higher scores on Nonreact, as well as higher FFMQ total score, predicted faster RT and fewer lapses in AV trials. The number of lapses was also negatively correlated to Describe scores. Finally, we did not find the expected positive association between dispositional mindfulness and the efficiency of the executive control network (nor did we find any association with phasic alertness or orienting). Overall, this pattern of findings suggests that dispositional mindfulness is related to improved global attentional and arousal vigilance performance, with non-reactivity to inner experience as the main facet driving the association. The size of the effects was within the anticipated range, being on average of about Kendall's τ_b = .11 (equivalent to Pearson's r = .17) for statistically significant correlations.

Non-reactivity was the facet most consistently and strongly associated with better objective attentional and vigilance performance. Interestingly, this indicates that a rather affective quality (i.e., not being reactive to the content of experience including thoughts and emotions and, thus, not being carried away by them) is more closely related to improved cognition than other more attention-related qualities (such as acting with awareness). This may be explained by considering the characteristics of the ANTI-Vea, which requires to perform (and switch among) three simultaneous tasks (ANTI, EV, and AV) throughout approximately 50 minutes. Being highly demanding and lengthy, the ANTI-Vea is experienced by participants as moderately aversive. As coping with stress requires cognitive resources (Muraven & Baumeister, 2000), our results seem to suggest that less reactive participants may have needed to invest fewer resources to downregulate the mild negative affect and associated automatic negative thoughts linked to task performance, thus being less overloaded by its cognitive demands. In turn, freeing up cognitive load would have translated into an improved general state of preparation during the task. This interpretation is in line with the fact that participants with higher non-reactivity scores were faster in responding to both ANTI and AV trials, assessments that index overall and sustained preparation throughout the task, respectively. Importantly, this association is not the result of a speed/accuracy trade-off since higher non-reactivity scores were also associated with a reduced error rate in ANTI trials.

These findings are consistent with several pieces of previous evidence. For instance, non-reactivity has been identified as the mindfulness facet most strongly associated with attentional accuracy in a breath counting task (Tortella-Feliu et al., 2020), and has been shown to be sensitive to the length of focused attention meditation practice (Cebolla et al., 2017). Furthermore, evidence shows that non-reactivity appears to be the best proxy for the broader construct of acceptance (Soler et al., 2014), which has also been shown to be critical for cognitive performance. In a randomized controlled study, Rahl et al. (2017)

evaluated vigilance performance in the SART after two different mindfulness interventions that incorporated either training in attention monitoring or training in both attention monitoring and acceptance. The study found that the attention monitoring and acceptance training group showed higher discriminability throughout the task, thus outperforming the one based on attention monitoring training alone. Altogether, these and our own findings suggest that the “how” of mindfulness (accepting attitude) is at least as relevant as the “what” (attention monitoring) for cognitive performance.

Contrary to expectations, we did not find dispositional mindfulness to be associated with executive vigilance. Although speculative, differences in task demands between the ANTI-Vea and other assessments used in previous research may account for this null result. The high cognitive demand that characterizes the ANTI-Vea as a triple task sets it apart from other classic executive vigilance assessments, in which participants are required to perform a single task (e.g., CPT, SART). As simpler, less demanding tasks lead to less motivation and engagement, they are also more prone to mind-wandering, which is likely one important factor driving poor vigilance performance in this type of assessment. In turn, since dispositional mindfulness is known to be linked to diminished mind-wandering (Mrazek et al. 2012; see also our own secondary results), it may be argued that more mindful individuals perform better in simple vigilance tasks due to their reduced tendency to mind-wander. However, being the ANTI-Vea relatively more demanding, it may leave fewer cognitive resources available for participants to engage in mind-wandering. If this is true, the aforementioned advantage of more mindful individuals would be undermined in the context of our task, in which there is relatively little mind-wandering to be downregulated. As discussed below, future research manipulating task cognitive load and measuring actual on-task mind-wandering (e.g., via thought probes) while assessing the relationship between dispositional mindfulness and vigilance may prove useful in testing the validity of this explanation.

Also against our hypotheses, we did not find dispositional mindfulness to correlate with executive control. The above-mentioned explanation for the lack of correlation with executive vigilance is also applicable here. Assuming that improvements in executive attention related to high mindfulness are due to better control over mind-wandering—as suggested by our secondary results—, we may not have observed the expected correlation with executive control because mind-wandering was already reduced for all participants. In line with this interpretation, it has been observed that the interference effect of the executive control network is smaller in the ANTI-Vea as compared to other simpler flanker tasks (Luna et al., 2020), a reduction that is hypothesized to be a consequence of the relatively high demands and low mind-wandering that characterize our task. In fact, the interference effect in the classic ANT is approximately twice as large as it is in the ANTI-Vea (usually ~100 ms and ~45 ms, respectively). As previously mentioned and discussed in more detail below, future research may find fruitful to include state (as opposed to trait) measures of mind-wandering, as well as retrospective reports of effort/fatigue, to further inquire whether or not and to what extent these factors are affecting the interference effect and, thus, the magnitude of its relationship to dispositional mindfulness.

A second plausible interpretation for the null result regarding executive control has to do with reliability and statistical power rather than with task characteristics. Note that while the ANTI-Vea measures for which we did observe statistically significant correlations demonstrated excellent reliability (raging from r_{SB} = .91 to r_{SB} = .99), the internal consistency of the executive control indices was not as high (ranging from r_{SB} = .51 to r_{SB} = .64). This has two consequences. On the one hand, it lends confidence to our correlational results regarding global attentional and arousal vigilance performance, further suggesting that they are indeed true positives and that their observed magnitude is not strongly attenuated by suboptimal measurement reliability (Dang et al., 2020). On the other hand, it means that our a priori power calculation underestimated the sample needed to detect correlations involving the attentional networks, including executive control.

Consider as an example the FFMQ total score (ω = .86) and the executive control RT efficiency score (r_{SB} = .64). In order to detect a two-tailed correlation of r = .20 between them, the actual effect size one should aim for when estimating the sample size is r = $.20 * \sqrt{.86 * .64}$ = .15. (see Dang et al., 2020). In this scenario, the sample needed to achieve the standard power of .80 would be of 346 participants, which stands in stark contrast to the 193 participants required in case of ideal reliability. By this logic, the observed null correlations involving the executive control indices might simply reflect Type II errors. In fact, the same holds true for all other attentional networks efficiency measures, which showed similar or lower reliability. In contrast, and importantly, this also implies that positive findings from previous (smaller) studies correlating dispositional mindfulness and attentional networks tasks may indeed be Type I errors (note that phasic alertness, orienting, and executive control outcomes in the ANTI-Vea are at least as reliable as those from previous ANT-related tasks; Luna et al., 2021). Considering all this, it is possible that the existing body of research assessing this relationship—our own study included—has been unable to address the phenomenon reliably. Future studies must consider factoring measurement reliability into their power calculations, and thus testing larger samples, in order to better gain access to it.

A subsidiary aim of our study was to explore the relationships between FFMQ and two subjective attention-related measures: the ACS and the MW-D/MW-S scales. Our results showed that participants with higher dispositional mindfulness (as assessed by the total FFMQ score) also reported having better attentional control and less spontaneous (but not voluntary) mind-wandering during daily life. This result is consistent with what can be theoretically expected: the higher the level of dispositional mindfulness, the larger the metacognitive capacity to voluntarily regulate attention in the presence of both external and internal distraction (as assessed by the ACS and MW-S, respectively). In turn, dispositional mindfulness was not related to deliberate mind-wandering (MW-D), arguably because this process reflects aspects that are both correlated and anticorrelated to mindfulness. For instance, while it is voluntary (reflecting, therefore, a metacognitive regulatory capacity possibly linked to mindfulness), it also entails the detachment from immediate sensory experience (thus opposing the construct of mindfulness).

Discussing the associations between these constructs and specific mindfulness facets is beyond the scope of the present report. Nonetheless, there is a rather wider observation that may be worth calling attention to, namely that the size of the correlations between FFMQ and objective ANTI-Vea measures is on average about half the size of the correlations between FFMQ and subjective self-report scores. This seeming discrepancy is not atypical when correlating measures addressing distinct levels of analysis of the same construct. For instance, Bernoster et al. (2019) addressed impulsivity (and other closely related constructs) simultaneously by using various self-report, behavioral, and electrophysiological measures. Similar to what we found, the authors observed that the measures were highly correlated within but not between each type of measurement (i.e., among self-report measures, but not between self-report and behavioral/electrophysiological measures), observation for which they could not find a convincing explanation. Although speculative, one possibility is that such discrepancy is reflecting systematic noise derived from the subjective nature of self-report assessments.

Consider as an example attentional control. If a participant believes she has high attentional control, she will likely score also relatively high in at least some aspects of mindfulness (e.g., acting with awareness subscale) and low in (spontaneous) mind-wandering, independently of whether her belief is true or not. In contrast, this participant would only score relatively high in the executive attention index of the ANTI-Vea if her belief is indeed true. In other words, self-report assessments may not only measure the actual capacities or tendencies of the participants but also their subjective beliefs about them (for a similar argument, see Quigley et al., 2017). If we assume that individuals will have similar beliefs about related constructs, a systematic bias may be introduced so that correlations between overlapping self-report measures could be artefactually enlarged—while the observed shared variance between cognitive-behavioral and self-report data will more closely reflect the underlying relationship of interest. This is one example of the so-called common method bias, or the biasing effect that can be introduced when assessing the relationship between several constructs that have been measured using the same method (for a review, see Podsakoff et al., 2012). Although this explanation remains speculative, it highlights the value of using objective cognitive-behavioral measures, in addition to self-reports, to assess attention when studying its relationship to mindfulness and meditation practice.

Limitations and Future Research

The present study is not without limitations. First, our sample was composed of young, healthy participants with no meditation experience. This methodological feature precludes the generalization of our results beyond this population. Second, the relatively low reliability of some of our measures (especially those related to the attentional networks) hindered their capacity to detect small correlations, thus potentially increasing the probability of Type II errors. And third, our subsidiary correlational results linking dispositional mindfulness, mind-wandering, and attentional control, were obtained entirely from self-report measures, and may have therefore suffered from common method bias. In light of this, future research should consider (1) extending our results both to the general population and to other specific populations (such as, and especially, experienced meditators); (2) when feasible, testing even larger samples to buffer the reduction in statistical power derived from suboptimal measurement reliability; and, (3) relying on multiple, distinct measurement methods (e.g., self-report, cognitive-behavioral, thought probing, neurophysiology) so as to more validly assess the relationship between dispositional mindfulness, mind-wandering, and attention.

As mentioned above, future studies may also consider assessing the relationship between dispositional mindfulness and vigilance while manipulating cognitive load (i.e., the task demand). The online ANTI-Vea website affords the configuration of task demand by choosing whether to present a single, double, or triple task, thus being an accessible and convenient tool for researchers aiming to further explore this topic. It is also worth mentioning that our investigation included only trait measures of mind-wandering (MW-D and MW-S), which precludes drawing solid conclusions about the actual prevalence of mind-wandering during the task and its potential role mediating the relationship (or lack thereof) between dispositional mindfulness and executive attention performance. Future studies will thus benefit from including on-task measures of state mind-wandering (such as thought probes or retrospective reports) to better understand the relationships among these constructs in the context of the ANTI-Vea and similar tasks.

Given that that our investigation entails the first attempt to research individual differences in trait mindfulness in relation to attention and vigilance performance by using the ANTI-Vea task, future studies replicating our findings are warranted. This may be particularly relevant for the correlations between Nonreact and the global attentional indices which, while robust when applying the preplanned contrasts, did no emerge using bidirectional comparisons. In addition, future similar research may also consider exploring alternative analytic approaches to the one reported here. Particularly, growth curve modeling may be a valuable alternative to address performance change over time (i.e., vigilance decrement), thus proving beneficial to further scrutiny the phenomena under investigation (McNeish & Matta, 2018). Finally, considering that we found non-reactivity to inner experience to be the facet most predictive of performance, future research may find it fruitful to deepen into the relationship between attention and vigilance and measures tapping into constructs related to non-reactivity, such as equanimity (Juneau et al., 2020) or non-attachment (Sahdra et al., 2010), to extend the findings reported herein.

Supplementary Materials

SUPPLEMENTARY MATERIAL S1: Online ANTI-Vea – technical specifications

Detailed task procedure The ANTI-Vea is comprised by three types of trials: ANTI, EV, and AV. In ANTI trials, participants performed a flanker task: by pressing either "c" or "m", they had to indicate the direction pointed by a central arrow (the target) while ignoring four distracting arrows appearing at its sides (the flankers). Stimuli was presented randomly either above or below the fixation point. To assess the control network, in half of the trials both the target and the flankers pointed to the same direction (congruent condition), whereas in the other half they pointed towards opposite directions (incongruent condition). To measure phasic alertness, in half of the trials a warning signal preceded the target (tone condition), whereas no warning signal was presented in the other half (no tone condition). Lastly, to assess the orienting network, participants were presented with a visual cue that could appear either at the same location than the arrows (valid condition, one third of trials), at the opposite location (invalid condition, one third of trials), or could not appear at all (no cue condition, one third of trials). In EV trials, the procedure was as for ANTI trials except for one difference: the target appeared upwardly or downwardly displaced from its usual position. Participants were instructed to remain vigilant to this vertical displacement, and to press the space bar when they detected it. Finally, in AV trials none of the above-mentioned stimuli was presented. Instead, the fixation point remained on the screen until a red millisecond countdown appeared. For these trials, participants were instructed to remain vigilant to the appearance of the counter, and to stop it as fast as possible by pressing any key.

The ANTI-Vea started with a practice phase, in which instructions were given so that participants could gradually familiarize with each type of trial. During this phase, participants were presented with four blocks comprised, respectively, of 16 ANTI trials (with visual feedback), 32 randomized trials (16 ANTI and 16 EV; with visual feedback), 48 randomized trials (24 ANTI, 8 EV and 8 AV; with visual feedback), and 40 randomized trials (24 ANTI, 8 EV and 8 AV; without visual feedback). Prior to begin with the experimental blocks, participants were invited to repeat the last practice block if needed. Lastly, six blocks of 80 randomized trials each (48 ANTI, 16 EV and 16 AV) were presented without visual feedback nor any break as the actual experimental task.

Stimuli characteristics The ANTI-Vea was designed and run with Javascript ES5, HTML5, CSS3, and Angular JS. In ANTI and EV trials, the stimuli were: a ~7 pixels (px) black cross as the fixation point; a ~13 px black asterisk as the visual cue; a 2000 Hz tone as the warning signal; and five black arrows of 50 px wide × 23 px high, separated horizontally from each other by ~63 px, as the target (central arrow) and the flankers (surrounding arrows). In EV trials, the target was vertically displaced by 8 px either upwards or downwards. Additionally, and to make more difficult the detection of displaced targets, a random variability of ±2 px was further applied to the vertical and horizontal locations of each arrow, for both ANTI (for target and flankers) and EV (only for flankers) trials. Concerning AV trials, the stimuli consisted of a millisecond countdown timer comprised by four red numbers of ~110 px height each (see also **Fig. 1** in main text).

SUPPLEMENTARY MATERIAL S2: Items of the Spanish version of the Five Facets Mindfulness Questionnaire (FFMQ)

We used the Spanish version of the FFMQ as validated by Cebolla et al. (2012). The items of the scale were as follows:

1. *Cuando camino, noto deliberadamente las sensaciones de mi cuerpo al moverse.*
2. *Se me da bien encontrar las palabras para describir mis sentimientos.*
3. *Me critico a mí mismo/a por tener emociones irracionales o inapropiadas.*
4. *Percibo mis sentimientos y emociones sin tener que reaccionar a ellos.*
5. *Cuando hago algo, mi mente divaga y me distraigo fácilmente.*
6. *Cuando me ducho o me baño, estoy atento a las sensaciones del agua en mi cuerpo.*
7. *Con facilidad puedo poner en palabras mis creencias, sentimientos y expectativas.*
8. *No presto atención a lo que hago porque sueño despierto, porque me preocupo o porque me distraigo.*
9. *Observo mis sentimientos sin perderme en ellos.*
10. *Me digo a mi mismo/a que no debería sentir lo que siento.*
11. *Noto cómo los alimentos y las bebidas afectan a mis pensamientos, sensaciones corporales y emociones.*
12. *Me es difícil encontrar palabras para describir lo que siento.*
13. *Me distraigo fácilmente.*
14. *Creo que algunos de mis pensamientos no son normales o son malos y que no debería pensar así.*
15. *Presto atención a las sensaciones que produce el viento en el pelo o el sol en la cara.*

16. *Tengo problemas para pensar en las palabras que expresan correctamente cómo me siento.*
17. *Hago juicios sobre si mis pensamientos son buenos o malos.*
18. *Me es difícil permanecer centrado/a en lo que está sucediendo en el presente.*
19. *Cuando tengo pensamientos o imágenes perturbadoras, soy capaz de dar un paso atrás, y me doy cuenta del pensamiento o la imagen sin que me atrape.*
20. *Presto atención a sonidos como el tic-tac del reloj, el gorjeo de los pájaros o los coches que pasan.*
21. *En situaciones difíciles, puedo parar sin reaccionar inmediatamente.*
22. *Cuando tengo sensaciones en el cuerpo es difícil para mí describirlas, porque no puedo encontrar las palabras adecuadas.*
23. *Conduzco en "piloto automático", sin prestar atención a lo que hago.*
24. *Cuando tengo pensamientos o imágenes perturbadoras, me calmo en poco tiempo.*
25. *Me digo a mi mismo/a que no debería pensar como pienso.*
26. *Percibo el olor y el aroma de las cosas.*
27. *Incluso cuando estoy muy enfadado, encuentro una forma de expresarlo con palabras.*
28. *Hago actividades precipitadamente sin estar de verdad atento/a a ellas.*
29. *Cuando tengo pensamientos o imágenes perturbadoras soy capaz de notarlas sin reaccionar.*
30. *Creo que algunas de mis emociones son malas o inapropiadas y que no debería sentirlas.*

31. *Percibo elementos visuales en la naturaleza o en el arte, como colores, formas, texturas o patrones de luces y sombras.*
32. *Mi tendencia natural es poner mis experiencias en palabras.*
33. *Cuando tengo pensamientos o imágenes perturbadoras, las noto y las dejo marchar.*
34. *Hago tareas automáticamente, sin ser consciente de lo que hago.*
35. *Cuando tengo pensamientos o imágenes perturbadoras, me juzgo como bueno o malo, dependiendo del contenido.*
36. *Presto atención a cómo mis emociones afectan a mis pensamientos y a mi conducta.*
37. *Normalmente puedo describir como me siento con considerable detalle.*
38. *Me sorprendo haciendo cosas sin prestar atención.*
39. *Me critico cuando tengo ideas irracionales.*

SUPPLEMENTARY MATERIAL S3: Items of the Spanish translation of the Attentional Control Scale (ACS)

We used the Spanish translation of the Attentional Control Scale as it has been used in other previous publications (e.g., Pacheco-Unguetti et al., 2011). The items of the scale were as follows:

1. *Me cuesta mucho concentrarme en tareas difíciles cuando hay mucho ruido.*
2. *Cuando necesito concentrarme y resolver problemas, tengo muchas dificultades para centrar mi atención.*
3. *Me distraigo con sucesos que ocurren a mi alrededor aunque esté trabajando intensamente en algo.*
4. *Mi concentración es buena aunque haya música en la misma habitación.*
5. *Cuando me concentro, puedo llegar a mantener tanto mi atención que no me doy cuenta de lo que ocurre a mi alrededor.*
6. *Cuando estoy leyendo o estudiando, me distraigo fácilmente si hay gente hablando en la misma habitación.*
7. *Cuando intento centrar mi atención en algo, tengo dificultades para impedir que surjan pensamientos distractores.*
8. *Me cuesta mucho concentrarme cuando estoy nervioso/a por algo.*
9. *Cuando estoy concentrado/a, no hago caso de las sensaciones de hambre o sed.*
10. *Puedo pasar rápidamente de una tarea a otra.*
11. *Me lleva mucho tiempo involucrarme en tareas nuevas.*
12. *Cuando estoy tomando apuntes en clase tengo dificultades para escuchar y escribir al mismo tiempo.*

13. *Cuando me interesa algo novedoso me implico en ello rápidamente.*
14. *Para mí es fácil leer o escribir mientras hablo por teléfono.*
15. *Tengo problemas para llevar dos conversaciones a la vez.*
16. *Tengo dificultad para encontrar ideas nuevas rápidamente.*
17. *Después de ser interrumpido/a o distraído/a, puedo dirigir mi atención fácilmente hacia lo que estaba haciendo y reanudarlo.*
18. *Cuando un pensamiento distractor me viene a la cabeza, me resulta fácil alejar mi atención de él e ignorarlo.*
19. *Fácilmente puedo alternar entre dos tareas diferentes.*
20. *Para mí es difícil cambiar la forma de pensar sobre algo y considerarlo desde otro punto de vista.*

SUPPLEMENTARY MATERIAL S4: Items of the Spanish translation of the Mind-Wandering Deliberate and Spontaneous scales (MW-D/MW-S)

We translated the MW-D and MW-S scales from the original English version (Carriere et al., 2013), as there is currently no such translation of the instrument to Spanish. The items and instructions were forward-translated and back-translated with the aid of a professional English translator who helped to resolve discrepancies between both translations. For both scales, instructions were: “Por favor, indica para las siguientes afirmaciones la respuesta que mejor refleja tu tendencia habitual a divagar mentalmente”. The items of the scales were as follows:

MW-D:

1. *Dejo a mis pensamientos divagar a propósito.*
2. *Disfruto dejando a mi mente divagar.*
3. *Dejar mi mente divagar me resulta una buena forma de lidiar con el aburrimiento.*
4. *Me permito ensimismarme en ensoñaciones agradables.*

MW-S:

1. *Me doy cuenta de que mis pensamientos divagan espontáneamente.*
2. *Cuando mi mente divaga, mis pensamientos tienden a saltar de una idea a otra.*
3. *Siento que no tuviera control sobre mi mente cuando divaga.*
4. *Mi mente divaga espontáneamente incluso cuando se supone que debería estar haciendo otra cosa.*

SUPPLEMENTARY MATERIAL S5: Assessing the vigilance decrement phenomenon in EV and AV measures

While previous research has shown the ANTI-Vea task to be sensitive to assess the vigilance decrement phenomenon (i.e., the decline in attentional performance *across* time on task), we decided to ascertain that the same classical decrement pattern was present in our own data. To that end, we analyzed the change in performance across the six blocks of the task for all EV and AV indices. By means of a series of repeated measures ANOVAs, EV decrement was observed as significant decrement in hits [$F(5, 990) = 15.31$, $p < .001$, $\eta p^2 = 0.07$], sensitivity (A') [$F(5, 980) = 4.63$, $p < .001$, $\eta p^2 = 0.02$] and false alarms [$F(5, 985) = 4.45$, $p < .001$, $\eta p^2 = 0.02$], and a significant increment in response bias (B'') [$F(5, 980) = 6.93$, $p < .001$, $\eta p^2 = 0.03$] across blocks. In turn, AV decrement was observed as a significant increment of reaction time (RT) [$F(5, 990) = 16.45$, $p < .001$, $\eta p^2 = 0.08$], standard deviation (SD) of RT [$F(5, 990) = 7.33$, $p < .001$, $\eta p^2 = 0.04$], and lapses [$F(5, 990) = 15.31$, $p < .001$, $\eta p^2 = 0.07$] across blocks. In line with what was expected, the results showed the vigilance decrement phenomenon in all EV and AV measures.

SUPPLEMENTARY MATERIAL S6: *P*-values for main correlations

Table S6

P-Values for Kendall's Tau Correlations Between Five Facets Mindfulness Questionnaire and Attentional Networks, Executive Vigilance, and Arousal Vigilance Outcomes

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
Attentional Networks						
RT Overall	.118	.385	.367	.268	.006	.043
% Errors Overall	.581	.125	.458	.396	.006	.047
RT Alerting	.459	.593	.040	.756	.676	.804
% Errors Alerting	.517	.586	.033	.817	.545	.709
RT Orienting	.965	.794	.450	.385	.026	.861
% Errors Orienting	.674	.384	.187	.096	.629	.102
RT Control	.384	.302	.963	.550	.299	.606
% Errors Control	.496	.425	.895	.750	.874	.829
Executive Vigilance						
% Hits	.921	.146	.386	.579	.412	.394
% Hits Slope	.434	.612	.712	.190	.758	.448
% FAs	.406	.239	.682	.650	.718	.661
% FAs Slope	.714	.737	.162	.270	.544	.330
A'	.973	.297	.558	.570	.298	.513
A' Slope	.440	.468	.599	.277	.368	.332
B''	.338	.486	.709	.781	.684	.568
B'' Slope	.187	.687	.105	.047	.175	.019
Arousal Vigilance						
RT Mean	.266	.050	.473	.198	.011	.025
RT Mean Slope	.357	.458	.740	.822	.206	.907
% Lapses	.478	.019	.834	.214	.026	.027
% Lapses Slope	.585	.366	.869	.079	.224	.134
SD of RT	.692	.395	.459	.641	.092	.350
SD of RT Slope	.978	.500	.930	.322	.185	.285

Note. $N = 219$. RT = Reaction time. FA = False alarm. SD = Standard deviation.

SUPPLEMENTARY MATERIAL S7: Two-tailed correlational analyses

Table S7

Kendall's Tau Two-Tailed Correlations Between Five Facets Mindfulness Questionnaire and Attentional Networks, Executive Vigilance, and Arousal Vigilance Outcomes

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
Attentional Networks						
RT Overall	−.055	−.014	−.016	−.029	−.118#	−.078
% Errors Overall	.010	−.054	.005	−.012	−.118#	−.078
RT Alerting	−.035	.025	.09#	−.014	−.020	.011
% Errors Alerting	−.031	−.026	.101#	.011	−.029	.017
RT Orienting	−.002	.012	−.035	−.040	.104#	−.008
% Errors Orienting	−.020	−.041	−.062	−.077	−.023	−.075
RT Control	−.014	−.024	.083	.006	−.025	.012
% Errors Control	−.001	−.009	.058	.031	.054	.044
Executive Vigilance						
% Hits	−.066	.049	.013	−.009	.010	.012
% Hits Slope	.008	−.013	−.026	.041	−.033	.006
% FAs	.011	.033	−.022	−.018	−.027	−.019
% FAs Slope	−.027	−.030	.046	.029	−.005	.020
A'	−.090	.025	−.007	−.008	.025	−.002
A' Slope	.007	.004	−.012	.027	.016	.002
B''	.045	−.032	.017	.013	.019	.026
B'' Slope	−.042	.023	−.058	−.078	−.044	−.096#
Arousal Vigilance						
RT Mean	.052	−.091	−.033	−.060	−.119*	−.103*
RT Mean Slope	.043	.034	.015	−.010	−.059	.005
% Lapses	.034	−.111*	.010	−.059	−.107*	−.103*
% Lapses Slope	.026	−.042	−.008	−.082	−.058	−.070
SD of RT	.018	−.039	.034	−.022	−.079	−.043
SD of RT Slope	.001	−.031	−.004	−.046	−.062	−.049

Note. *N* = 219. RT = Reaction time. FA = False alarm. SD = Standard deviation. Number sign (#) indicates correlations declared significant ($p < .05$) prior to Benjamini-Hochberg procedure. Asterisks (*) indicate correlations held significant after Benjamini-Hochberg procedure. All comparisons are two-tailed.

* $p < .05$; ** $p < .01$.

SUPPLEMENTARY MATERIAL S8: Separate correlational analyses for 1st half (blocks 1-3) and 2nd half of the ANTI-Vea task

Table S8

Kendall's Tau Correlations Between Five Facets Mindfulness Questionnaire and Attentional Networks for 1st Half (Blocks 1-3) and 2nd Half (Blocks 4-6) of the ANTI-Vea Task.

		Blocks 1-3						Blocks 4-6					
		Obs	Des	Act	Nonj	Nonr	Tot	Obs	Des	Act	Nonj	Nonr	Tot
RT Overall	τ_b	−.069	−.022	−.024	−.017	−.102#	−.082#	−.045	−.009	.001	−.039	−.129**	−.078#
	p	.069	.315	.302	.356	.015	.037	.165	.421	.501	.199	.003	.044
% Errors Overall	τ_b	.030	−.014	−.033	−.005	−.087#	−.045	.002	−.078	−.003	−.030	−.103#	−.090#
	p	.732	.384	.243	.457	.036	.172	.520	.050	.478	.260	.016	.027
RT Alerting	τ_b	−0.45	.029	.134**	.012	−.037	.024	−.008	.014	.013	−.051	−.011	−.020
	p	.333	.536	.004	.790	.428	.598	.861	.759	.778	.273	.815	.658
% Errors Alerting	τ_b	−.047	−.087	.075	−.010	−.056	−.025	−.032	.049	.085	.030	.011	.054
	p	.355	.082	.137	.849	.273	.616	.521	.320	.086	.546	.824	.269
RT Orienting	τ_b	−.035	.049	−.030	−.021	.110#	.012	.027	−.042	−.050	−.005	.070	−.021
	p	.457	.292	.520	.649	.018	.791	.565	.366	.278	.921	.136	.648
% Errors Orienting	τ_b	−.051	−.009	−.057	−.074	−.032	−.071	−.008	−.071	−.014	−.077	−.003	−.070
	p	.293	.854	.235	.123	.512	.140	.864	.134	.776	.106	.951	.140
RT Control	τ_b	−.006	−.038	.085	−.001	−.025	.008	−.025	−.029	.057	.010	−.015	−.002
	p	.452	.207	.966	.489	.300	.570	.295	.268	.891	.587	.378	.481
% Errors Control	τ_b	−.006	.037	.066	.012	.081	.073	.042	−.054	.021	.030	−.005	−.003
	p	.453	.785	.920	.602	.956	.941	.816	.124	.670	.741	.459	.474

Note. *N* = 219. RT = Reaction time. τ_b = Kendall's Tau correlation. *p* = *p*-value. Number sign (#) indicates correlations declared significant ($p < .05$) prior to Benjamini-Hochberg procedure. Asterisks (*) indicate correlations held significant after Benjamini-Hochberg procedure.

* $p < .05$; ** $p < .01$.

The table above shows Kendall's Tau correlations between attentional network indices and mindfulness facets, both during the first half (blocks 1 to 3) and second half (blocks 4 to 6) of the task. After correcting for multiple comparisons, two correlations remained significant. First, consistent with our main results, higher Nonreact scores predicted faster RT, particularly during the second half of the task ($\tau_b = -.129$, $p = .003$). Before correction, however, statistically significant correlations were found between Nonreact and both RT and error rate during the first and the second half of the task, which also parallels our main results. Note that small fluctuations are to be expected when splitting whole-task data into two parts. Particularly, since each part contains half of the data points that comprise the full task, their reliability is diminished along with the statistical power that they can achieve. Taken both the main findings and the present results together, our data suggest that while Nonreact seems to be related to global attentional performance in terms of RT and accuracy during the whole task, the effect appears especially strong for RT during the second half. This indicates that the advantage in processing speed of less reactive individuals tends to increase over time, likely because at later stages of the ANTI-Vea fatigue builds up and the task becomes increasingly aversive, which would entail less of a handicap for these participants as compared to more reactive ones.

Second, we also found that Actaware scores were positively correlated with the phasic alertness RT effect in the first half of the task ($\tau_b = .134$, $p = .004$). No effect was found for the same correlation in the second half, not even before correcting for multiple comparisons. This result seems to indicate that participants scoring high in Actaware might benefit more from the exogenous alerting sound to accelerate their response to the target. Interestingly, this effect appeared at the beginning of the task only, when, importantly, there were still high levels of vigilance. In turn, by the end of the task, when vigilance had diminished, the effect was lost. Although it might appear counterintuitive, this lack of correlation with the alerting effect in the second as compared to the first half of the task seems *not* to reflect impoverished performance—on the contrary, the pattern is consistent with evidence showing that high phasic alertness in the context of reduced endogenous vigilance does reflect suboptimal attentional performance. Such a pattern has been found in states of sleep deprivation (Roca et al., 2012) and when comparing the attentional performance of non-musicians with that of expert musicians (Román-Caballero et al., 2021). In both cases, impoverished attentional performance was characterized by low vigilance and high phasic alertness. Although future studies are warranted to establish the robustness of the pattern of effects found here (especially given the relatively low reliability of the RT phasic alertness index and the *post hoc* nature of these analyses), our results seem to suggest that participants with higher Actaware have a more efficient phasic alertness network, which would have manifested as faster responses after alerting tones but only the context of high vigilance states.

SUPPLEMENTARY MATERIAL S9: *p*-values for secondary correlations

Table S9

P-Values for Kendall's Tau Correlations Between Five Facets Mindfulness Questionnaire and ACS, MW-S, and MW-D.

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
ACS	.939	<.001	<.001	<.001	<.001	<.001
MWS	<.001	.019	<.001	<.001	.058	<.001
MWD	.002	.788	.004	.406	.116	.781

Note. *N* = 219. ACS = Attentional Control Scale. MW-S = Mind-Wandering Spontaneous. MW-D = Mind-Wandering Deliberate.

CHAPTER V: STUDY III

From Distraction to Mindfulness: Latent Structure of the Spanish Mind-Wandering Deliberate and Spontaneous Scales and Their Relationship to Dispositional Mindfulness and Attentional Control

The content of this chapter has been submitted for publication as:

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Abstract

Objectives: Mind-wandering is a form of internal distraction that may occur both deliberately and spontaneously. This study aimed to provide a psychometric evaluation of the Spanish version of the Mind-Wandering Deliberate and Spontaneous (MW-D/MW-S) scales, as well as to extend prior research investigating their associations with dispositional mindfulness (Five Facets Mindfulness Questionnaire) and with the ability for attentional control of external distraction (Attentional Control Scale). **Methods:** In two large samples (n_1 = 795; n_2 = 1084), we examined latent structure, item- and dimension-level descriptive statistics, and internal consistency reliability scores of the Spanish MW-D/MW-S scales. Partial correlations were used to evaluate their associations to dispositional mindfulness and attentional control. Multiple linear regression and relative weight analyses were used to investigate whether or not, and to what extent, the facets of mindfulness could be uniquely predicted by internal and external distraction. **Results:** The Spanish MW-D/MW-S scales demonstrated a two-factor structure, high internal consistency reliability scores, and good nomological validity. Dispositional mindfulness was independently explained by internal and external distraction. Across facets, MW-S was the largest (negative) predictor of mindfulness, being this association particularly strong for Acting with awareness. Conversely, MW-D was mildly associated to increased mindfulness. In addition, attentional control was found moderately negatively associated with MW-S and mildly positively associated with MW-D. **Conclusions:** Our results indicate that the Spanish version of the MW-D/MW-S scales are a useful tool to assess individual differences in deliberate and spontaneous mind-wandering, shed light on the relationship between mindfulness and both internal and external distraction, and accentuate the critical role of intentionality in the study of the mind-wandering phenomena.

Introduction

Remaining attentive without getting distracted is a challenging endeavour. As the writer and inventor Hugo Gernsback (1925) described it, "[p]erhaps the most difficult thing that a human being is called upon to face is long, concentrated thinking" (p. 214). Whether it is sustaining attention to environmental stimuli or maintaining a train of thought in a goal-directed manner, external distraction can readily disturb our focus. This is the case, for example, of the noisy construction work across the street arresting our attention when we are trying to finish an important report. External, sensory stimuli, however, are not the only cause by which we can get distracted, since, as Gernsback (1925) went on, "even if supreme quiet reigns, you are your own disturber practically fifty per cent of the time" (p. 214). In fact, the detour of our attention away from a given task can also be self-generated, or caused by internal distraction. This is the case, for instance, when repetitive thoughts about an uncertain personal circumstance are the reason why we struggle to finish our report. This kind of self-generated distraction refers to the phenomenon most commonly known as task-unrelated thought or mind-wandering.

Mind-wandering can be defined as the cognitive process by which we engage in thoughts unrelated to the current demands of the external environment (Schooler et al., 2011). Likely due to its fundamentally private nature, mind-wandering has traditionally been relatively understudied as compared to other psychological phenomena. Over the last 15 years, however, the scientific interest in understanding why and how the mind wanders has seen a striking surge. A reason why this phenomenon may have inevitably gained popularity can be found in how ubiquitous it is. Conservative estimates of its prevalence indicate that we spend around 20% of our waking time in mind-wandering (Seli, Beaty, et al., 2018); less conservative estimations suggest that we spend up to 50% engaged in it (Killingsworth & Gilbert, 2010). Mind-wandering can be assessed using various subjective techniques, most commonly questionnaires, probe-caught, and self-caught methods (Smallwood & Schooler, 2015). Interestingly, mind-wandering has been linked not only with costs (e.g., impaired reading comprehension due to attentional disengagement) but also with certain benefits in areas including future planning or creative thought (Mooneyham & Schooler, 2013).

While mind-wandering was originally considered a single, unitary phenomenon, in recent years it has become increasingly acknowledged that it is best characterized, rather, as a family of related yet distinct processes (Seli, Kane, et al., 2018). One of the earliest and most prominent categorizations of the mind-wandering phenomena highlights that it can occur both with and without intention (Seli, Risko, Smilek, et al., 2016). Providing an example of the importance of this distinction, one study investigated the role of task difficulty in the prevalence of intentional and unintentional mind-wandering using thought-probes during a cognitive-behavioural assessment (Seli, Risko, & Smilek, 2016). The study found that, although overall rates of mind-wandering did not differ across conditions, participants reported more intentional mind-wandering in the easy condition, but more unintentional mind-wandering in the difficult one. Had the distinction between intentional and unintentional mind-wandering been ignored, the authors would have incorrectly concluded that there was no effect of task difficulty over the rates of task-unrelated thought.

Individual Differences in Deliberate and Spontaneous Mind-Wandering

The tendency to engage in intentional versus unintentional mind-wandering has also been studied at the individual differences level. In this vein, Carriere et al. (2013) developed the Mind-Wandering: Deliberate (*MW-D*) and Mind-Wandering: Spontaneous (*MW-S*) scales to address the role of the intentionality of mind-wandering in its relationship to fidgeting. The instrument was composed by eight statements (four items per scale) reflecting the proposed bifactorial structure of mind-wandering. Although this study lacked of an assessment of the dimensionality of the MW-D/MW-S scales, it provided initial evidence of their discriminant associations by showing that only MW-S was a (positive) predictor of fidgeting. More recently, Marcusson-Clavertz & Kjell (2018) conducted a formal psychometric validation procedure of the MW-D/MW-S scales, showing that they were optimally fitted by a two-factor solution (with the best fit attained excluding the third item from the MW-S) and demonstrated a psychometrically sound behaviour, including strong measurement invariance across gender and time, and good reliability of their scores (α/ω ≥ .81/.82; test-retest ≥.75 [2-week-interval]). This seminal validation study also showed that MW-D and MW-S differed in their prediction of external outcomes: Whereas MW-D was linked to openness and experience-sampling reports of intentional mind-wandering, MW-S predicted generalized anxiety and experience-sampling reports of unintentional mind-wandering.

Subsequent psychometric research has translated and validated the MW-D/MW-S scales to other languages and cultures, including Chinese (Carciofo & Jiang, 2021), Italian (Chiorri & Vannucci, 2019), and German (Martarelli et al., 2021). These studies successfully replicated the original bifactorial structure, and provided further evidence of their nomological validity by examining correlates with a wide range of external variables. Chiorri & Vannucci (2019) found that MW-S was more strongly correlated to other self-report measures of mind-wandering, and to attentional control, than was MW-D (while both scales predicted daydreaming to a similar extent). Martarelli et al. (2021) examined the associations of the MW-D and MW-S scales to trait boredom, similarly finding that the correlation was substantially weaker for MW-D than for MW-S. Carciofo & Jiang (2021) found that MW-S showed stronger positive correlations with negative affect and attentional lapses, and stronger negative correlations with agreeableness and positive affect; on the contrary, MW-D was more strongly positively associated to openness (in line with Marcusson-Clavertz & Kjell, 2018). Overall, these studies made possible to disentangle deliberate and spontaneous expressions of mind-wandering at the individual differences level in various cultural contexts other than the original (i.e., reinforcing the cross-cultural validity of the scales). Note however that, to date, there is no available version of the MW-D/MW-S scales that can be administered in Spanish samples.

Linking Mindfulness with Internal and External Distraction

Classically, mind-wandering has been considered antithetical to the construct of mindfulness, which can be broadly defined as the psychological inclination to attend to present-moment experience while having an attitude of acceptance towards it (Baer, 2019; Bishop et al., 2004). The distinction between intentional and unintentional mind-wandering, however, has revealed that this relationship may be more complex. In one study, Seli et al. (2015) investigated the unique contributions of the MW-D and MW-S scales to the five facets of mindfulness (as assessed by the Five Facets Mindfulness Questionnaire, FFMQ; Baer et al., 2006). The study found that the two types of mind-wandering were dissociable (i.e., an effect was observed for one but not the other, or the effects were in opposite direction) in their relationship to four of the five facets, and that deliberate mind-wandering was actually positively related to two of them (Observing and Non-reactivity to inner experience). These results thus nuanced the relationship between mindfulness and mind-wandering, emphasizing again the necessity of considering intentionality when investigating the wandering mind phenomena.

As just described, Seli and collages (2015)'s study provided the first trait-level evidence characterizing the facets of mindfulness in terms of (spontaneous and deliberate) mind-wandering, or what we above have termed as internal distraction. However, to our knowledge, no study has yet attempted to extend these findings to encompass also external distraction as part of its nomological network. In particular there are two specific sets of questions that remain to be addressed in regards to external distraction as it relates to internal distraction and mindfulness, as described next.

First, it is as yet unclear how MW-D and MW-S associate to the vulnerability to engage in external distraction. From an individual differences perspective, external distraction can be assessed with the Attentional Control Scale (ACS), a well-stablished two-factorial measure of the capacity to sustain (*Focus*) and reorient (*Shift*) attention in a goal-directed manner in the face of external events (e.g., music or other people talking around; Derryberry & Reed, 2002). Prior research has found that both Focus and Shift dimensions were largely negatively correlated to MW-S, while MW-D was only slightly negatively correlated (Carriere et al., 2013) or unrelated to them (Chiorri & Vannucci, 2019). However, and importantly, these studies relied exclusively on bivariate correlational analyses, which hinders the interpretation of their results given that MW-D and MW-S are also highly correlated constructs themselves. Instead, the study of the relationships of the MW-D/MW-S scales to attentional control or any other external variable is better suited by analytical approaches that can account for their commonality, thus quantifying the amount of variance that is uniquely explained by each of them (e.g., partial correlation or multiple linear regression analyses; Seli et al., 2015).

Second, it is also not known whether the tendency to engage in internal distraction (as assessed by MW-D and MW-S) and external distraction (as assessed by Focus and Shift) uniquely contribute to explain individual differences in the facets of mindfulness, and to what extent. Given that internal and external distraction are also expected to be moderately overlapping processes (Carriere et al., 2013; Chiorri & Vannucci, 2019; for a latent variable approach, see also Unsworth & McMillan, 2014), addressing both simultaneously as predictors of mindfulness is required to dissentangle the distinctive contributions of each distraction-related dimension to the latter construct. Critically, without a combined analytical approach it is not possible to know whether the variance common to mindfulness and internal distraction (as reported by Seli et al., 2015) is unique, or can be accounted for by individual differences in external distraction instead.

The Present Study

On the basis of these considerations, we conducted the present study pursuing two intertwined aims: (1) to develop and validate the Spanish-language version of the MW-D/MW-S scales for research use with Spanish samples; and, (2) to replicate and extend prior findings on the relationship between the facets of mindfulness, internal distraction (MW-D and MW-S), and external distraction (Focus and Shift). Regarding our second aim, and more precisely, we set out to (2a) replicate Seli et al. (2015)'s findings linking internal distraction and the facets of mindfulness; (2b) provide original evidence of the relationship between internal and external distraction; and, (2c) provide original evidence of the unique contributions of internal and external distraction to the facets of mindfulness. In order to address our first aim, we conducted a forward- and back-translation procedure from the original instrument and evaluated its psychometric adequacy including item- and dimension-level distributional properties, dimensionality, and internal consistency reliability. Our second aim was addressed by means of partial correlations and multiple linear regressions combined with relative weight analyses. Note that while this second part was primarily motivated by an interest to empirically characterize the structure of relationships between dispositional mindfulness, mind-wandering, and attentional control, it was also a means to provide evidence of the nomological validity of the Spanish version of the MW-D/MW-S scales.

Methods

Participants

Two independent samples of 808 and 1095 participants were collected for this study. In both cases, the subjects were invited using the institutional email lists of the University of [omitted for blinded review], and participated in exchange of course credits (if they were undergraduate Psychology students) or monetary compensation (if they were students from other programs or university personnel). From each sample, we removed participants identified as completion time outliers (i.e., those with ±3 standard deviations [SD] from the group mean in completing the survey; $n_{excluded}$ = 13 and $n_{excluded}$ = 11, respectively). The samples were thus finally comprised by 795 (Sample 1 [S1]: 72.01% women; M_{age} = 23.80 years, *SD* = 5.54) and 1084 (Sample 2 [S2]: 74.91% women; M_{age} = 22.80, *SD* = 5.49) participants, respectively. All subjects gave informant consent prior to participation.

Procedure

The development of the Spanish version of the MW-D/MW-S scales comprised (1) translation of instructions for administration and items from the original English version (Carriere et al., 2013) into Spanish by two of the authors (LC and JL); and (2) independent back-translation into English by a professional native English translator. Inconsistencies between both versions were assessed through discussion and iterations of translation and back-translation until consensus among authors and translator was achieved.

In regard to the administration of the measures during the study session, the procedure was virtually identical for S1 and S2. After providing informant consent, participants were presented with a battery of sociodemographic questions, followed by the MW-D/MW-S, the FFMQ, and the ACS. Measures were implemented and data were collected online using the platform LimeSurvey (http://www.limesurvey.org). Participants were informed that their participation was voluntary and that they could withdraw from the study at any time.

Measures

Mind-Wandering Deliberate and Spontaneous Scales

The MW-D/MW-S scales (Carriere et al., 2013) comprise four items each, assessing the propensity to engage in task-unrelated thought or mind-wandering voluntarily (e.g., “I allow my thoughts to wander on purpose") and involuntarily (e.g., "I mind wander even when I'm supposed to be doing something else"), respectively. Items are rated on a seven-point Likert scale ranging from one ("rarely") to seven ("a lot"), except for the third item of the MW-D (from 1 = "not at all true" to 7 = "very true") and the third item of the MW-S (from 1 = "almost never" to 7 = "almost always"). The original English version has been recently validated by Marcusson-Clavertz & Kjell (2018), demonstrating adequate factorial and construct validity, as well as good internal consistency reliability scores (MW-D: ranging from α = .86 to α = .90; MW-S: ranging from α = .81 to α = .82). The psychometric properties of the Spanish version of the MW-D and MW-S can be found in the Results section. The items and instructions for administration of the scales are provided in Supplementary Material S1.

Five Facets Mindfulness Questionnaire

The FFMQ (Baer et al., 2006; Spanish version by Cebolla et al., 2012) is a 39-item instrument rated on a five-point Likert scale ranging from one ("never or very rarely true") to five ("very often or always true"), designed to assess five distinct domains of trait mindfulness. (1) Observing (from here on referred to as *Observe*), or the tendency to attend to and noticing internal and external experiences including sensations, emotions, and thoughts (e.g., "I notice the smells and aromas of things"). (2) Describing (*Describe*), or the ability to label internal experiences, and particularly emotions, with words (e.g., "I can usually describe how I feel at the moment in considerable detail"). (3) Acting with awareness (*Actaware*), or the tendency to be grounded on present-moment experience as opposed to behaving mindlessly or in autopilot (e.g., "I do jobs or tasks automatically without being aware of what I'm doing", reversed item). (4) Non-judging of inner experience (*Nonjudge*), or the tendency to appraise thoughts and feelings from a non-evaluative stance (e.g., "I disapprove of myself when I have irrational ideas", reversed item). And (5) non-reactivity to inner experience (*Nonreact*), or the capacity to experience thoughts and emotions without having to reflexively respond to nor being caught up by them (e.g., “I watch my feelings without getting lost in them”). The Spanish version of the FFMQ has shown adequate factorial and external validity, as well as good internal consistency reliability scores, both in previous research (ranging from α = .80 to α = .91; Cebolla et al., 2012) and in the two samples reported herein (see Results section).

Attentional Control Scale

The ACS (Derryberry & Reed, 2002; Spanish by Pacheco-Unguetti et al., 2011) is a 20-item questionnaire rated on a four-point Likert scale ranging from one (“almost never”) to four (“always”). It was developed to assess two distinct attention-related factors, namely the capacity to maintain the focus of attention in the presence of distractors (Focus; e.g., “I have difficulty concentrating when there is music in the room around me”, reversed item) and the ability to efficiently switch attention between tasks or stimuli including the reorienting of attention from distractors to the primary task (Shift; e.g., “After being interrupted, I have a hard time shifting my attention back to what I was doing before”, reversed item). While originally comprised by 20 statements, subsequent psychometric research has proposed alternative, more efficient versions of the scale (12-item version in Judah et al., 2014; 8-item version in Carriere et al., 2013). For the present study, we conducted three competing confirmatory factor analyses on the ACS as translated into Spanish by Pacheco-Unguetti et al. (2011) in order to obtain the best fitting version of the Spanish version of the scale (i.e., 20 vs. 12 vs. 8 items). As detailed in Supplementary Material S2, the best fit was attained by the 8-item version, which was therefore the one used for analyses. The 8-item ACS has shown adequate internal consistency reliability scores, both in previous research (Focus: ranging from α = .77 to α = .81; Shift: ranging from α = .69 to α = .82; Carriere et al., 2013) and in the two samples reported herein (see Results section).

Data Analyses

To analyse the psychometric properties of the MW-D/MW-S scales, first descriptive statistics (i.e., mean, standard deviation, skewness, and kurtosis) and corrected item-total correlations were computed for all the items. The dimensionality of both scales was assessed by means of a set of confirmatory factor analyses (CFA) with robust maximum likelihood (MLR) estimator. The relative fit of three models was tested: (a) one-factor structure or general factor of mind-wandering (Model 1); (b) two-factor structure reflecting the deliberate and spontaneous components of mind-wandering (Model 2); and, (c) the same two-factor structure but excluding the item 3 of the MW-S (Model 3) as recommended in the validation study of the original version of the scale (Marcusson-Clavertz & Kjell, 2018). Model fit was assessed following (Kaplan, 2009)'s recommendations, with CFI ≥ .90, TLI ≥ .90, RMSEA ≤ .08, and SRMR ≤ .08 reflecting adequate fit. After corroborating the internal structure of our scales, dimension-level descriptive statistics were calculated for the MW-D/MW-S scales, as well as for all other outcome variables, along with their internal consistency reliability coefficients using both Cronbach's alpha (α) and McDonald's omega (ω).

Pearson's correlations were used to assess the bivariate relationships between MW-D/MW-S, FFMQ, and ACS. Subsequently, partial correlations were conducted to assess the unique associations of MW-D and MW-S (controlling for each other) with mindfulness facets and attentional control. Finally, multiple linear regressions along with relative weight analyses (RWA) were conducted to assess the unique contributions of both internal distraction (MW-D and MW-S) and external distraction (Focus and Shift) to each of the mindfulness facets. By also introducing RWA into our analytic strategy we overcame one limitation of the regression approach, namely that it does not reliably estimate the specific variance explained by *each* predictor under analyses, particularly when they are intercorrelated (see Tonidandel & LeBreton, 2011). To account for the influence of sociodemographics, age and sex were introduced in a first step in the regression model, and internal and external distraction variables in a second step (both methods: enter). For parsimony, only the final models are reported.

All the analyses were independently conducted in both S1 and S2. To control for the Type I error rate, significance level was set at $\alpha = .01$ and results were only interpreted as true positives when replicated in both samples. To avoid drawing conclusions upon findings without practical significance, we set the smallest effect size of interest (SESOI) at $r = .10$, $R^2 = .01$. Note that both S1 and S2 were sensitive enough to statistically detect effect sizes equal or higher than the SESOI, given $\alpha = .01$. We used Mplus 8.1 software (Muthén & Muthén, 2017) and RStudio 2021.09.0 (RStudio Team, 2021) to conduct the CFA and RWA, respectively; all other analyses were conducted in Jamovi 1.6.23 (Jamovi Project, 2021).

Results

Psychometric Properties of the Spanish MW-D and MW-S Scales

Item Analyses

Descriptive statistics for all the items of the Spanish MW-D/MW-S scales in S1 and S2 are provided in Supplementary Material S3. As shown, no floor/ceiling effects in item-responses were detected ($5.08 \geq M \geq 2.96$). High between-subject variabilities also emerged ($SD \geq 1.65$). Skewness and kurtosis indexes strongly suggested scores for all items to follow the normal distribution (≤ |2| in all cases; Pituch & Stevens, 2015). Finally, the items of both scales displayed high discrimination indexes in both samples (MW-D from .65/.60 [item 4] to .81/78 [item 2] in S1/S2; and MW-S from .58/.51 [item 1] to .67/62 [item 4] in S1/S2). Together, these results indicate adequate item properties for Spanish-language version of the MW-D/MW-S scales.

Factor Structure

As shown in **Table 1**, fit indices indicated that both two-factor structures (Models 2 and 3) outperformed the one-factor solution (Model 1) in terms of model fit. Mirroring the Marcusson-Clavertz & Kjell (2018)'s validation study for the English version of the instrument, the exclusion of the item 3 of the MW-S scale (Model 3) outperformed the version with the full set of items (Model 2). Model 3 thus appeared as the best fitting factor structure, globally yielding acceptable to good fit indices across both S1 and S2. We thus conducted the remaining analyses excluding the item 3 of the MW-S scale. All items were significant and showed high loadings in their corresponding latent factors across both samples, namely: MW-D ≥.69/.65 and MW-S ≥.62/.58 in S1/S2. Latent correlation between the scores of the MW-D and MW-S only reflected a moderated overlapping (≈ .50), which provides further support for a two-factorial model of mind-wandering as the most interpretable solution.

Table 1

Model Fit Indices for the Spontaneous and Deliberate Mind-Wandering Scales in the Three Spanish Samples

	Model	χ^2	*df*	CFI	TLI	RMSEA [90% CI]	SRMR
Sample 1 (*n*=795)	Model 1	883.450	20	.637	.492	.233 [.220, .246]	.157
	Model 2	262.785	19	.898	.849	.127 [.114, .141]	.082
	Model 3	**93.388**	**13**	**.959**	**.933**	**.088 [.072, .105]**	**.044**
Sample 2 (*n*=1084)	Model 1	883.636	20	.677	.548	.200 [.188, .211]	.139
	Model 2	303.371	19	.894	.843	.118 [.106, .129]	.081
	Model 3	**109.228**	**13**	**.956**	**.929**	**.083 [.069, .097]**	**.042**

Note. χ^2 = Chi-square test of model fit; *df* = Degrees of freedom; CFI = Comparative fit index; TLI =Tucker-Lewis index; RMSEA = Root mean square error of approximation; CI = Confidence interval; SRMR = Standardized Root Mean Square Residual. Model 1 = Unidimensional structure or general factor of mind-wandering; Model 2 = Bifactorial structure reflecting the deliberate and spontaneous mind-wandering scales (8 items); Model 3 = Model 2 excluding the item 3 of the mind-wandering spontaneous scale as in Marcusson-Clavertz & Kjell (2018)'s study.

Descriptive Statistics and Reliability

As shown in **Table 2** (upper rows), the mean scores, standard deviations, skewness, and kurtosis of the Spanish MW-D/MW-S scales closely resemble the values originally obtained by Marcusson-Clavertz & Kjell (2018). Importantly, skewness and kurtosis coefficients indicated normal-like distribution of the scores of the MW-D and MW-D across both S1 and S2 (≤ |2| in all cases). In terms of the internal consistency of their scores, the Spanish MW-D/MW-S scales showed convincing coefficients for research purposes (all $\alpha/\omega \geq .71$). Note that both estimators (α and ω) largely converged in S1 and S2.

Table 2

Descriptive Statistics and Reliability Indices for MW-D, MW-S, Focus, Shift and Mindfulness Facets in Sample 1 (n = 795) and Sample 2 (n = 1084)

	Sample 1						Sample 2					
	M	*SD*	*SK*	*K*	*α*	*ω*	*M*	*SD*	*SK*	*K*	*α*	*ω*
MW-D	4.39	1.56	−0.2	−0.8	.88	.88	4.81	1.46	−0.5	−0.3	.86	.86
MW-S [a]	4.55	1.43	−0.3	−0.5	.76	.77	4.39	1.41	−0.2	−0.5	.71	.71
Observe	3.29	0.72	−0.2	0.08	.77	.78	3.25	0.69	−0.1	−0.2	.75	.75
Describe	3.38	0.88	−0.1	−0.5	.91	.91	3.01	0.90	−0.2	−0.5	.93	.93
Actaware	3.35	0.80	−0.2	−0.3	.87	.87	2.43	0.77	−0.2	−0.3	.87	.88
Nonjudge	3.21	0.94	−0.1	−0.6	.91	.91	2.13	0.95	−0.1	−0.7	.91	.91
Nonreact	3.07	0.63	−0.0	0.05	.73	.73	3.11	0.62	−0.0	0.11	.73	.73
Focus	2.36	0.71	0.15	−0.5	.75	.75	2.38	0.70	0.14	−0.6	.74	.74
Shift	2.72	0.62	−0.1	−0.3	.69	.70	2.75	0.62	−0.1	−0.3	.70	.71

Note. MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous; *SK* = Skewness; *K* = Kurtosis; α = Cronbach's Alpha reliability; *ω* = McDonals Omega reliability.
[a] Excluding item 3.

Bivariate and Partial Correlation Analyses

As can be seen in **Table 2** (mid and bottom rows), the distributional properties and internal consistency reliability scores of the FFMQ facets and ACS factors were also satisfactory.

Table 3 displays the structure of bivariate correlations among the three sets of constructs, for both S1 and S2. The pattern is highly similar across samples, highlighting the stability of the associations. As found in previous research (Carriere et al., 2013; Chiorri & Vannucci, 2019; Seli et al., 2015), MW-S was more strongly related to both dispositional mindfulness and attentional control than MW-D, as reflected by a larger number of observed correlations and stronger effect sizes. However, also in line with these studies, the MW-D and MW-S scales showed to be strongly associated to each other (*r* ≈ .40), which hinders direct interpretation of their bivariate relationships with external variables (Seli et al., 2015). Thus, a series of partial correlations was conducted next.

Table 3

Pearson Correlations Between MW-D, MW-S, Focus, Shift and Mindfulness Facets in Sample 1 (n = 795; Below Diagonal) and Sample 2 (n = 1084; Above Diagonal)

	1	2	3	4	5	6	7	8	9
1. MW-D	—	**.41****	−.01	.01	**.30****	.01	**−.20****	**−.11****	**.14****
2. MW-S [a]	**.42****	—	**−.26****	**−.21****	**.26****	**−.20****	**−.60****	**−.36****	−.09*
3. Focus	.03	**−.27****	—	**.34****	−.04	**.23****	**.37****	**.19****	**.25****
4. Shift	.02	**−.19****	**.38****	—	.06	**.29****	**.40****	**.22****	**.31****
5. Observe	**.28****	**.29****	.01	.07	—	**.18****	**−.14****	**−.18****	**.19****
6. Describe	.09*	−.05	**.18****	**.22****	**.23****	—	**.33****	**.26****	**.30****
7. Actaware	**−.24****	**−.60****	**.41****	**.33****	**−.13****	**.25****	—	**.43****	**.23****
8. Nonjudge	−.04	**−.34****	**.27****	**.25****	**−.17****	**.19****	**.40****	—	**.28****
9. Nonreact	**.16****	.01	**.17****	**.18****	**.24****	**.23****	**.11***	**.18****	—

Note. MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous.

[a] Excluding item 3.

* = *p* < .01, ** = < .001 (two tailed). Correlations equal or above SESOI (i.e., *r* ≥ .10) are boldfaced.

The results of the partial correlation analyses between MW-D and MW-S, controlling for each other, and the mindfulness facets in both S1 and S2 can be found in **Table 4** (left columns). As shown, the pattern of findings was similar across samples. Observe was found to be positively related to both types of mind-wandering, while the only consistent finding revealed for Describe, Actaware, and Nonjudge was their negative relationship to MW-S. In turn, Nonreact demonstrated to be positively associated with MW-D. All other contrast resulted non-significant either statistically, $p \geq .01$, or practically, $r < .10$, in at least one of both samples. Nonjudge and Actaware showed medium-to-large and large (negative) correlations to MW-S, respectively; effect sizes for all other results ranged from small to medium. This pattern of findings closely replicates the seminal study by Seli et al. (2015).

Table 4

Partial Correlations of MW-D (Controlling for MW-S) and MW-S (Controlling for MW-D) with FFMQ and ACS in Sample 1 (n = 795) and Sample 2 (n = 1084)

	FFMQ					ACS	
	Observe	Describe	Actawar	Nonjudg	Nonreac	Focus	Shift
Sample 1							
MW-D	**.19****	**.13****	.01	**.12***	**.17****	**.16****	**.12***
MW-S [a]	**.19****	**−.10***	**−.56****	**−.36****	−.07	**−.31****	**−.22****
Sample 2							
MW-D	**.22****	.09*	.06	.05	**.20****	**.11****	**.11****
MW-S [a]	**.16****	**−.22****	**−.58****	**−.35****	**−.16****	**−.28****	**−.24****

Note. MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous; FFMQ = Five Facets Mindfulness Questionnaire; ACS = Attentional Control Scale.

[a] Excluding item 3.

* = $p < .01$, ** = < .001 (two tailed). Correlations equal or above SESOI (i.e., $r \geq .10$) are boldfaced.

Going beyond Seli et al. (2015)'s findings, we further investigated the pattern of associations between deliberate and spontaneous mind-wandering (controlling for each other) and the two factors of attentional control. The results of these set of partial correlations are also displayed in **Table 4** (right columns). As can be seen, small positive associations were found between MW-D and both Focus and Shift, while small-to-medium negative associations were revealed between these and MW-S. This was indicative of a double dissociation (see also **Fig. 1**).

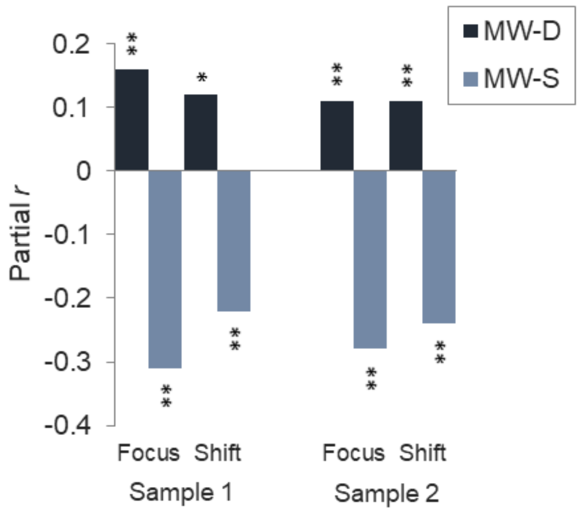

Fig. 1 Partial correlations of MW-D (controlling for MW-S) and MW-S (controlling for MW-D) with Focus and Shift in Sample 1 (*n* = 795) and Sample 2 (*n* = 1084). MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous. * = *p* < .01, ** = < .001 (two tailed).

Regression and Relative Weight Analyses

The results of the linear regression and RWA characterizing the facets of mindfulness in terms of internal distraction (MW-D and MW-S) and external distraction (Focus and Shift) are provided in **Table 5** and **Table 6** for S1 and S2, respectively. They are also displayed graphically in **Fig. 2**, which depicts for each of the mindfulness facets (1) the absolute variance explained by predictor (R^2), and (2) the relative variance (or percentage of the total variance explained by the full model) explained by predictor (%R^2). As shown, the pattern of findings obtained by using this analytic approach, too, is consistent across samples. In Step 1, age and sex demonstrated to be generally unrelated to mindfulness, with two exceptions: (1) older participants self-reported higher scores on Describe; and, (2) male participants tended to self-report higher scores on Nonreact. Note that both effects were small in magnitude.

Internal and External distraction variables were introduced in the Step 2 of the regression procedure. The total variance explained by the full model ranged from R^2 = .079 (Describe) to R^2 = .460 (Actaware), indicating that internal and external distraction explained the mindfulness facets by a medium to large extent in all cases. In both samples, internal distraction was the domain most strongly predictive of Observe, Actaware and Nonjudge, whereas external distraction was the best predictor of Describe and Nonreact. Averaged across mindfulness facets and samples, the variance explained by internal and external distraction was R^2 = .111 and R^2 = .077, respectively; as per each individual factor, MW-S was the variable with the largest predictive power, R^2 = .086, followed by Shift, R^2 = .043, Focus, R^2 = .034, and MW-D, R^2 = .025.

At the level of individual mindfulness facets, each of them followed a distinctive pattern of contributions of MW-D, MW-S, Focus, and Shift, as described next (see also **Fig. 2**; the direction and statistical significance of the relationships are provided in **Tables 5** and **6**). The facet Observe demonstrated small-to-medium positive associations with both MW-D and MW-S. Describe, on the contrary, only appeared to be consistently linked to external distraction, showing a small-to-medium positive association to Shift. Notably, Actaware was the facet most strongly related to both internal and external distraction (see the central peak in the upper panels of **Fig. 2**), demonstrating medium positive associations to Focus and Shift, and a large negative association to MW-S. Nonjudge, in turn, showed a pattern similar to the former facet but of reduced magnitude, revealing small-to-medium positive associations to Focus and Shift, and a medium negative association to MW-S. Finally, Nonreact showed positive associations in the small-to-medium range with MW-D, Focus, and Shift. All other predictors resulted non-significant either statistically, $p \geq .01$, or practically, $R^2 < .01$, in at least one of both samples.

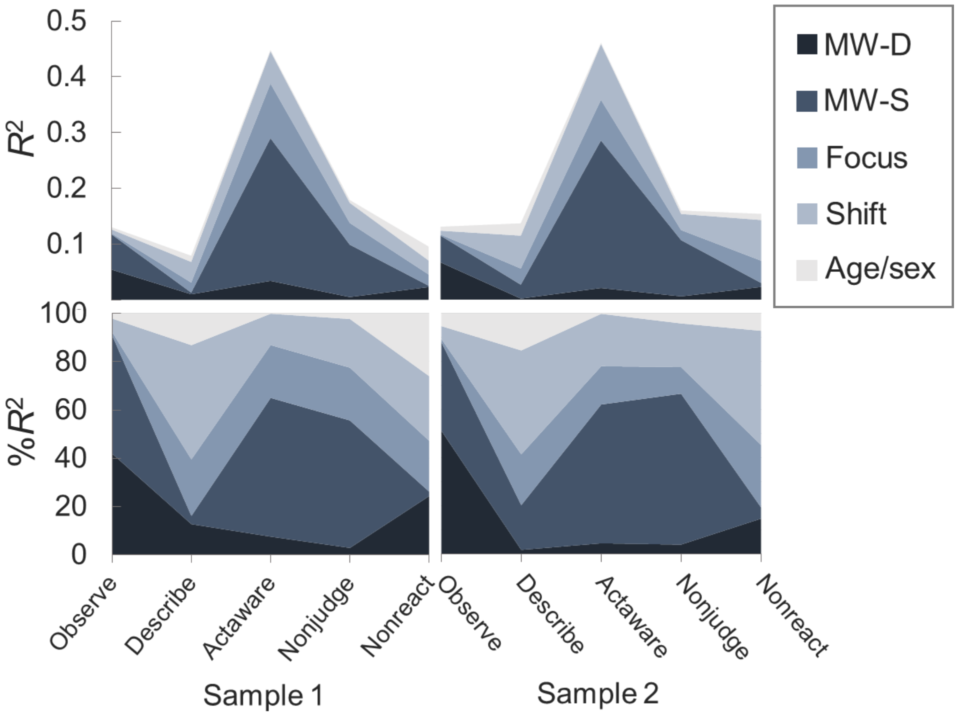

Fig. 2 Stacked area plots depicting the absolute and relative variance explained (upper and lower panels, respectively) by internal distraction (MW-D and MW-S) and external distraction (Focus and Shift) across mindfulness facets, after controlling by age and sex, in Sample 1 (n = 795) and Sample 2 (n = 1084). MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous

Table 5

Multiple Linear Regression and Relative Weight Analysis Testing for Unique Contributions of MW-D, MW-S, Focus, and Shift on Mindfulness Facets after Controlling for Age and Sex (Sample 1, n = 795)

	Observe			Describe			Actaware			Nonjudge			Nonreact		
Predictors	β	RW	*%RW*	β	RW	*%RW*	β	RW	*%RW*	β	RW	*%RW*	β	RW	*%RW*
Age	−0.005	.001	0.10	**0.102***	**.010**	**12.86**	−0.023	.001	0.06	0.053	.004	2.09	−0.016	.001	0.30
Sex	−0.055	.003	2.03	0.009	.001	0.28	−0.006	.001	0.06	0.020	.001	0.21	**0.154****	**.024**	**25.68**
MW-D	**0.180****	**.054**	**41.94**	**0.102***	**.010**	**12.70**	**−0.053**	**.034**	**7.55**	0.087	.005	2.87	**0.143****	**.023**	**24.34**
MW-S [a]	**0.236****	**.063**	**48.99**	−0.039	.003	3.43	**−0.480****	**.256**	**57.47**	**−0.317****	**.094**	**52.79**	−0.002	.002	1.83
Focus	0.032	.002	1.38	**0.095**	**.018**	**23.42**	**0.226****	**.098**	**21.87**	**0.126****	**.039**	**21.87**	**0.117***	**.020**	**21.07**
Shift	0.104*	.007	5.56	**0.174****	**.037**	**47.31**	**0.156****	**.058**	**12.99**	**0.149****	**.036**	**20.17**	**0.139****	**.025**	**26.78**
Full model	**R^2 = .128****			**R^2 = .079****			**R^2 = .441****			**R^2 = .182****			**R^2 = .091****		

Note. MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous; β = *Standardized Beta Coefficient;* RW = Raw Relative Weight (R^2 Explained by Predictor); %RW = Rescaled Relative Weight (Percentage of Total R^2 Explained by Predictor). Age and Sex entered in Step 1; MW-D, MW-S, Focus, and Shift entered in Step 2. For Observe, Step 1 ΔR^2 = .002; Step 2 ΔR^2 = .125. For Describe, Step 1 ΔR^2 = .013; Step 2 ΔR^2 = .066. For Actaware, Step 1 ΔR^2 = .001; Step 2 ΔR^2 = .440. For Nonjudge, Step 1 ΔR^2 = .004; Step 2 ΔR^2 = .178. For Nonreact, Step 1 ΔR^2 = .024; Step 2 ΔR^2 = .067. Variance Inflation Factor (VIF) was $1.01 \leq VIF \leq 1.35$ in all cases.

[a] Excluding item 3.

* = $p < .01$, ** = < .001 (two tailed). Predictors with Raw Relative Weight equal or above SESOI (i.e., $R^2 \geq .01$) are boldfaced.

Table 6

Multiple Linear Regression and Relative Weight Analysis Testing for Unique Contributions of MW-D, MW-S, Focus, and Shift on Mindfulness Facets after Controlling for Age and Sex (Sample 2, n = 1084)

	Observe			Describe			Actaware			Nonjudge			Nonreact		
Predictors	β	RW	*%RW*	β	RW	*%RW*	β	RW	*%RW*	β	RW	*%RW*	β	RW	*%RW*
Age	0.089*	.005	4.08	**0.144****	**.021**	**15.12**	−0.010	.001	0.04	0.064	.005	3.38	0.002	.001	0.10
Sex	−0.051	.002	1.22	−0.026	.001	0.29	−0.019	.001	0.15	0.035	.001	0.82	**0.103****	**.011**	**7.17**
MW-D	**0.229****	**.067**	**51.28**	0.069	.002	1.79	**0.009**	**.021**	**4.52**	0.027	.006	3.97	**0.164****	**.023**	**14.75**
MW-S [a]	**0.188****	**.048**	**36.79**	**−0.141****	**.025**	**18.58**	**−0.507****	**.265**	**57.62**	**−0.324****	**.101**	**62.64**	−0.066	.007	4.68
Focus	−0.024	.002	1.29	**0.115****	**.029**	**21.09**	**0.164****	**.073**	**15.89**	**0.065**	**.018**	**11.04**	**0.150****	**.040**	**25.93**
Shift	0.102**	.007	5.34	**0.214****	**.059**	**43.13**	**0.241****	**.100**	**21.77**	**0.129****	**.029**	**18.15**	**0.244****	**.073**	**47.37**
Full model	**R^2 = .130****			**R^2 = .136****			**R^2 = .460****			**R^2 = .161****			**R^2 = .153****		

Note. MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous; β = *Standardized Beta Coefficient;* RW = Raw Relative Weight (R^2 Explained by Predictor); %RW = Rescaled Relative Weight (Percentage of Total R^2 Explained by Predictor). Age and Sex entered in Step 1; MW-D, MW-S, Focus and Shift entered in Step 2. For Observe, Step 1 ΔR^2 = .004; Step 2 ΔR^2 = .126. For Describe, Step 1 ΔR^2 = .022; Step 2 ΔR^2 = .114. For Actaware, Step 1 ΔR^2 = .002; Step 2 ΔR^2 = .458. For Nonjudge, Step 1 ΔR^2 = .008; Step 2 ΔR^2 = .153. For Nonreact, Step 1 ΔR^2 = .012; Step 2 ΔR^2 = .141. Variance Inflation Factor (VIF) was 1.03 ≤ VIF ≤ 1.34 in all cases.

[a] Excluding item 3.

* = p < .01, ** = < .001 (two tailed). Predictors with Raw Relative Weight equal or above SESOI (i.e., $R^2 \geq .01$) are boldfaced.

Discussion

Testing two independent samples and over 1800 participants, the present study aimed to evaluate the psychometric adequacy of the Spanish version of the MW-D/MW-S scales and to replicate and extend prior findings of their relationship with the facets of mindfulness and attentional control. The psychometric evaluation of the Spanish MW-D/MW-S scales indicated adequate validity and reliability. Factor analyses confirmed that the instrument is best characterized as two distinct factors reflective of deliberate and spontaneous or mind-wandering, as was initially conceived by Carriere et al. (2013). Mirroring the study formally assessing the psychometric properties of the original version of the scales (Marcusson-Clavertz & Kjell, 2018), the best model fit was attained excluding the third item from the MW-S scale; we thus recommend future research not include it into analyses. All remaining items showed convincing distributional properties, as did the two mind-wandering dimensions themselves. In all cases, internal consistency coefficients (α/ω) were ≥ .71 for MW-S and ≥ .86 for MW-D, which can be interpreted as evidence of high reliability, specially taking into account the concision and brevity of administration of the scales, composed by 3 and 4 items, respectively.

We successfully replicated the seminal findings relating spontaneous and deliberate mind-wandering to the five facets of mindfulness (Seli et al., 2015). There was only one exception, namely: whereas a negative relationship between Non-reactivity to inner experience and MW-S was reported originally, we could only reproduce this result in our second sample (but not in the first one). This seeming discrepancy, however, may not be surprising in the context of a fairly small effect size. Note that the statistical power achieved by our first sample (n = 795) to capture true effects of small size (ρ = .10) with a two-tailed test (α = .01) was .60; meaning that the probability of committing a Type II error was 40% (Faul et al., 2009). To further explore this interpretation, we conducted a fixed-effects meta-analysis of the results across both samples (*n* = 1879), which afforded a statistical power of .96 in the same scenario. A small yet significant negative partial correlation between Non-reactivity to inner experience and spontaneous mind-wandering was revealed ($r = -.12$, $p < .001$; see Supplementary Material S4 for details). Considering also this result, the pattern of findings obtained with the Spanish MW-D/MW-S in the present study appears virtually interchangeable with the findings obtained by Seli et al. (2015) using the original scales.

Interestingly, our assessment of the relationships between deliberate and spontaneous mind-wandering (controlling for each other) and the two factors of attentional control revealed the existence of a double dissociation: While participants more susceptible to engage in spontaneous mind-wandering also reported higher vulnerability to external distraction, those with a higher propensity to engage in mind-wandering in a voluntary fashion reported being less vulnerable to it (regarding both Focus and Shift). This finding is suggestive of the idea of “strategic” mind-wandering, which posits that individuals are able to and benefit from modulating their level of mind-wandering to accommodate the demands of the environment (e.g., Seli, Carriere, et al., 2018). Prior research has shown that this ability differs across individuals and situations. For instance, it has been shown that participants with high versus low working memory capacity display less mind-wandering during high demanding tasks (Kane & McVay, 2012), while, on the contrary, tend to engage more in mind-wandering when task demands are low (Levinson et al., 2012). In line with these findings, our results suggest that the proclivity to voluntarily let the mind wander, presumably when the environmental demands are permissive, may be protective in more attention-demanding situations not only against subsequent task-unrelated though (as prior studies suggest) but, also, against becoming distracted by external events.

The present study also revealed various key aspects of the relationship between dispositional mindfulness and internal and external distraction. While, as discussed above, both deliberate and spontaneous mind-wandering have shown predictive capacity in explaining inter-individual variability in the facets of mindfulness (Seli et al., 2015), our study extend these results by showing that the capacity for attentional control of external distraction independently explains the facets of mindfulness over and above the variance accounted for by the mind-wandering factors. This finding, moreover, seems relatively stable across mindfulness facets, as in four of them at least one of the two factors of attentional control significantly contributed to explain a unique proportion of variance (the only exception was Observe). Complementarily, in all but one case both deliberate and spontaneous mind-wandering were retained as significant predictors of the mindfulness facets after including Focus and Shift in the regression model (the previously observed relationship between Describe and MW-S was entirely accounted for by external distraction). Importantly, these findings indicate that internal and external distraction are (partially) independent domains in their relationship to dispositional mindfulness, being both relevant insofar the two of them uniquely contribute to explain it.

On average, internal distraction showed greater predictive capacity than did external distraction in explaining individual differences in dispositional of mindfulness (11.1% vs. 7.7% of variance). While the contribution of external distraction was evenly shared by Focus and Shift (3.4% and 4.3% of variance), the great majority of the variance explained by internal distraction was accounted for by spontaneous mind-wandering—by far the stronger predictor across mindfulness facets (8.6% of variance on average). Importantly, these results suggest that dispositional mindfulness, while also protective against external distraction, is most strongly predictive of a decreased vulnerability to engage in mind-wandering, particularly without intention (note however that for Observe the effect was in the opposite direction). By contrast, the results also indicate that dispositional mindfulness is linked, to a lesser degree, to an increased tendency to engage in mind-wandering voluntarily (2.5% of variance).

This latter finding echoes the one discussed above about the positive link between deliberate mind-wandering and attentional control, in that both indicate that the proclivity to allow the mind to wander on purpose, presumably in low attention-demanding contexts, may be mildly linked to traits that are adaptive in nature. Interestingly, both results are in line with earlier research indicating that mind-wandering may come not only with costs but also with certain benefits (e.g., Franklin et al., 2013; Gable et al., 2019), while in addition suggest that the intentionality with which it occurs may be a critical aspect determining its adaptive value. This can be interpreted under the so-called content and context regulation hypothesis (Smallwood & Andrews-Hanna, 2013), which proposes that the adaptive or maladaptive nature of a given mind-wandering episode is dependent on both its thought content and the task context in which it appears. While speculative, it seems reasonable to conceive deliberate mind-wandering as characterized by being positive in content and deployed in contexts where it is not critical for performance in the primary task, maximizing its adaptive value. As will be further discussed below, future research may find fruitful to further examine the intentionality of mind-wandering under the context and content regulation framework.

A finer-grained analysis at the level of individual mindfulness facets revealed that each of them was characterized by a distinctive pattern of unique contributions of the factors of distraction. While discussing these patterns in detail is beyond the scope of the present report, there is one salient observation worth mentioning: Acting with awareness was, by a large difference, the facet of mindfulness most strongly predicted by both internal and external distraction (28.8% and 16.5% of variance, respectively). Indeed, the total variance explained for this facet was more than twice than for any of the remaining ones. Importantly, virtually all variation accounted for by internal distraction was attributable to spontaneous mind-wandering (deliberate mind-wandering did not reach significance as predictor in any of our two samples). Acting with awareness thus appeared as the most protective facet against distraction, being particularly strongly associated to a decreased vulnerability to involuntarily engage in task-unrelated thought. This finding is consistent with the theoretical characterization of dispositional mindfulness, within which Acting with awareness was originally described as “attending to one’s activities of the moment [as] contrasted with behaving mechanically while attention is focused elsewhere” (Baer et al., 2008, p. 330). It is also consistent with recent meta-analytical evidence indicating that Acting with awareness is the only mindfulness facet reliably linked with enhanced performance across a range of cognitive-behavioral attentional tasks, most of which are presumably affected by both external and internal types of distraction (Verhaeghen, 2021).

All in all, the main contributions of the present study can be summarized as follows. First, we have shown that the Spanish MW-D/MW-S scales have favorable psychometric properties, including factor structure, distributional properties, and internal consistency reliability scores. We have also shown that they have adequate nomological validity, since displayed a notably similar pattern of relationships with the facets of mindfulness as compared to the original scales, while also demonstrated satisfactory discriminant properties in relation to the factors of attentional control. Collectively, these findings suggest that the Spanish MW-D/MW-S scales constitute a promising measure to assess individual differences of intentional and unintentional mind-wandering with Spanish samples. Second, we have shown that dispositional mindfulness, as primarily driven by the facet Acting with awareness, is independently associated to both enhanced attentional control of external distractions and, more prominently, decreased vulnerability to spontaneous mind-wandering. We have also shown that deliberate mind-wandering, by contrast, is mildly associated to increased dispositional mindfulness. Deliberate mind-wandering, in addition, was also found to be mildly linked to greater attentional control, which in turn was linked to diminished spontaneous mind-wandering. Together, these findings broaden our understanding of the relationship between mindfulness and (internal and external) distraction, while continue to accentuate the critical role of intentionality in the study of the mind-wandering phenomena.

Limitations and Future Research

This study is not without limitations. First, we used convenience samples primarily composed of young, well-educated, healthy participants mostly without meditation experience, a methodological feature that precludes the generalization of our conclusions beyond this particular population. In light of this, future research must consider extending our results to other distinct, more specific populations. Second, the model fit of the CFA, while generally good, had margin for improvement. To obtain an even clearer representation of the latent structure of mind-wandering, future studies could consider creating additional indicators specifically targeting central aspects of each type of mind-wandering, so as to more strongly demarcate its two-factorial nature. Third, our results were entirely based on self-report measures, which place them at risk of method bias (Podsakoff et al., 2012) and other artifacts (Quigley et al., 2017). Future research must consider exploring the correlates of deliberate vs. spontaneous mind-wandering using alternative methodologies, such as cognitive-behavioral tasks tapping into distractibility processes; as for their relation to mindfulness, the breath counting task may serve as an alternative, more ecological assessment (Levinson et al., 2014). Finally, and as outlined above, future research may find fruitful to explore the intentionality of mind-wandering in light of the content-context regulation hypothesis (Smallwood & Andrews-Hanna, 2013). For instance, it is conceivable that the positive links of deliberate mind-wandering with mindfulness and attentional control were stronger in individuals who are especially skillful at engaging in strategic mind-wandering, and that do so about topics particularly positive or constructive (and vice versa). Future research is warranted to further explore this possibility.

Supplementary Materials

SUPPLEMENTARY MATERIAL S1: Items and instructions for administration of the Spanish MW-D and MW-S scales

Item
Deliberate
1. *Dejo a mis pensamientos divagar a propósito.*
2. *Disfruto dejando a mi mente divagar.*
3. *Dejar mi mente divagar me resulta una buena forma de lidiar con el aburrimiento.*
4. *Me permito ensimismarme en ensoñaciones agradables.*
Spontaneous
1. *Me doy cuenta de que mis pensamientos divagan espontáneamente.*
2. *Cuando mi mente divaga, mis pensamientos tienden a saltar de una idea a otra.*
3. *Siento que no tuviera control sobre mi mente cuando divaga.*
4. *Mi mente divaga espontáneamente incluso cuando se supone que debería estar haciendo otra cosa.*

Instructions: *Por favor, indica para las siguientes afirmaciones la respuesta que mejor refleja tu tendencia habitual a divagar mentalmente.* Rating: Items are rated on a seven-point Likert scale ranging from 1 = *Rara vez* to 7 = *Mucho*, except for the third item of the MW-D (from 1 = *Para nada cierto* to 7 = *Muy cierto*) and the third item of the MW-S (from 1 = *Casi nunca* to 7 = *Casi siempre*).

SUPPLEMENTARY MATERIAL S2: Competing confirmatory analyses of the Attentional Control Scale factor structure

Table S2

Model Fit Indices for the Attentional Control Scale.

	Model	χ^2	*df*	CFI	TLI	RMSEA [90% CI]	SRMR
Sample 1 (n = 795)	Model 1	879.04	169	.786	.759	.073 [.068, .077]	.064
	Model 2	214.40	53	.920	.900	.062 [.053, .071]	.047
	Model 3	**78.06**	**19**	**.948**	**.923**	**.063 [.048, .077]**	**.044**
Sample 2 (n = 1084)	Model 1	1209.58	169	.767	.738	.075 [.071, .079]	.062
	Model 2	415.716	53	.871	.840	.079 [.072, .087]	.056
	Model 3	**152.68**	**19**	**.918**	**.880**	**.081 [.069, .093]**	**.051**

Note. Estimator = Robust maximum likelihood; χ^2 = Chi-square test of model fit; *df* = Degrees of freedom; CFI = Comparative fit index; TLI =Tucker-Lewis index; RMSEA = Root mean square error of approximation; CI = Confidence interval; SRMR = Standardized Root Mean Square Residual. Model 1 = Original Factor Structure (i.e., Focus and Shift [20-items]); Model 2 = Modified Original Factor Structure (i.e., Focus and Shift [12-items: Judah et al., 2014]); Model 3 = Modified Original Factor Structure (i.e., Focus and Shift [8-items: Carriere et al., 2013])

SUPPLEMENTARY MATERIAL S3: Item-Level Descriptive Statistics of the Spanish version of the Deliberate and Spontaneous Mind-Wandering Scales

Table S3

Item-Level Descriptive Statistics of the Spanish version of the Deliberate and Spontaneous Mind-Wandering Scales in Sample 1 (n = 795) and Sample 2 (n = 1084)

Items	S1				S2			
	M	*SD*	*SK*	*K*	*M*	*SD*	*SK*	*K*
MW-D1	4.24	1.77	−0.07	−0.96	4.66	1.68	−0.39	−0.63
MW-D2	4.41	1.80	−0.21	−1.04	4.81	1.71	−0.51	−0.62
MW-D3	4.24	1.89	−0.17	−1.11	4.69	1.91	−0.43	−0.93
MW-D4	4.68	1.79	−0.35	−0.85	5.08	1.68	−0.68	−0.39
MW-S1	4.67	1.65	−0.41	−0.63	4.62	1.66	−0.35	−0.66
MW-S2	4.80	1.72	−0.49	−0.69	4.75	1.78	−0.46	−0.78
MW-S3	3.27	1.85	0.42	−0.99	2.96	1.79	0.60	−0.72
MW-S4	4.17	1.86	−0.08	−1.12	3.81	1.86	0.08	−1.09

Note. S1 = Sample 1; S2 = Sample 2; MW-D = Mind-Wandering: Deliberate; MW-S = Mind-Wandering: Spontaneous; *M* = Mean; *SD* = Standard deviation; *SK* = Skewness; *K* = Kurtosis.

SUPPLEMENTARY MATERIAL S4: meta-analysis of the results across both samples of the correlation between Nonreact and MW-S

Using a fixed-effects model, we imputed a standard error for the partial correlation coefficients based the size of the effect and the size of the sample, as per Bowley (1928):

$$SE = \frac{1 - r^2}{\sqrt{N - 2}}$$

Resulting summary effect [95%CI] and significance level:

$r = -.12$ [−.17, −.08], $p < .001$.

Bowley, A. L. (1928). The Standard Deviation of the Correlation Coefficient. *Journal of the American Statistical Association*, *23*(161), 31–34.

CHAPTER VI: GENERAL DISCUSSION

Summary of findings

The general aim of this dissertation was to increase our understanding of the relationship between mindfulness and executive control in adult population, in terms of both the existence and magnitude of such a relationship as well as the mechanisms that could potentially explain it. Three studies were conducted to approach distinct aspects of this general aim. In **Study I**, we sought to stablish a causal link (or lack thereof) between mindfulness training and the classic executive control functions of inhibitory control, working memory, and cognitive flexibility by conducting a systematic review and meta-analysis of RCT studies. Our results indicated that training in mindfulness meditation yields small-to-medium enhancements in inhibitory control and working memory ($g \approx 0.4$ in both cases), while no effect was found for cognitive flexibility. Further analyses suggested that this result was not likely to be inflated by publication bias (although this finding should be interpreted with caution due to the relatively small set of studies included in the meta-analysis; $n = 13$).

In **Study II**, we aimed to examine the executive control basis of dispositional mindfulness. To this end, we conducted a well-powered individual differences investigation linking scores in the FFMQ with performance in the ANTI-Vea task, a cognitive-behavioral measure of multiple transient and sustained attentional indices including executive attention and executive vigilance. The use of the FFMQ, moreover, allowed us to assess whether any particular mindfulness facet or facets were of special relevance in their relationship to executive control, and thus to inquire into potential mechanisms at play. The results revealed, against hypotheses, a lack of relationship between dispositional mindfulness and both executive attention and executive vigilance. We interpreted this null finding to plausibly be a consequence of the high demands and low mind-wandering that characterize the ANTI-Vea task. On the contrary, we did find that the facet Non-reactivity to inner experience was consistently linked to various global attentional and arousal vigilance outcomes (faster reaction times, higher accuracy, and fewer lapses), with effect sizes in the small-to-medium range ($r \approx 0.2$).

Finally, in **Study III** we sought to investigate whether trait mindfulness could be independently predicted by self-reported vulnerability to external distraction (i.e., executive control of attention) and internal distraction (i.e., mind-wandering), as well as to assess the relative importance of each type of distraction in their relationship to mindfulness. Importantly, we also determined to explore the potentially distinct role played by intentional and unintentional types of mind-wandering. To this end, we successfully validated the Spanish version of the Deliberate and Spontaneous Mind-Wandering Scales. Multiple linear regressions then revealed that both types of distraction independently predicted the facets of mindfulness (i.e., they explained unique portions of variance). While dispositional mindfulness was also linked to a decreased vulnerability to external distraction, its largest (negative) predictor was internal distraction, and particularly spontaneous mind-wandering, being this association remarkably strong for Acting with awareness (on the contrary, and interestingly, we found MW-D to be mildly associated to increased mindfulness). Effects ranged from small to medium ($0.01 < R^2 < 0.1$), except for the relationship between MW-S and Acting with awareness ($R^2 \approx 0.25$, large effect).

In sum, the results from these three studies point to the existence of a relationship between mindfulness and executive control (**Studies I** and **III**); hint at the relevance of the "how" of mindfulness (e.g., Non-reactivity to inner experience) for cognitive performance, at least in demanding and moderately aversive contexts (**Study II**); and suggest that (spontaneous) mind-wandering may play an important role in the relationship between mindfulness and performance on task requiring executive control (**Studies II** and **III**). Note that while our findings in isolation are insufficient to make any strong claims, they seem to be consistent with recent empirical and theoretical advances, as will be discussed next.

Findings in context

Mindfulness and enhanced executive control

The meta-analysis described in **Chapter III** (**Study I**) pioneered a series of other meta-analyses of (randomized) controlled trials that examined the effectiveness of mindfulness, mostly as a type of training, in enhancing cognitive outcomes in adult participants. To our knowledge, there are to date six meta-analyses assessing the relationship between mindfulness and the three classic executive control functions of inhibitory control, working memory, and cognitive flexibility (Cásedas et al., 2020a; Millett et al., 2021; Sumantry & Stewart, 2021; Verhaeghen, 2021; Whitfield et al., 2021; Zainal & Newman, 2021), all of which investigated the cognitive impact of mindfulness training, except for Verhaeghen (2021) which addressed mindfulness as both training and trait. A summary of the results of these meta-analyses can be found in **Table 1**. Notably, while they differ in some features related to methodology (e.g., some include non-RCT along with RCT studies) or population assessed (e.g., some include children, adolescents, or the elderly along with adult participants), their findings are fairly consistent in suggesting that mindfulness is linked to enhanced inhibitory control and working memory, while is unrelated to cognitive flexibility (see **Table 1**).

It must be noted that there are two additional similar meta-analyses testing the effectiveness of mindfulness training in enhancing cognition, which however do not follow the taxonomy for executive control used in this dissertation (Im et al., 2021; Yakobi et al., 2021). These two meta-analyses, instead, computed a global, miscellaneous summary effect for executive control, as well as a separate summary effect for working memory (which was not subsumed under the global executive control index). In both cases, an effect was found for the global index of executive control, but not for the summary effect of working memory. These findings, along with the fact that the only meta-analysis addressing mindfulness as trait did not find a significant association with working memory, suggest that the effect under investigation may be less robust for working memory than for inhibitory control. At the same time, they provide further support for the broader claim that mindfulness (training) is indeed linked to enhanced executive control.

Table 1

Meta-Analyses of the Relationship between Mindfulness and Executive Control

	Inhibitory control	Working memory	Cognitive flexibility	Mindfulness
Cásedas et al. (2020a)	x	x		Training
Verhaeghen (2021)	x	x	x	Training
Verhaeghen (2021)	x			Trait
Sumantry et al. (2021)	x	x		Training
Millett et al. (2021)	x	x		Training
Whitfield et al. (2021)		x		Training
Zainal et al. (2021) [a]	x	x	x	Training

Note. x = reported a statistically significant meta-analytical effect. [a] Effect only for accuracy measures.

A final note can be made about the size of the effects of interest, which appear to be smaller in more recent meta-analyses. According to the latest and largest meta-analyses reviewed, the relationship between mindfulness training and executive control would be around $g \approx 0.2$ (rather than around $g \approx 0.4$, as found in our study). Interestingly, this may be indicative of the so-called *decline effect* (i.e., the tendency, documented in various research areas, by which the number and magnitude of statistically significant findings for a given scientific phenomenon decays over time; Schooler, 2011). Complementarily, it could be that the rapid evolution of meta-analytic methods that we are witnessing in the last years is also reflected in the size of the summary effects that are obtained (Harrer et al., 2021). For instance, recent advances in meta-analytical modelling, or in the methods used for detection and correction of publication bias, can be expected to yield more accurate, and likely smaller, summary effects; similarly, the proportion of preregistered meta-analyses is increasing over time, which is likely to translate into a deflation of effect sizes[6]. These postulations, however, remain as yet speculative, and future systematic meta-research is needed to further inquire into their plausibility.

The importance of the "how"

The research described in **Chapter IV** (**Study II**) showed that the facet Non-reactivity to inner experience of the FFMQ was by far the best predictor of enhanced performance in the ANTI-Vea task. Interestingly, this result in line with a number of other investigations demonstrating the importance of the affective domain (i.e., accepting and related attitudes, or the "how" of mindfulness) for performance in executive and attentional cognitive-behavioral tasks. Consider for instance the study by Teper and Inzlicht (2013), who compared the performance of meditators and non-meditators in a Stroop task, while also measured their present-moment awareness and emotional acceptance (both by means of a self-report measure, the Philadelphia Mindfulness Scale), as well as an electroencephalographic index of performance monitoring (the Error Related Negativity). The results indicated better performance for meditators as compared to non-meditators (i.e., the former committed less Stroop errors). Crucially, they also revealed that this finding was primarily mediated by the scores on emotional acceptance and, to a lesser degree, to the ERN (both of which were higher for meditators), while it was unrelated to present-moment awareness (which did not differ between meditators and non-meditators).

[6] We refer to this potential complementary source of progressive decay in the strength of a given effect—which to our knowledge has not yet been given a name in the scientific literature—as the "meta-decline effect".

Another example is provided in the study by Rahl et al. (2017), where performance in the SART was evaluated after two different mindfulness-based interventions that incorporated either training in attention monitoring or training in both attention monitoring and acceptance, versus a relaxation training control group. Results showed that the attention monitoring and acceptance training group outperformed the group based on attention monitoring alone (i.e., the former showed higher discriminability, computed as hits minus commission errors). Further, the attention monitoring-only group scores were found to be numerically lower than those from the relaxation training control group (although this difference did not reach statistical significance). Note that the relaxation group trained participants in a domain presumably closer to the affective than to the cognitive domain.

As the last example, Petranker and Eastwood (2021) conducted an individual differences study assessing the relationship between the FFMQ total score and performance on the SART. Results revealed higher dispositional mindfulness to be linked to higher SART accuracy. Interestingly, this correlation remained significant after controlling for self-reported attentional control (a construct closer to the “what” of mindfulness) but did not held after controlling for experiential avoidance (which is closer to the “how”). Even more direct evidence of the importance of the affective domain was provided by the results of a set of mediation analyses, which showed that the positive correlation between FFMQ and SART performance was mediated by scores on a measure of during-task negative affect (i.e., self-reported discomfort and boredom, assessed in between the SART blocks).

Taken together, the results from these and other studies (e.g., Banks et al., 2015; Jonkman et al., 2017; Xu et al., 2017) suggest that the affective-related quality of mindfulness may be the most relevant—if not critical—for enhanced performance in cognitive-behavioral tasks tapping into attention and executive control processes (for theoretical accounts of the relationship between distinct aspects cognition and emotion in mindfulness training, see also Lindsay & Creswell, 2017; Teper et al., 2013).

Executive control or mind-wandering?

The investigation reported in **Chapter V** (**Study III**) suggests that mindfulness is independently linked to the capacity for executive control of external distraction and the propensity to engage in mind-wandering (i.e., internal distraction), being the effect larger in the latter case, particularly in regard to *spontaneous* mind-wandering. This characterization of internal and external types of distraction as (partially) independent processes has been reported before. For instance, Unsworth and McMillan (2014) conducted a study in which participants were provided with a range of cognitive-behavioral tasks during which thought probes assessing both internal and external distraction were presented. Using a latent variable approach, their results showed that mind-wandering and external distraction, albeit overlapping (i.e., correlated), reflected clearly differentiable constructs. As another example, Kiss and Linnell (2021) investigated the effect of preferred (i.e., self-selected by participants) background music (vs. silence) on the rates of mind-wandering vs. external distraction (both measured by though probing) during a sustained attention task. The results showed that the music condition enhanced task-focus states by reducing mind-wandering, while the rates of external distraction remained unchanged.

The strong negative relationship between mindfulness and spontaneous mind-wandering, in turn, has been extensively documented in studies using self-report, behavioral, and neuroimaging methodologies (e.g., Banks et al., 2015; Bennike et al., 2017; Brewer et al., 2011; Farb et al., 2007; Greenberg et al., 2018; Morrison et al., 2014; Mrazek et al., 2013; Scheibner et al., 2017; Xu et al., 2017) and is entirely consistent with the theoretical characterization of the cognitive processes occurring during practice of (mindfulness) meditation (as described in the **Introduction**; see Dahl et al., 2015; Lutz et al., 2008; Malinowski, 2013). Further, if we assume a certain degree of independence between the regulation of mind-wandering and external distraction, it may be logical from a theoretical standpoint to expect a larger influence of mindfulness in the former process, given that during meditation the practitioner primarily copes with self-generated distraction and not (or at least to a much lesser degree) with distraction by external stimuli.

Following this line of thought, and also considering the unexpected results from **Study II** regarding executive attention and executive vigilance (interpreted as being a consequence of high demands and low mind-wandering in the task used), leads us to the intriguing possibility that the enhancements in performance that are commonly found in meta-analyses in regard to inhibitory control and working memory after mindfulness training (or linked to high levels of mindfulness trait) are at least partially driven—perhaps to a large extent—by reductions in mind-wandering. Note that while certain classic neuropsychological and cognitive-behavioral measures, such as for instance the flanker or n-back tasks, were designed to assess aspects of executive control, it is rather undeniable that they are also indexing rates of mind-wandering, i.e., the extent to which mind-wandering affects executive control (Smallwood & Schooler, 2006, 2015). As Smallwood & Schooler (2006) originally expressed it: “The frequency of mind wandering, even in demanding cognitive tasks such as encoding and reading, suggests that every laboratory study is at least partially a study of mind wandering. It seems that, in almost any cognitive task, mind wandering inevitably accounts for a substantial proportion of an individual’s time” (p. 956).

Consider for example the flanker paradigm (Eriksen & Eriksen, 1974), where participants are required to indicate the direction pointed at by a target arrow while ignoring a set of surrounding distracting arrows that can be pointed in the same (congruent condition) or the opposite direction (incongruent condition). Consistently, participants are shown to be slower and less accurate in incongruent vs. congruent trials. This pattern of impoverished performance in incongruent trials will certainly be partially determined by the capacity for executive inhibition of distracting external stimuli (the surrounding arrows). However, the emergence of mind-wandering during the task may also explain to some extent the phenomenon. At the very least, the presence of task-unrelated thoughts will compete for the resources needed for task goal maintenance, leading to longer reaction times and an increased probability of incorrect responses (a process sometimes referred to as *goal neglect*; Duncan et al., 1996; Mcvay et al., 2009). In more severe cases, mind-wandering may produce complete perceptual decoupling and disengagement from the task (Schooler et al., 2011; Smallwood & Schooler, 2006).

In sum, we believe that it is theoretically reasonable to postulate that the enhanced inhibitory control and working memory performance observed to be linked to mindfulness (as training and trait) is mediated, at least partially, by reductions in mind-wandering, leading to a potential confusion between mind-wandering and executive control. In the next section, we will return to this possibility along with what was discussed in the sections above, in an attempt to provide an original, integrative theoretical account of the relationships between mindfulness, mind-wandering, and executive control.

Integrative theoretical proposal

Prelude – Mechanisms of cognitive training

The previous sections offered a discussion of some of the key findings of this dissertation in light of other relevant empirical and theoretical analyses. Particularly, it was shown that (a) mindfulness appears to be linked to enhanced inhibitory control and working memory; (b) the “how” (affective domain) of mindfulness seems to be key for cognitive performance;

and, (c) mind-wandering may play a central (yet often neglected) role in mediating the above-mentioned gains in inhibitory control and working memory tasks. We believe that this outlook is consistent with the state of the art of the cognitive training literature, both generally (von Bastian et al., 2022) and in particular as it regards to meditation practice (Tang et al., 2022; Tang & Posner, 2009, 2014)[7].

In a recently published review, von Bastian et al. (2022) provided a comprehensive theoretical analysis of the cognitive training literature in an attempt to clarify whether or not available training interventions are effective in producing cognitive enhancement (i.e., in inducing *transfer* effects, or the improvement performance beyond the trained task) and to characterize the nature of the mechanisms by which this is achieved. The review shows that, while there is ample evidence for improvements in the trained tasks, transfer effects are less consistent (for similar views, see Sala & Gobet, 2019; Simons et al., 2016). Critically, von Bastian and colleagues conclude that when transfer does occur it seems to be primarily driven by improvements in *cognitive efficiency*, rather than in *cognitive capacity.* In other words, available methods for cognitive enhancement do not appear to increase the overall cognitive resources available to the individual, but, rather, they seem to optimize performance within existing cognitive capacity limits. As an example, while an increase in the amount of items that can be held in working memory at any given moment would represent an increase in capacity, the implementation of strategies that allow to remember more items more easily would index an increase in efficiency (von Bastian et al., 2022).

This perspective mirrors, to an extent, the proposal put forward by Yi-Yuan Tang and Michael Posner that classifies methods for cognitive enhancement as either *network*

[7] Given that this and the following section are devoted to cognitive training, for parsimony we will only discuss here mindfulness as a type of training; however, our reasoning can, in principle, as in other sections of the dissertation, be extrapolated to mindfulness as trait.

training or *state training* (Tang & Posner, 2009, 2014; see also Tang et al., 2022). According to these authors, network training involves effortful practice of a particular task (e.g., computerized training in a working memory task) with the aim of exercising the specific cognitive function and brain network underpinning it. This approach is suggestive of the “brain as muscle” metaphor (Simons et al., 2016), according to which any given cognitive skill becomes strengthened by means of repeated use, just as a muscle does with repeated physical activity. In practice, however, this explanation for cognitive enhancement has proven to be overly simplistic, and in fact network training efforts have demonstrated very limited transfer effects. State training, on the other hand, would involve rather effortless practices that influence the operations of many networks indirectly via changes in global brain and bodily states, purportedly mainly by triggering parasympathetic dominance in the autonomic nervous system. Examples of state training would be meditation practice or exposure to nature. In contrast to network training regimes, state training approaches would have demonstrated to carry over enhancing effects to (largely) unrelated tasks and activities (Tang et al., 2022; Tang & Posner, 2009, 2014).

As we have tried to illustrate, the two theoretical perspectives that have just been described seem to map onto each other: network training approaches, on the one hand, can be considered attempts to enhance cognitive capacity, which in practice result, at best, in limited transfer effects; state training approaches, in contrast, can be conceptualized as methods that affect performance indirectly, likely by increasing cognitive efficiency, resulting more often in performance gains (both in trained and untrained tasks). Under this general premise, in the next section we will introduce an original mechanistic account to explain the executive performance gains commonly observed after mindfulness training, which we have coined the *Capacity-Efficiency Mindfulness framework.*

The Capacity-Efficiency Mindfulness framework

The Capacity-Efficiency Mindfulness (CEM) framework postulates, first of all, the existence of two distinct yet interacting pathways through which mindfulness training improves executive-related task performance: the *cognitive pathway*, related to the cultivation of attention and monitoring skills (the “what”), and the *affective pathway*, which is related to the development of acceptance, equanimity, and other adaptive emotional attitudes (the “how”). Up to this level of analysis, the CEM framework resembles, and has been inspired by, the *Monitoring and Acceptance Theory* (MAT; Lindsay & Creswell, 2017) and other proposals (e.g., Bishop et al., 2004; Teper et al., 2013) that similarly postulate *monitoring* and *acceptance* to be two separate but interacting qualities that are developed by mindfulness practice. Our CEM framework, however, goes further in suggesting that these two plausibly distinct mechanistic routes correspond to the domains of network-capacity training and state-efficiency training described above, respectively. Each training pathway, in turn, is described in three levels of analysis (conceptual, neurocognitive, and process) and postulated to lead to beneficial effects on executive task performance (i.e., at the functional level). See **Fig. 1** for a visual representation of the CEM framework.

As illustrated in **Fig. 1**, the cognitive pathway is proposed to be primarily instantiated in (task-positive) brain regions related to executive control, including top-down visuospatial attention. While at this early stage of development of the CEM framework we are not able to make any fine-grained predictions at the neural level, for this pathway we generally expect the involvement of regions spanning the anterior cingulate and dorsal and lateral frontoparietal cortices (Tang et al., 2015; Uddin et al., 2019). If we consider again the flanker task example mentioned above, performance gains obtained through the cognitive pathway via network-capacity training will be a consequence of an increased capacity for executive inhibition of external distraction (i.e., the flankers). This pathway can be expected to be relatively more relevant in initial training stages, when practice is

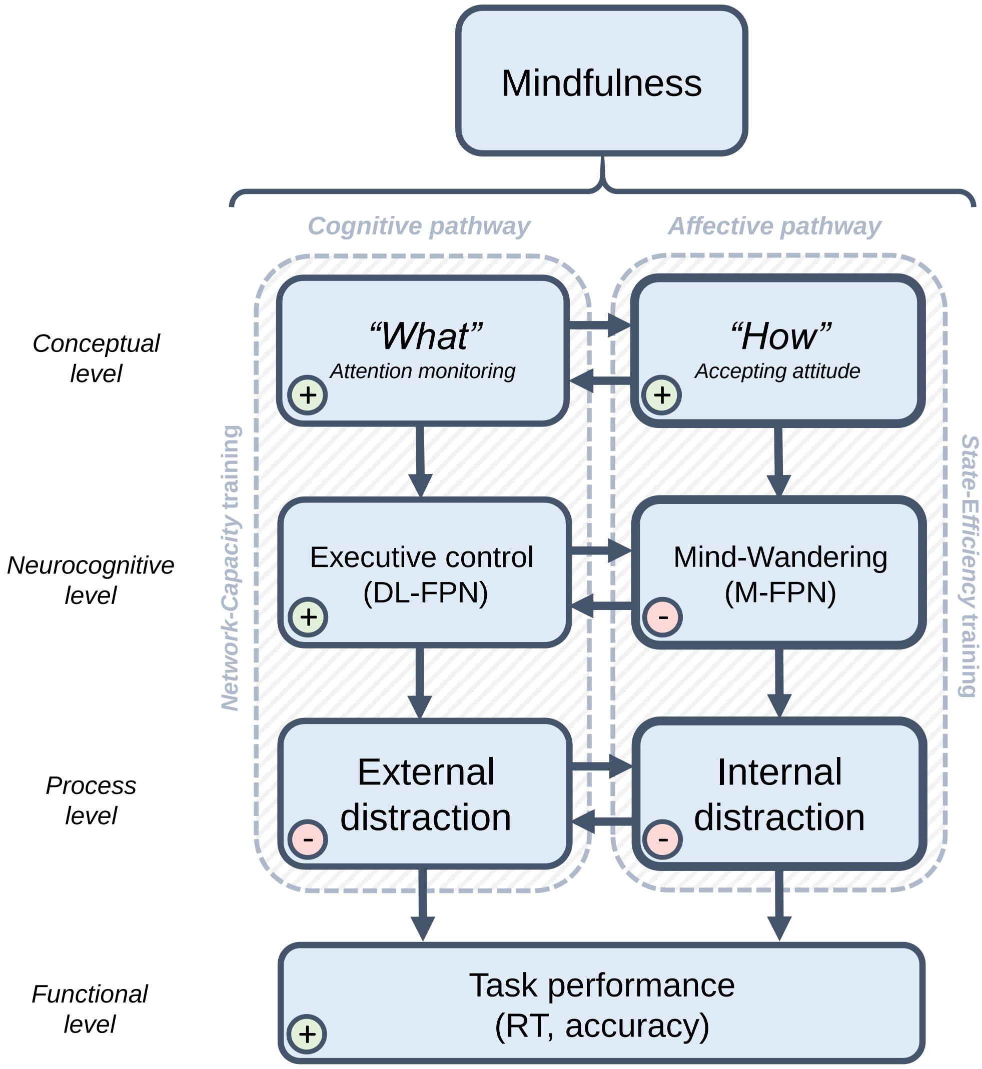

Fig. 1 The Capacity-Efficiency Mindfulness (CEM) framework. The CEM framework postulates that mindfulness training enhances performance in executive control tasks via two distinct (yet interacting) routes: the cognitive pathway, which operates through mechanisms related to *network training* and the enhancement of *cognitive capacity*; and the affective pathway, which entails mechanisms related to *state training* and the improvement of *cognitive efficiency*. Critically, the CEM framework also hypothesizes a relative preponderance of the affective pathway in bringing about functional-level performance gains, as represented by increased box contour thickness for this pathway's variables. Note that mind-wandering here refers, particularly, to its spontaneous kind (deliberate mind-wandering may require more explicit collaboration between executive control and mind-wandering systems). For further details on the framework see main text.

generally more effortful and there is a preponderance of focused attention meditation (which requires explicit engagement, disengagement, and reengagement of several brain networks; Malinowski, 2013).

The affective pathway, in turn, is likely to be instantiated in a wide range of brain regions both cortical and subcortical. For what the CEM framework is concerned (i.e., performance in executive-related tasks), however, we believe that state-efficiency training may be primarily reflected in downregulation of activity in areas related to (spontaneous) mind-wandering, including various medial frontoparietal regions (i.e., the default mode network; Tang et al., 2015; Uddin et al., 2019). As it was discussed in the introduction, it is broadly acknowledged that mind-wandering is primarily initiated by personal current concerns (McVay & Kane, 2010; Smallwood & Schooler, 2006). In line with this, mind-wandering has been shown to be more prevalent in healthy individuals who are prone to worry and anxiety, as well as in severe affective disorders such as major depression (e.g., Hoffmann et al., 2016; Robison et al., 2017). The state-efficiency training pathway, by addressing the affective domain (likely, in part at least, by means of physiological mechanisms that trigger the activity of the parasympathetic nervous system), would reduce the occurrence of mind-wandering (at least when it is unintended), thus reducing the process of internal distraction and, consequently, allowing a more efficient use of available executive control resources. The affective pathway is expected to be relatively more relevant in advanced training stages, when open monitoring predominates and meditation practice is experienced as relatively less effortful, a set of conditions that might also be tied to an increased ability to self-generate flow-like states (Tang et al., 2022)[8].

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[8] While this is not yet formally included at the current stage of development of the CEM framework, we believe that the key process producing the cascade of effects through the cognitive and affective pathways is the cultivation of *meta-awareness* (of both cognitive and affective processes). For theoretical conceptions emphasizing the key role of meta-awareness as a catalyst of the salutary effects of mindfulness meditation, see Bernstein et al. (2015), Dorjee (2016), and Vago and Silbersweig (2012).

Importantly, albeit the CEM framework postulates the cognitive and affective pathways as being both conceivable training routes, one key aspect of the model resides in its marked *asymmetry.* On the basis of the evidence discussed in previous sections of this chapter—regarding both the role of affect and mind-wandering as critical mediators of cognitive performance, as well as the mechanisms by which cognitive training is theorized to operate—the CEM framework proposes that the affective pathway, by means of state-efficiency training, is the primary mechanistic route by which mindfulness practice enhances performance in executive control tasks. Compared to Tang and Posner's view of meditation as purely state training (Tang & Posner, 2009, 2014), our framework may fall closer to alternative conceptions that consider it to be both network training and state training (Malinowski, 2013; Malinowski & Shalamanova, 2017). However, unlike these latter views, the CEM framework hypothesizes that network training mechanisms will only account for a very limited fraction of the gains observed.

There is an important alternative route within the affective pathway worth discussing, namely that gains in the affective domain can produce enhancements in cognitive-behavioral performance *without* the meditating role of mind-wandering. For instance, it is conceivable that the increased capacity to tolerate and endure negative affective states that mindfulness training cultivates has a direct impact in the individual's behavioral engagement with executive-related tasks, which are generally experienced as aversive. In other words, mindfulness training, by increasing tolerance to frustration, may increase the individual's willingness to exert effort (which is aversive in itself; Inzlicht et al., 2015; Kurzban, 2016). This, in turn, is expected to increase task engagement and, accordingly, performance gains. Importantly, if this reasoning holds true, such an increased ability to exert effort would not be a consequence of enlarging any sort of "effort muscle" (effort capacity); rather, it would be the result of modifying the affective context that surrounds the exertion of effort (effort efficiency).

Translating this reasoning from cognitive-behavioral tasks to other more ecologic scenarios, we believe that this mechanism may have far-ranging consequences. If mindfulness does train people to engage with tasks that may result effortful and aversive at first, and does increase their chances of success in them, then effort can become a so-called secondary reinforcer. Put differently, if mindfulness, by increasing engagement with challenging tasks, helps individuals associate the exertion of effort with the achievement of positive outcomes, then the very exertion of effort may become rewarding in itself. This, in turn, is likely to increase the probability of future engagement with difficult tasks, in a process known as *learned industriousness* (Inzlicht et al., 2018). Given that this plausible mechanism is applicable to virtually every effortful daily-life activity (e.g., learning new skills), it may bear potential for relatively large and diverse enhancing effects, both in the cognitive domain and beyond.

In closing, it must be noted that the CEM framework as described here represents just the first iteration of the account and has to be considered as only tentative and requiring of further refinement. That being said, in the next section we will provide some indications for testing the framework as it is in its current stage of development, along with other general directions for future research at the intersection between mindfulness, mind-wandering, and executive control.

Future lines of research

Although the studies included in this dissertation are relatively heterogeneous in both content and methodology and therefore allow for a variety of future lines of research, we believe there are three developments that should be pursued with higher priority: a systematic umbrella review on mindfulness training and executive control, a line to test the CEM framework, and a line to explore the distinction between spontaneous and deliberate types of mind-wandering

Systematic umbrella review

First, a systematic umbrella review of the available meta-analytical literature of mindfulness training and executive control is worth to be conducted. Importantly, this work should not only be concerned with clarifying whether or not the practice of mindfulness meditation does enhance executive control—although this is surely an important question to ask—but, instead, it should also be used as a tool to address a number of other relevant theoretical and methodological questions (Román-Caballero et al., 2022). For instance, one could ask whether there are consistent moderators among meta-analyses, or whether reported effect sizes vary as a function of the specific population assessed (e.g., young adults vs. older adults), the cognitive taxonomy chosen (e.g., executive functions model vs. other executive taxonomy), the study designs of the primary studies (e.g., only RCT or also non-RCT), the meta-analytical methods used (e.g., using multilevel methods vs. aggregates), or the overall quality of the meta-analysis (e.g., registered vs. non-registered meta-analyses). A meta-study like this, we believe, would provide a comprehensive, timely, and useful overview of this particular research area.

Testing the CEM framework

Mindfulness training reduces mind-wandering

A second future line of research worth pursuing is concerned with testing the CEM framework, of which several specific predictions can be derived and put to test. As perhaps the most immediate one, the CEM framework predicts that mindfulness training (1) will have a salutary effect over the affective domain, and (2) will reduce spontaneous mind-wandering. While the first prediction has already been addressed and confirmed in various meta-analyses (Goldberg, Tucker, Greene, Davidson, et al., 2018; Goyal et al., 2014; Khoury et al., 2015), to date no meta-study has been conducted in regard to the second one. In addressing the second prediction, thus, we are currently carrying out a systematic review and meta-analysis to evaluate the impact of mindfulness meditation over mind-wandering processes. Note that while this work can be taken as a preliminary step in testing the CEM framework, we also expect it to be a valuable contribution to the field in itself. The study is being conducted in collaboration with Professor Jonathan Schooler at the University of California, Santa Barbara, and is part of a 3-month international research stay that the candidate enjoyed at this institution during his doctoral training[9].

While this is currently a work in progress, the present discussion offers an opportunity to share some preliminary results, along with the methodology used to obtain them. The meta-analysis addresses, in particular, the effectiveness of mindfulness training in reducing mind-wandering as assessed by self-caught, probe-caught, self-report, and cognitive-behavioral methods in adult participants. In order to distil the best available evidence, only randomized controlled studies using active comparators are included in analysis at this stage. To minimize the impact of publication bias, both published and unpublished reports were considered, summing up a total of 14 studies (33 outcomes). We used a random variance estimation approach to deal with non-independent effect sizes (Hedges et al., 2010), and assessed the impact of publication bias with the trim-and-fill (Duval & Tweedie, 2000), rank correlation (Begg & Mazumdar, 1994), and Egger regression (Egger et al., 1997) tests, using aggregates. After outlier removal, a total of 12 studies (28 outcomes) were retained and included into analyses. Results indicated a weighted averaged effect of g = 0.24, 95% CI [0.05, 0.42], $p < .05$ (see **Fig. 2** for a forest

[9] Readers interested in the relationship between mindfulness and mind-wandering are also directed to a recently published interview we conducted to Prof. Jonathan Schooler about these and other topics (Cásedas, 2022). The interview can be found at www.cienciacognitiva.org/?p=2220.

plot). Heterogeneity was moderate (I^2 = 52%, τ^2 = 0.05). No evidence of publication bias was revealed by any of the methods used (see **Fig. 3** for a funnel plot).

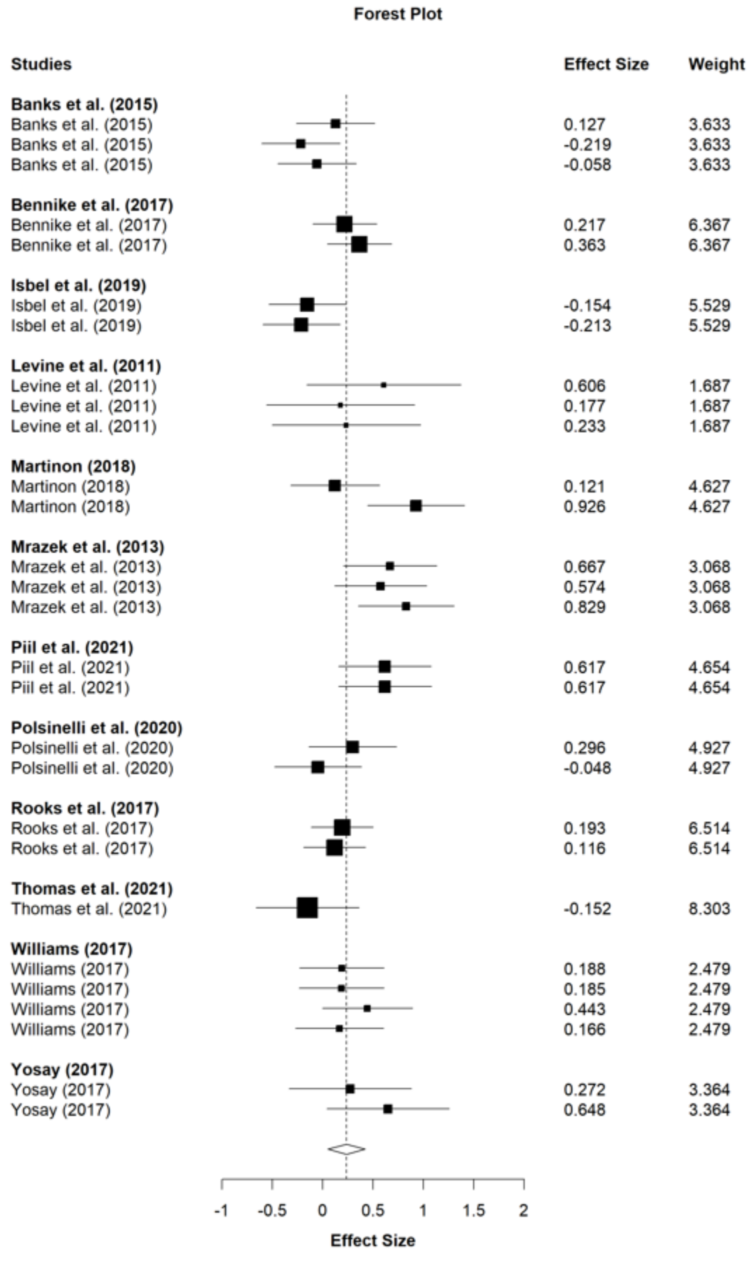

Fig. 2 Forest plot of studies included in meta-analysis

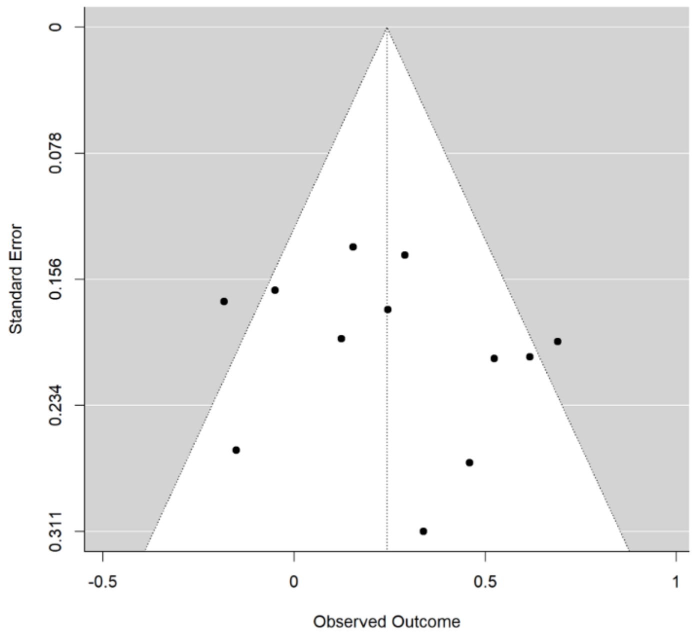

Fig. 3 Funnel plot of studies included in meta-analysis

These results suggest that, as expected, mindfulness training does decrease rates of spontaneous mind-wandering. The effect found was small in magnitude, which may not be surprising considering that we adopted the most stringent approach available (analysis of only active-controlled RCTs, including unpublished dissertations and data sent through personal communications). In any case, at this stage of the project neither the dataset nor the analytic approach are in their final version, and therefore these results can only be taken as preliminary.

Affect and mind-wandering explain executive gains

A second prediction made by the CEM framework is that the gains observed in inhibitory control and working memory tasks after mindfulness training will be mediated, partially at least, by affective variables and mind-wandering. This prediction could be tested in a pre-post RCT design using a low-demand ANTI-Vea (see **Study II**) that also incorporates thought probes assessing online mind-wandering and affective states including, for instance, subjective effort and frustration with the task. Note that in the standard ANTI-Vea participants need to monitor and execute three different tasks: responding to the central arrow direction (ANTI trials), detecting the infrequent vertical displacement of the central arrow (Executive Vigilance trials), and quickly stopping the down counter (Arousal Vigilance trials). As discussed in **Study II**, the high demands of this triple task may leave little room for mind-wandering, resulting in no relationship between mindfulness and executive processes. However, in a low demand version of the task that only requires the detection of the infrequent vertical displacement of the central target (see Luna et al., 2022) it is expected that participants will experience more mind-wandering, thus allowing for a modulation of mindfulness over executive attention. In this scenario, expected results include enhanced performance in the mindfulness group vs. the control group from pre- to post-intervention, and this variance being explained for the most part by changes in online negative affective states and mind-wandering (which are also expected to reveal a larger decline in the mindfulness group after the intervention).

In a similar design, the prediction that mindfulness will have a stronger enhancing effect whenever the likelihood of mind-wandering is high could be tested by orthogonally manipulating the putative presence of mind-wandering and executive control. A modified ANTI-Vea task could be used in which mind-wandering is manipulated by including high and low demand conditions (i.e., executive and arousal vigilance trials vs. only executive vigilance trials, as in Luna et al., 2022) and executive control by including difficult and easy interference conditions (i.e., low vs. high proportion of no-go, critical executive vigilance trials). The task could be composed by four blocks, crossing mind-wandering and control conditions (high-high, high-low, low-high, low-low), and presenting them in a counterbalanced order between participants in each group. The CEM framework predicts enhanced performance in the mindfulness group (vs. controls) in the high vs. low mind-wandering condition, while a less strong interaction (or no interaction at all) is expected to be found around the manipulation of control (at least in the low mind-wandering condition, in which the mindfulness group is not expected to have their characteristic advantage).

These and other similar studies could be conducted to test whether or not, and to what extent, the affective domain and mind-wandering explain performance gains over other variables (including executive control itself, as described in the second example).

Deliberate vs. spontaneous mind-wandering

The third and last future line of research that may be worth pursuing has to do with disentangling deliberate from spontaneous mind-wandering in their relationship to mindfulness and executive control. It bears repeating that mind-wandering is not always necessarily maladaptive, nor mindfulness is necessarily antithetical to it; for instance, open monitoring meditation resembles a kind of (voluntary) mind-wandering of which one is non-reactively meta-aware (for an excellent discussion of similarities and differences between mindfulness and mind-wandering, see Vago & Zeidan, 2016). In this vein, we believe that the distinction between deliberate and spontaneous mind-wandering will spur numerous inquiries and prove highly relevant in the theoretical characterization of the interrelationships between mindfulness, mind-wandering, and executive control. For example, shall we expect deliberate mind-wandering to also mediate the positive relationship between mindfulness and executive performance, as we do for spontaneous mind-wandering, and to what extent? Should we characterize deliberate mind-wandering purely as a form internal distraction, or could it rather be the result of the cooperation of default mode and executive control systems? Could the incorporation of this recent theoretical distinction into classic theoretical models of mind-wandering offer key insights in the dispute between executive control (Smallwood & Schooler, 2006) and executive failure (McVay & Kane, 2010) accounts? Future studies addressing deliberate and spontaneous forms of mind-wandering by means of self-report and though-probing methodologies, in combination with behavioral and neuroimaging techniques, are warranted to explore these and other intriguing questions.

Concluding remarks

This dissertation has attempted to comprehensively answer the question of whether or not and to what extent mindfulness is linked to enhanced executive control, while also aiming to provide a theoretical mechanistic account to explain this relationship. To this end, three studies were conducted along with a broad review and conceptual analysis of the state of the evidence in the field. Based on currently available evidence, it can be asserted with a moderate degree of confidence that mindfulness is indeed linked to enhanced executive control performance. This effect would be specifically circumscribed to the domains of inhibitory control and working memory (leaving cognitive flexibility unaffected), and is expected to be rather small under most circumstances. Critically, it is not likely that mindfulness brings about this salutary cognitive effect by enhancing executive control capacity in itself, but by enabling a more efficient use of it, possibly by causal routes that include downregulation of both affective reactivity and unintended mind-wandering as core mechanisms.

While at present the above-mentioned causal pathways remain largely speculative, the accumulation of evidence in the years to come may allow us to truly unravel the intricate mechanisms by which mindfulness works. Importantly, this is not only a fascinating theoretical enterprise; it will also lead us to understand under what circumstances these practices are most effective and, ultimately, how they should be delivered to be of maximal benefit in helping individuals live more functional, healthy, and fulfilling lives. It is our hope that the present work has brought us one small step closer to that goal.

APPENDIX

A Trip through the Science of Meditation

Review of the book ‘Altered Traits: Science Reveals How Meditation Changes Your Mind, Brain, and Body’ *by D. Goleman and R. J. Davison*

The content of this appendix has been published as:

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A trip through the science of meditation

Can meditation bring about enduring changes to our mind, brain, and body? This is the question Daniel Goleman and Richard J. Davidson started asking in the early 70's, while still graduate students at Harvard University. Since then, Goleman and Davison have been actively engaged in contemplative science, a research field both of them have played prominent roles in defining, establishing, and advancing. Almost 50 years later, their book *Altered Traits* has been published as a compendium of all they have lived and learned throughout the journey. *Altered Traits* is an immersive dive into the science of meditation, covering both its origins and history as well as its most consolidated findings to date. The authors make a dedicated effort to address limitations in the existing literature and to dismiss claims from less rigorous research, thus drawing their conclusions only from the best available studies. As a result, the book offers an entertaining and trustworthy introduction to anyone with an interest in contemplative science, and in what meditation can (and cannot) do for us.

Altered Traits can be divided into four main sections. The first section (chapters 1 to 4) acts as the historical and conceptual preface to the book. Chapters 1 and 2 narrate the starting point of the friendship between Goleman and Davidson, as well as their initial trips to India to learn and practice meditation. The authors also describe how they started envisioning the "altered traits" hypothesis—their original intuition that meditation could potentially generate long-lasting, trait-like changes in our brain and behavior—when virtually no research had yet been done on the topic. Chapter 3 introduces the concept of neuroplasticity (i.e., the ability of neural networks to grow and reorganize through experience) as a critical mechanism underlying the benefits of meditation practice. Finally, Chapter 4 offers a discussion about the quality of research in contemplative science and informs the reader about the various methodological biases to bear in mind when interpreting findings in this field of study.

In the second section of the book (chapters 5 to 10), Goleman and Davidson synthesize the scientific evidence available for the salutary effects of meditation practice in a number of key domains. At this point, they focus on research conducted in beginner (up to 100 hours of practice) and expert (having 9,000 hours of practice on average) meditation practitioners. In Chapter 5, the authors address the effectiveness of meditation to bring about “a mind undisturbed”—a mind less vulnerable to stress. They also discuss the neural processes underlying this soothing effect, highlighting prefrontal control of amygdala reactivity as the main mechanism at play. Chapter 6 reviews the literature concerning the practices of loving-kindness and compassion meditation, showing their positive impact in a variety of outcomes including empathic concern and implicit intergroup bias. In Chapter 7, the authors discuss the effectiveness of meditation in enhancing attention. Even though they show that various kinds of meditation have proven highly effective in enhancing a range of attentional functions, the reader is cautioned that continuous practice might be needed in order to maintain many of these gains.

Chapter 8 addresses the self. Particularly, it discusses the extent and means by which both mindfulness and loving-kindness meditation disrupt the process of mind-wandering (which by nature involves self-referential processing of mostly negatively valenced content) and diminish the activity of the main neural system involved, namely, the default mode network. In Chapter 9, Goleman and Davidson assess the literature that links meditation practice to basic biological functioning. Among other examples, they describe research showing that even short doses of mindfulness meditation practice can downregulate the production of pro-inflammatory cytokines (which have been linked to a variety of diseases), while both mindfulness and loving-kindness meditation can increase the activity of the enzyme telomerase (known for slowing down cellular aging). On the other hand, the authors warn that current evidence linking meditation practice to structural brain changes remains inconclusive, highlighting the need for more research in this particular vein. Finally, Chapter 10 addresses the value of meditation as a tool in psychotherapy. As the chapter unfolds, evidence is presented for meditation having a positive psychotherapeutic effect on a range of disorders, the strongest being in the treatment of depression and anxiety.

In the third section of the book (chapters 11 and 12), Goleman and Davidson switch their focus from research conducted in beginners and experts to the study of what they call the "Olympic-level" meditation group. These are Tibetan meditation masters with an average of 27,000 hours of practice. Chapter 11 narrates the case study of Mingyur Rinpoche—likely the most seasoned meditation practitioner who has ever entered the lab—describing how his brain activity immediately and dramatically increased up to an impressive 800% when asked to enter a meditative state. Equally fascinating, this research revealed the extent to which the monk's brain appears to resist the effects of aging: at the age of forty-one, it resembled what is typically expected for a 33-year-old. Chapter 12 presents research conducted in other Olympic-level practitioners. Among other findings, the authors describe how the monks' neural activity is characterized by a unique whole-brain pattern of high-amplitude gamma waves (frequency linked to attention and awareness), up to 25 times greater than that found in the control group. Despite this pattern being stronger during meditation, it was also present at rest and even during deep sleep, a feature interpreted as a genuine trait-like change.

In the last section (chapters 13 and 14), Goleman and Davison summarize the research unpacked throughout the book while reflecting on the future of contemplative science and its potential for societal change. Chapter 13 revisits the main findings for beginner, expert, and Olympic-level practitioners, showing how the consequences of meditation unfold in a dose-response fashion and, eventually, crystalize into trait-like changes. In Chapter 14, the authors look back at their years in graduate school and reflect on all that has been discovered since then, concluding that they were not mistaken in their initial intuition: meditation has the potential to bring about significant, long-lasting effects. They also discuss the future, value, and limitations of the use of new technologies to deliver meditation training to widespread sectors of society. In closing, Goleman and Davidson provide an encouraging reflection on how the systematic training of attention and compassion through contemplative practice can drive not only individual flourishing, but also positive change in our communities and the world at large.

Altered Traits is a brilliant combination of storytelling and popular science writing. The reader will become familiar with the unfolding of the personal and professional pathways of the authors, as well as with the field of contemplative science itself. From convoluted low-budget trips to India, to insightful encounters with itinerant *sadhus*, to scientific expeditions through the Himalayas, the book is packed with entertaining anecdotes and stories. Yet, at the same time, it offers a thorough overview of research in the field, covering findings relevant to all its core scientific areas. Moreover, it is careful to caution the reader about the hype meditation research is often surrounded by, thus stimulating a critical and balanced perspective on the matter. In sum, *Altered Traits* is an engaging, comprehensive, and reliable take on the science of meditation. A must-read that will be of interest to researchers, practitioners, and the general public alike.

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From mastering a new skill, to planning our finances, to navigating the complex and dynamic world of interpersonal relationships, we oftentimes face situations in which relying on reactive or automatic behavior would lead us astray. Such situations, instead, require us to apply top-down, voluntary control of our attention and actions. This critical ability, which comprises the functions of *inhibitory control, working memory, and cognitive flexibility*, is commonly referred to as *executive control*. *Mindfulness*, in turn, is the name given to a family of mental training regimes intended to foster the regulation of attentional and emotional processes (*mindfulness training*), as well as to the psychological faculty that these practices develop (*mindfulness trait*).

Could the cultivation of mindfulness help us strengthen our executive control? This dissertation offers a tentative answer to the question of whether or not, to what extent, and by which mechanisms the construct of mindfulness is linked to enhanced executive control.

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