NEURONAL AND BEHAVIORAL MECHANISMS OF PRO-ENVIRONMENTAL BEHAVIOR

Zarah Le Houcq Corbi

Graduate School of Systemic Neurosciences
LMU Munich

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Summary

Pro-environmental decisions, which involve balancing personal benefits with environmental considerations, are ubiquitous in our daily lives. While systemic, organizational, and technological structures are crucial for mitigating climate change, these efforts ultimately require changing individual behavior (Ray, Franz, Jarrett, & Pickett, 2021; Schultz & Kaiser, 2012). Therefore, understanding the factors driving individuals to engage in pro-environmental behaviors is critical, especially given the substantial investments in interventions and policies whose success is not guaranteed (Wamsler, Osberg, Osika, Herndersson, & Mundaca, 2021). A significant challenge in this field is the attitude-behavior gap, where pro-environmental attitudes rarely translate into pro-environmental behavior (Kollmuss & Agyeman, 2002). To create more effective interventions and policies, it is essential to gain deeper insights into the mechanisms underlying pro-environmental behavior (and the attitude-behavior gap)—not just theoretically, but empirically and ideally neurobiologically. This thesis aims to elucidate the mechanisms underlying pro-environmental behavior using a multidisciplinary approach that integrates behavioral and neuroscientific methods. For this purpose, the dissertation (i) investigates a potential contributor to pro-environmental behavior: mindfulness; (ii) studies the intricate relationship between pro-environmental, prosocial and future-oriented behavior at a behavioral and neuronal level; and lastly (iii) investigates the neuronal mechanism of the attitude-behavior gap.

The dissertation's first study investigated mindfulness training's effects on pro-environmental behavior. In addition, building on the theoretical link between pro-environmental, prosocial, and future-oriented behavior, we investigated how their baseline preferences are related at a behavioral level (Pfattheicher, Sassenrath, & Schindler, 2016;

Weber, 2017). Lastly, given that mindfulness is also associated with these behaviors we examined the roles of prosociality and future orientation as mediators of the mindfulness-environmental link. Contrary to previous correlational and theoretical accounts, mindfulness training decreased, instead of increased, environmental and prosocial choices, and no significant effects were found for future orientation (Ericson, Kjønstad, & Barstad, 2014; Geiger, Grossman, & Schrader, 2019). Although prosocial and environmental choices were correlated, prosocial decisions did not moderate the link between mindfulness and pro-environmental behavior. Therefore, while pro-environmental and prosocial behaviors are related, prosocial behavior alone does not fully explain the connection between mindfulness and pro-environmental behavior. These findings challenge previous theoretical accounts suggesting a positive effect of mindfulness on pro-environmental and prosocial behavior (Ericson et al., 2014).

The second project investigated the neuronal underpinnings of pro-environmental behavior. To test whether the hypothesized link between pro-environmental, prosocial, and future-oriented behavior is mirrored at the neuronal level, we compared their neuronal correlates in a single study testing their shared neuronal mechanisms, a novel approach in the literature (Gladwin, Krause, & Kennelly, 1995; Weber, 2017). We also examined whether these mechanisms play a role in bridging the attitude-behavior gap. Our study found that pro-environmental behavior exhibited higher brain activation in the dorsomedial prefrontal cortex (DMPFC), precuneus, and temporoparietal junction (TPJ). The TPJ was also activated during the neuronal overlap of pro-environmental and prosocial behavior, and it modulated the attitude-behavior gap. These findings are in line with previous neuroscientific studies demonstrating the causal role of the TPJ (Langenbach, Savic, Baumgartner, Wyss, & Knoch, 2022). Our results contribute to the existing literature on TPJ and pro-environmental behavior by showing that TPJ activation is associated with both environmental and prosocial decisions and highlighting its role in the major challenge of this field, namely the attitude-behavior gap.

Taken together, our findings challenge previous theoretical accounts by suggesting potential reverse effects of mindfulness on pro-environmental behavior (Ericson et al., 2014). However, they do not imply a general negative impact of mindfulness on pro-environmental and prosocial behaviors. Instead, they underscore the nuanced nature of pro-environmental behavior and the need for future research. Moreover, our research highlights a closer relationship between pro-environmental and prosocial decisions compared to future-oriented preferences, both at behavioral and neuronal levels. This relationship is further supported by the involvement of the TPJ, known for its association with prosocial behavior (Van Overwalle, 2009), in bridging the attitude-behavior gap. These findings might have broader implications for public interventions and policies, advocating for the integration of prosocial aspects alongside environmental elements in their development.

Table of Contents

1. General introduction

1.1 Pro-environmental behavior: fundamentals and psychological mechanisms

Climate change poses serious risks for both humans and natural systems, making it one of the greatest challenges of our society (Freitas, 2021; IPCC, 2014). Researchers have emphasized the urgent need to promptly reduce carbon dioxide (CO2) emissions, as they are the primary driver of climate change (Hoegh-Guldberg, Jacob, Taylor, Bindi, Brown, Camilloni et al., 2018). Notably, individual consumption contributes up to 60% of global greenhouse gas emissions (Ivanova, Stadler, Steen-Olsen, Wood, Vita, Tukker et al., 2016). For example, an average German citizen emits between eight and nine tons of CO_2 annually (German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV); Federal Statistical Office of Germany). This highlights the critical role of individual pro-environmental behavior in building a sustainable society. In fact, while addressing climate change requires a variety of strategies—such as technological advancements, political initiatives, and community-based programs—any solution will ultimately necessitate changes in individuals' behaviors (Midden, Kaiser, & Teddy McCalley, 2007; Schultz & Kaiser, 2012).

Political efforts are implementing various measures to promote a sustainable future, exemplified by initiatives like the European Green Deal which aims to achieve zero emissions by 2050 (European Green Deal, 2020). However, existing policies often face challenges in achieving these objectives due to public opposition (Reich & Boss, 2022; Żuk & Żuk, 2022). Such opposition can delay effective climate change mitigation measures and significantly waste public resources. For instance, the European Green Deal is estimated to cost over 1 trillion euros, and results are not assured (European Green Deal, 2020). Thus, designing policies and interventions that the public might not accept can have tremendous consequences. Hence, understanding the underlying mechanisms of individuals' pro-environmental behavior—how and why people make environmentally conscious decisions—is imperative.

Every day, we are confronted with decisions affecting our natural environment, whether the choice is between driving or cycling to work or between a vegetarian or beef dish at a restaurant. This trade-off between personal interests and environmental benefits characterizes pro-environmental decisions. The majority of people acknowledge the severity of climate change and have the desire to address it. However, there is often a gap between these attitudes and behavioral changes (Kollmuss & Agyeman, 2002). This discrepancy, known as the attitude-behavior gap, represents one of the primary challenges in environmental psychology, and researchers have spent decades developing models and studying relevant factors in an attempt to understand it (Gatersleben, Steg, & Vlek, 2002; Grandin, Boon-Falleur, & Chevallier, 2021; Wyss, Knoch, & Berger, 2022). Two broad categories of factors have been identified to influence pro-environmental behavior and thus also the attitude-behavior gap, namely extrinsic and intrinsic factors (Kollmuss & Agyeman, 2002). External factors encompass infrastructural, political, and socioeconomic features, among others. In contrast, internal factors relate to individual characteristics such as knowledge and awareness of climate change, value systems, emotions, personality traits, and environmental attitudes.

While the relevance of external structural barriers is evident, it is also crucial to understand the factors that promote pro-environmental behavior at an individual level (i.e., internal system) to reduce individuals' carbon footprint and effectively address climate change (Clayton, Devine-Wright, Stern, Whitmarsh, Carrico, Steg et al., 2015). Multiple psychological barriers can impede pro-environmental behavior at an individual level, including conflicting values, uncertainty, perceived inequity, or perceived behavior control

(Gifford, 2011). Nevertheless, the literature highlights that social and temporal discounting are particularly significant barriers to pro-environmental behavior (Aoki, Ito, Izuma, & Saijo, 2020; Grandin et al., 2021; Wittmann & Sircova, 2018). Social discounting describes how our willingness to engage in prosocial behavior—actions intended to benefit others (Fehr & Fischbacher, 2003)—depends on the social distance from the recipient (Jones & Rachlin, 2006). Essentially, we are more likely to be generous toward those who are socially closer to us; as the social distance from the recipient increases, our willingness to be generous decreases. Similarly, individuals often devalue rewards that will be received in the future compared to those available immediately. This means that people often favor immediate, smaller benefits over larger future rewards, as the subjective value of these rewards decreases with delay (Ainslie, 1975; Frederick, Loewenstein, & O'donoghue, 2002; Green, Fristoe, & Myerson, 1994). At a decision-making level, these tendencies can pose a problem for pro-environmental behavior since pro-environmental decisions involve the trade-off between selfish interest and environmental benefits, with the latter primarily benefitting others —in particular, future generations who are frequently perceived at greater social distances (i.e., social discounting) (Jones & Rachlin, 2006)— rather than oneself. Thus, prosocial behavior and future-oriented behavior—prioritizing long-term goals over immediate temptations (Ainslie, 1975)—have been theoretically associated with pro-environmental behavior (Gladwin et al., 1995; Weber, 2017). One goal of the present dissertation is to investigate the interconnection between pro-environmental, prosocial, and future-oriented behavior. By investigating these relationships, the dissertation seeks to uncover the mechanisms underlying pro-environmental behavior and contribute to a deeper understanding of how individuals decide environmentally friendly.

Another way to gain deeper insights into the underlying mechanism of pro-environmental behavior is to investigate potential contributors to pro-environmental behavior, such as mindfulness. Mindfulness, characterized by the ability to direct attention to the present moment non-judgmentally, has been theoretically linked to pro-environmental behavior (Kabat-Zinn, 2013). However, empirical evidence in this area remains inconclusive. On the one hand, meta-analytic findings suggest a correlation between dispositional mindfulness (i.e., individuals' inherent mindfulness trait) and self-reported pro-environmental attitudes (Geiger et al., 2019). On the other hand, studies investigating mindfulness interventions (i.e., practices aimed at enhancing dispositional mindfulness) on pro-environmental behavior did not show significant effects on self-reported pro-environmental behavior (Geiger, Fischer, Schrader, & Grossman, 2020; Riordan, MacCoon, Barrett, Rosenkranz, Chungyalpa, Lam et al., 2022). Therefore, the question of whether mindfulness training (i.e., mindfulness intervention) modulates pro-environmental preferences is still open. The first project of this dissertation aims to investigate this question to elucidate how mindfulness practices can influence and potentially foster pro-environmental behavior.

While research has generated some empirical evidence on pro-environmental behavior, understanding its neuronal mechanisms is a recent endeavor. Investigating the neuronal mechanisms underlying pro-environmental behavior allows us to clarify and provide support for theoretical and behavioral empirical findings (Doell, Berman, Bratman, Knutson, Kühn, Lamm et al., 2023). Recent neuroscientific studies identified neuronal substrates of pro-environmental behavior, and there is extensive neuronal research on prosocial and future-oriented behavior available (Baumgartner, Guizar Rosales, & Knoch, 2023; Baumgartner, Langenbach, Gianotti, Müri, & Knoch, 2019; Guizar Rosales, Baumgartner, & Knoch, 2022; Langenbach et al., 2022). However, no previous study has concurrently investigated these three behaviors within a single study. To further characterize the underlying mechanisms driving pro-environmental behavior, this dissertation investigates its neuronal mechanism and tests whether theoretical links between pro-environmental, prosocial, and future-oriented behavior are mirrored at the neuronal level by directly comparing their neuronal mechanism

To sum up, this dissertation investigates the underlying mechanisms of pro-environmental behavior using a multidisciplinary approach that combines behavioral and neuronal methods. Concretely, we investigate the potential influence of mindfulness on pro-environmental behavior and compare pro-environmental, prosocial, and future-oriented preferences at a behavioral and neuronal level. In the upcoming section, I will (i) review the literature on the psychological mechanisms that connect pro-environmental behavior with prosocial and future-oriented behavior, (ii) describe methods used to measure pro-environmental behavior, (iii) report literature describing the connection between mindfulness and pro-environmental behavior, and lastly (iv) review research on the neuronal mechanisms underlying pro-environmental behavior, particularly on their link to prosocial and future-oriented behavior. The final section will outline the dissertation's goals.

1.2 The link between pro-environmental, prosocial and future-oriented behavior

Previous research proposes that promoting pro-environmental behavior is particularly challenging because of the unique combination of two dilemmas: the social and temporal dilemma between the present and future generations (Aoki et al., 2020; Hurlstone, Price, Wang, Leviston, & Walker, 2020; Milfont, Wilson, & Diniz, 2012). In line with this, it has been suggested that prosocial behavior and future-oriented preferences are likely related to pro-environmental behavior (Gladwin et al., 1995; Grandin et al., 2021; Weber, 2017). To better understand their interrelationship, in this section I will define prosocial and future-oriented behavior and review the literature supporting their link to pro-environmental behavior.

Prosocial behavior is crucial for guiding human social interactions and thus foundational to societal functioning. Defined as actions intended to benefit others (Fehr & Fischbacher, 2003), prosocial behavior can be motivated by both self-interest and altruism (Penner & Orom, 2010). Prosocial behavior can be measured with interpersonal tasks by examining the trade-off between selfish behaviors (such as keeping money to oneself) and social choices (such as sharing money with another person), taking into account varying levels of social distance (Jones & Rachlin, 2006). Thus, these tasks assess social discounting, the tendency for generosity to decrease as social distance increases.

In broader contexts, environmental and social challenges are deeply intertwined. On the one hand, environmental problems often lead to social consequences (Gladwin et al., 1995; Milfont et al., 2012). Climate change not only damages natural habitats but also destroys people's homes, causing forced displacement (Warner, 2010). This results in societal distress (Steinbruner, Stern, & Husbands, 2013), with minorities often bearing a disproportionate impact (Baird, 2008; IPCC, 2014). On the other hand, combating environmental challenges often relies on social cooperation (Raihani & Aitken, 2011). Thus, prosocial behavior might theoretically be a relevant psychological factor to pro-environmental behavior (Gladwin et al., 1995; Grandin et al., 2021). The theoretical link between pro-environmental behavior and prosocial behavior is also supported by empirical data correlating self-reported environmental attitudes with compassion, which is thought to be related to prosocial behavior (Batson & Shaw, 1991; Eisenberg & Miller, 1987; Pfattheicher et al., 2016).

Moreover, future-oriented behavior is crucial for predicting individual life success and health. It enables individuals to prioritize long-term goals, such as maintaining good health, over immediate temptations, like indulging in a chocolate cake (Boals, Vandellen, & Banks, 2011; Mischel, Shoda, & Peake, 1988). This behavior is often assessed using intertemporal choice tasks, which evaluate how individuals balance smaller amounts of money in the present (or near future) against larger amounts in the distant future (Fujita, 2011). Therefore, we can measure individuals' temporal discount function, which describes the rate at which future rewards are devalued based on their delayed delivery.

Pro-environmental behavior requires significant upfront costs in the present that yield benefits to individuals far beyond the lifetimes of today's decision-makers (Carson & Roth Tran, 2009; Wittmann & Sircova, 2018). Thus, theoretical frameworks propose a link between pro-environmental behavior and future orientation since to achieve the long-term goal of conserving natural resources for future generations requires resisting the urge for immediate gratification, such as driving to work for the sake of comfort (Weber, 2017). In line with this, a recent meta-analysis showed that future time perspective significantly affected self-reported pro-environmental attitudes and behaviors (Milfont et al., 2012).

To sum up, existing literature indicates a relationship between pro-environmental and prosocial as well as future-oriented behavior. However, this assumption mainly relies on theoretical frameworks and self-reported data; evidence based on more robust methods, such as experimental tasks, is missing. Interestingly, it has been emphasized that while future orientation may be relevant to pro-environmental behavior, social cognition appears to be the most impactful factor, particularly in addressing the attitude-behavior gap (Grandin et al., 2021). To understand the intricate relationship between these behaviors, this dissertation aims to compare pro-environmental, prosocial, and future-oriented behavior at a behavioral level using experimental tasks.

1.3 Measuring pro-environmental behavior

The recent introduction of experimental tasks for measuring pro-environmental behavior represents a critical advancement in environmental psychology. Before this development, only self-reported measurements— such as the new ecological paradigm (NEP) (Dunlap, Liere, Mertig, & Jones, 2000)—were available (Lange, 2023). However, these measurements face significant limitations regarding response, consistency, and social biases (Kormos & Gifford, 2014). Pro-environmental behavior is often characterized by its environmental consequences; however, by implementing self-reported measurements, these studies do not examine behavior with actual environmental consequences but instead focus on observing verbal behavior (Lange, 2023). These observations usually target participants' attitudes toward the natural environment. Yet, the established attitude-behavior gap describes how higher attitudes rarely translate into higher environmental behaviors (Kollmuss & Agyeman, 2002). Alternatively, studies can assess pro-environmental behavior using experimental paradigms (Lange, 2023). Indeed, in recent years, research groups have created experimental paradigms to evaluate the environmental consequences of pro-environmental behavior, which allows the investigation of the underlying mechanism of pro-environmental behavior and facilitates the testing of interventions on pro-environmental behavior in a controlled setting before translating them into real-world practices (Lange, 2023). In the following sections, I will briefly give an overview of experimental paradigms measuring different pro-environmental consequences.

Pro-environmental consequences can manifest in various forms: time, effort, or financial investment. Accordingly, the literature outlines various tasks to address these diverse costs. For instance, the Pro-environmental Behavior Task (Lange, Steinke, & Dewitte, 2018) involves decisions between pro-environmental and non-pro-environmental options, with the ecological choice leading to a longer waiting time compared to the non-pro-environmental one that translates into real-world waste of energy. Moreover, the Work for Environmental Protection Task involves exerting additional effort in an identification task for the pro-environmental option, which translates into donations to environmental organizations (Lange & Dewitte, 2022). Furthermore, during our study, we developed the environmental donation task, where participants traded between selfish monetary rewards and donations to environmental organizations, which had real-world consequences.

Next, one can assess the direct consequences of individuals' behavior, namely CO_2 emissions. In this sense, Berger and Wyss developed the Carbon Emission Task measuring the trade-off between personal reward and long-term environmental goals (Berger & Wyss, 2021). Specifically, the non-environmental option includes a financial reward but emitts CO_2, whereas the environmental option entails no personal reward and is carbon-neutral. For the present dissertation, we adapted this task so that the non-environmental option provided participants with a reward but only reduced minor (or none) amounts of CO_2, and the environmental option had no reward but reduced higher amounts of CO_2. As in the original task, we used the one payoff method and choices had real consequences. We either added participants' rewards to their end payment or bought CO_2 certificates from the European Commission to destroy them and reduce real-world CO_2. We refer to this task as the environmental decision task in the mindfulness study or the CO_2 emission task in the functional magnetic resonance imaging (fMRI) study.

This dissertation implements two tasks, the environmental donation task and the CO_2 emission task, to unravel the underlying mechanism driving pro-environmental behavior. These tasks target two distinct environmental impacts—financial cost and CO_2 emissions.

Furthermore, the CO_2 emission task provides a distinct advantage by reducing its conceptual overlap with prosocial components. This distinction is particularly relevant as one of the primary objectives is directly comparing pro-environmental behavior to prosocial behavior.

1.4 Mindfulness training as a contributor to promote pro-environmental behavior

Mindfulness has been theoretically linked to pro-environmental behavior (Ericson et al., 2014). However, it remains uncertain whether mindfulness training (i.e., mindfulness intervention rather than dispositional mindfulness) directly impacts pro-environmental behavior (Geiger et al., 2019). Here, I explain the concept of mindfulness, discuss its theoretical connection to pro-environmental behavior, and present the available empirical evidence supporting this link.

In the last decade, mindfulness received significant scientific interest and is often defined as the capacity to direct one's attention to the present moment without judgment (Kabat-Zinn, 2013). However, it has been highlighted that a standardized definition for mindfulness is missing (Van Dam, van Vugt, Vago, Schmalzl, Saron, Olendzki et al., 2018). In fact, the term "mindfulness" is frequently used broadly and encompasses a range of meditation techniques, such as Vipassana, Zen meditation, or yoga practices. Moreover, mindfulness is also characterized in the literature as both a psychological disposition (i.e., dispositional mindfulness) or a set of techniques aimed at enhancing mental levels of mindfulness (i.e., mindfulness intervention) (Crane, Brewer, Feldman, Kabat-Zinn, Santorelli, Williams et al., 2017; Rau & Williams, 2016). Depending on the specific training implemented, mindfulness-based interventions can target various mental states, such as attentional control, non-reactivity, present-moment awareness, acceptance, non-judgment, and compassion (Trautwein, Kanske, Böckler, & Singer, 2020). The most commonly utilized mindfulness-based intervention in research is the eight-week Mindfulness-Based Stress Reduction (MBSR) program developed by Kabat-Zinn, which has been shown to enhance dispositional mindfulness (Giannandrea, Simione, Pescatori, Ferrell, Olivetti Belardinelli, Hickman et al., 2019; Kabat-Zinn, 2013).

Given the diversity of approaches within mindfulness research, it is crucial to establish clear definitions and specify the training methods used (Van Dam et al., 2018). Throughout this dissertation, we will use the term "mindfulness training" to describe intervention exercises aimed at guiding participants to focus their attention on the present moment and cultivate non-judgment and kindness. We implemented a 31-day mindfulness training of 15-minute daily sessions, incorporating exercises targeting attention, compassion, and open awareness. This dissertation aimed to evaluate the initial effects of mindfulness on pro-environmental behavior; thus, we opted for a shorter training duration. If necessary, longer trainings could be considered in subsequent studies. We used active control training focusing on health enhancement, with sessions matching the duration and frequency of the mindfulness training. Additional details on both training protocols can be found in the method section of our study.

Understanding the mechanism underlying mindfulness is essential to comprehend how mindfulness might affect pro-environmental choices. Theoretical frameworks have described mindfulness as a bidimensional construct (Bishop, Lau, Shapiro, Carlson, Anderson, Carmody et al., 2004). The first component involves attention regulation, while the second component focuses on adopting a present-moment orientation marked by openness and acceptance. Over time, this two-component model has evolved into multifaceted constructs. For instance, Hölzel and colleagues describe the components of attention regulation, body awareness, emotion regulation, and change in perspective on the self. (Hölzel, Lazar, Gard, Schuman-Olivier, Vago, & Ott, 2011). These components can be targeted separately or simultaneously during mindfulness practices (Hölzel et al., 2011).

Previous theoretical frameworks suggested a link between mindfulness and pro-environmental behavior (Ericson et al., 2014). Mindfulness is hypothesized to affect pro-environmental behavior in multiple ways. Theoretically, mindfulness is thought to reduce automatic responses (Kang, Gruber, & Gray, 2013; Ostafin, Bauer, & Myxter, 2012), increase value-behavior concordance (Franquesa, Cebolla, García-Campayo, Demarzo, Elices, Pascual et al., 2017; Warren, Wray-Lake, & Syvertsen, 2018) and decrease emotional automaticity (Britton, Shahar, Szepsenwol, & Jacobs, 2012; Kral, Schuyler, Mumford, Rosenkranz, Lutz, & Davidson, 2018). These changes are predicted to disrupt unsustainable habits and potentially translate into higher sustainable efforts (Wamsler et al., 2021).

Empirical findings partially support the mindfulness-environmental link. While recent meta-analytical evidence indicates a positive correlation between dispositional mindfulness and self-assessed pro-environmental attitudes (Geiger et al., 2019), an eight-week controlled mindfulness-based intervention did not directly impact self-reported sustainable consumer behavior (Geiger et al., 2020). Similarly, another intervention study found that an eight-week training in Mindfulness-Based Stress Reduction did not improve environmental behavior on self-reported ecological footprint calculator among meditation-naive individuals (Riordan et al., 2022). We argue that the lack of intervention effects may be attributed to methodological limitations in previous studies, which predominantly relied on self-reported measurements of pro-environmental behavior. These measures are susceptible to social desirability, response, and consistency biases (Kormos & Gifford, 2014) and often do not assess actual environmental consequences (Lange, 2023). To overcome this limitation, our mindfulness study incorporates mindfulness training on two experimental tasks—the CO_2 emission task and the environmental donation task—which assess real-world implications of pro-environmental behavior.

Moreover, theoretical accounts suggest a connection between mindfulness and prosocial behavior. Several pathways have been described on how mindfulness can affect prosocial behavior. First, mindfulness enhances attentional components, potentially enabling individuals to perceive the needs of others better, thereby promoting higher prosocial behavior (Donald, Sahdra, Van Zanden, Duineveld, Atkins, Marshall et al., 2019). Next, mindfulness contributes to emotional regulation, decreasing the likelihood of individuals suppressing compassionate responses in situations and thereby promoting actions consistent with their values (Donald et al., 2019). Finally, mindfulness has the potential to transform one's sense of self from a rigid, self-protective entity to a more interdependent, flexible, and non-attached perspective. The association between mindfulness and prosocial behavior is also supported by meta-analytical evidence indicating a positive correlation between both (Donald et al., 2019; Ericson et al., 2014).

Moreover, mindfulness has also been related to future-oriented behavior (Hendrickson & Rasmussen, 2013; Morrison, Madden, Odum, Friedel, & Twohig, 2014). At first, it might seem counterintuitive to relate mindfulness, which emphasizes the awareness of each present moment, with future-oriented decisions. However, evaluating choices across past, present, and future occurs within an extended present; effectively shifting time perspectives may be closely linked to a present-oriented mindfulness practice (Vowinckel, Westerhof, Bohlmeijer, & Webster, 2017; Wittmann & Sircova, 2018). Being mindfully present entails being aware of the present without avoiding negative feelings. This meta-awareness of one's mental state can aid in resisting immediate gratifications and opting for more challenging long-term goals (Wittmann & Sircova, 2018). These theoretical assumptions are, however, only partially supported by empirical data, which show that mindfulness effects on future orientation vary depending on the type of rewards involved, with stronger effects observed for primary rewards compared to secondary rewards and on inter-individual differences on baseline impulsivity, with more impatient individuals showing more pronounced effects (Hendrickson & Rasmussen, 2013; Morrison et al., 2014).

Given the established links between pro-environmental behavior, prosociality, future orientation, and mindfulness, a key aim of the first project is to test whether prosocial and future-oriented behaviors mediate the relationship between mindfulness and pro-environmental behavior, thereby further characterizing the mindfulness-environmental link.

1.5 Neuronal mechanisms of pro-environmental behavior

Neuroscientific approaches investigating pro-environmental behavior are a recent endeavor. Although only a few studies have been published so far, the potential contribution of neuroscience to climate policy-making has been underscored (Doell et al., 2023). Integrating various disciplines, such as neuroscience and psychology, is beneficial and essential for researching human interactions with climate change (Clayton et al., 2015). Neuroscience can significantly contribute by providing techniques that offer additional objective measures and empirical evidence, thereby further supporting behavioral findings (Aoki et al., 2020; Sawe & Chawla, 2021; Wang & Van Den Berg, 2021). Given the theoretical link between pro-environmental, prosocial, and future-oriented behavior, I review neuroscientific evidence suggesting that this association may also be present at the neuronal level.

Recent neuroscientific studies have identified brain regions related to prosocial behavior also to be activated during pro-environmental behavior, namely the temporoparietal junction (TPJ) and dorsomedial prefrontal cortex (DMPFC) (Guizar Rosales et al., 2022; Langenbach et al., 2022). The TPJ plays a crucial role in prosocial behavior, enabling individuals to shift their perspective to the needs of others and thus promoting prosocial over selfish behavior (Christian, Kapetaniou, & Soutschek, 2023; Hutcherson, Bushong, & Rangel, 2015; Soutschek, Ruff, Strombach, Kalenscher, & Tobler, 2016; Strombach, Weber, Hangebrauk, Kenning, Karipidis, Tobler et al., 2015; Van Overwalle, 2009). Stimulating the cortical excitability of the right TPJ has also been shown to increase pro-environmental choices, determining a causal link (Langenbach et al., 2022). These findings suggest that the theoretically hypothesized interactions between environmental and social decisions may also manifest at the neuronal level (Gladwin et al., 1995; Pfattheicher et al., 2016). This claim is further supported by the involvement of the DMPFC in pro-environmental behavior, a region also linked to prosocial behavior (Rilling & Sanfey, 2011; Van Overwalle, 2009). Structural imaging studies have revealed that individuals who engage in environmentally friendly behavior have greater cortical thickness in the DMPFC compared to those who do not (Guizar Rosales et al., 2022). Moreover, a recent functional connectivity study reinforces these findings, showing that higher connectivity between the TPJ and DMPFC is associated with greater pro-environmental behavior, indicating that these regions likely interact during such decisions (Baumgartner et al., 2023).

In contrast to the environmental-social neuronal link, the neuronal connection between pro-environmental and future-oriented behavior is less clear. Individuals who engage in pro-environmental behavior showed higher EEG-baseline activity over the lateral prefrontal cortex and greater cortical thickness in the dorsolateral prefrontal cortex (DLPFC) compared to none-environmental individuals (Baumgartner et al., 2019; Guizar Rosales et al., 2022). However, evidence on the causal role of DLPFC in pro-environmental behavior is inconsistent. While disrupting the DLPFC using transcranial magnetic stimulation did not affect pro-environmental choices (Langenbach, Baumgartner, Cazzoli, Müri, & Knoch, 2019), a more recent brain stimulation study demonstrated that applying cathodal tDCS over the DLPFC indeed increases environmentally friendly choices (Wyss, Baumgartner, Guizar Rosales, Soutschek, & Knoch, 2024).

While the neuroscientific evidence reveals potential association between pro-environmental, prosocial, and future-oriented behavior, a direct comparative investigation of these behaviors has not yet been conducted. This represents a crucial gap in comprehending the intricate neuronal link between these behaviors. The second study in this dissertation is designed to bridge this gap by utilizing fMRI neuroimaging on healthy participants engaged in experimental tasks related to pro-environmental, prosocial, and future-oriented behavior. These findings are expected to provide initial empirical evidence of the potentially shared mechanisms of these behaviors at a neuronal level, thereby advancing our understanding in this field.

1.6 Aim of the thesis

The overarching aim of this dissertation is to contribute to the understanding of the underlying mechanisms of pro-environmental behavior. We adopt a multidisciplinary approach to achieve this, integrating behavioral experiments and fMRI. As mindfulness has been hypothesized to contribute to pro-environmental behavior theoretically, we investigated whether mindfulness training (and not only dispositional mindfulness) modulates real-life pro-environmental choices (study 1, goal 1) (Ericson et al., 2014). Moreover, given that prosocial behavior and future orientation have been identified as significant psychological factors to pro-environmental behavior, we further aim to investigate their relationship to pro-environmental behavior at both behavioral (study 1, goal 2) and neuronal levels (study 2, goal 3) (Aoki et al., 2020; Grandin et al., 2021; Pfattheicher et al., 2016; Weber, 2017). Finally, we address the attitude-behavior gap by testing whether prosociality and future orientation mechanisms can explain how positive attitudes towards the environment can be more effectively translated into pro-environmental decisions (study 2, goal 4).

Theoretical and correlational studies suggested a link between mindfulness and pro-environmental behavior (Ericson et al., 2014; Geiger et al., 2019), yet the direct interventional effects of mindfulness on pro-environmental behavior remain unclear (Geiger et al., 2020). Most of these studies rely on self-reported pro-environmental measures, while our first project employs experimental tasks focused on pro-environmental behavior with real-world environmental consequences. By implementing these tasks in a pre-post-test design with both mindfulness and active control trainings, we aimed to extend the existing literature on the mindfulness-environmental link. Given the association between prosociality as well as future-orientation behavior with pro-environmental behavior, we also tested whether participants' baseline environmental decisions correlate with social and future-oriented preferences (Aoki et al., 2020; Grandin et al., 2021; Pfattheicher et al., 2016; Weber, 2017). Research has also shown a link between these behaviors and mindfulness (Donald et al., 2019; Ericson et al., 2014; Hendrickson & Rasmussen, 2013; Morrison et al., 2014). In line with this, we further elucidate the underlying mechanisms of the mindfulness-environmental relationship by investigating whether prosocial and future-oriented behaviors mediate this link.

To enhance our understanding of the underlying mechanisms of pro-environmental behavior, we aim to identify its neuronal mechanism and to determine whether hypothesized relationships between pro-environmental, prosocial, and future-oriented behavior are also mirrored at the neuronal level. While several studies have examined the neuronal correlates of prosocial and future-oriented behaviors, and recent imaging studies have begun to uncover the neuronal mechanisms of pro-environmental behavior, no single study has compared these factors within one design (Baumgartner et al., 2023; Baumgartner et al., 2019; Christian et al., 2023; Doell et al., 2023; Guizar Rosales et al., 2022; Langenbach et al., 2022; McClure, Laibson, Loewenstein, & Cohen, 2004; Rilling & Sanfey, 2011; Strombach et al., 2015; Van Overwalle, 2009). This comprehensive approach is necessary to understand their intricate relationships and neuronal mechanisms. To achieve this, we used fMRI methods on 30 healthy participants who engaged in pro-environmental, prosocial, and future-oriented behavior tasks. Lastly, we investigated whether the neuronal mechanisms underlying prosocial and future-oriented behaviors can explain the attitude-behavior gap in pro-environmental behavior.

While this dissertation primarily contributes to fundamental research related on underlying mechanism of pro-environmental, our multidisciplinary approach can offer valuable insights to inform broader contexts and applications, potentially leading to more effective interventions and policies for promoting pro-environmental behavior.

2. Chapter I : Mindfulness training reduces the preference for sustainable outcomes

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Mindfulness training reduces the preference for sustainable outcomes

Zarah Le Houcq Corbi*[1], Kathrin Koch[2], Britta Hölzel[2], and Alexander Soutschek[1]

[1]Department of Psychology, Ludwig-Maximilians-Universität München, Munich, Germany

[2]Department of Neuroradiology, Technical University of Munich, Munich, Germany

Author contributions

ZLHC, KK, BH, and AS designed research; ZLHC performed research; ZLHC and AS analyzed data; ZLHC and AS wrote manuscript with contributions from KK, and BH; all authors approved final manuscript version

*Corresponding author:
Zarah Le Houcq Corbi
Department for Psychology
LMU Munich
Leopoldstr. 13, 80802 Munich, Germany
Email: zarah.lehoucq@psy.lmu.de

Abstract

Theoretical accounts posit that mindfulness promotes pro-environmental behavior. While this claim is supported by correlational findings, past intervention studies provided no evidence that enhancing mindfulness increases self-report measures of pro-environmental attitudes or behavior. Here, we tested whether a 31-day mindfulness intervention strengthens preferences for pro-environmental outcomes with decision tasks involving real conflict between participants' selfish interests and beneficial consequences for the environment. To unravel the psychological mechanisms underlying the impact of mindfulness on sustainability, we assessed the impact of mindfulness training on prosociality and future orientation. Contrary to our hypotheses, the mindfulness intervention reduced instead of increased preferences for pro-environmental and prosocial outcomes, whereas no effects were observed on future orientation. Baseline preferences for pro-environmental and prosocial outcomes (and the intervention effects on them) were correlated, providing empirical evidence for a link between sustainability and prosociality. Together, the current data suggest that the relationship between mindfulness and sustainability as well as prosociality may be more complicated than assumed in the literature.

Keywords: pro-environmental behavior, mindfulness, delay discounting, social discounting, drift diffusion model

Introduction

The global climate crisis is characterized by unprecedented annual increases in greenhouse gas (GHG) emissions, particularly carbon dioxide, with significant implications for the environment and biodiversity (Shivanna, 2022). Individual behavior plays a crucial role in driving these emissions (Clayton et al., 2015; Ivanova et al., 2016): in Germany, for example, an average of eight to nine tons of CO_2 is emitted per person and year (German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV); Federal Statistical Office of Germany), underlining the need for individuals to make more sustainable choices to reduce their carbon footprint (Kollmuss & Agyeman, 2002). It is therefore important to obtain a better understanding of the psychological determinants of pro-environmental behavior (Lilley, Wilson, Bhamra, Hanratty, & Tang, 2017; Steg & Vlek, 2009). Theoretical accounts suggest a link between pro-environmental behavior and mindfulness (Ericson et al., 2014). Mindfulness involves the cultivation of non-judgmental awareness of the present moment (Bishop et al., 2004). The current study therefore tested the hypothesis that mindfulness practice strengthens the preference for pro-environmental behavior.

While theoretical accounts assume that mindfulness promotes pro-environmental behavior (Ericson et al., 2014), evidence for such a relationship is mixed. On the one hand, a recent meta-analysis reported a positive correlation between dispositional mindfulness and pro-environmental attitudes (Geiger et al., 2019). However, these results were only correlational in nature, whereas a mindfulness intervention reported in the same study observed no direct effects of an eight-week mindfulness program on self-report measures of sustainable consumer behavior. Another study reported cross-sectional evidence for stronger pro-environmental attitudes in long-term meditators compared to a meditation-naïve control group, but there was no difference in pro-environmental behavior. Furthermore, the same study used a mindfulness intervention in meditation-naïve individuals, which again showed no effects on both attitudes and behavior (Riordan et al., 2022). Taken together, despite findings showing that individual differences in mindfulness are associated with self-reported pro-environmental attitudes, evidence for a direct influence of mindfulness practice on pro-environmental behavior is lacking. A limitation of previous intervention studies is that they used only self-report questionnaire measures of pro-environmental behavior (Steg & Vlek, 2009). The main goal of the current study therefore was to test the influence of a mindfulness intervention on pro-environmental preferences measured with a decision task that – in contrast to previous research – involved real trade-offs between a decision maker's self-interest and beneficial consequences for the environment.

A further goal of our study was to unravel the psychological mechanisms underlying a potential influence of mindfulness on pro-environmental behavior. In particular, we focused on prosociality and future-orientation as possible mediators of the mindfulness-sustainability relationship. Theoretical accounts posit close links between concerns for environment and society (Gladwin et al., 1995), because pro-environmental actions require individuals to weigh their selfish interests against the preservation of natural resources; the latter incurs no direct benefits for the individual but mainly for others, in particular future generations. In line with this assumption, empathy was empirically found to correlate with pro-environmental behavior (Pfattheicher et al., 2016). Furthermore, meta-analytical evidence suggests that mindfulness interventions promote prosociality (Donald et al., 2019). It seems therefore plausible to assume that mindfulness may promote sustainability via enhancing prosociality.

Another cognitive mechanism that might connect mindfulness to pro-environmental behavior is future-orientation. Previous research suggests that mindfulness might promote future-oriented behavior, although this effect may be stronger for primary than for secondary rewards (Hendrickson & Rasmussen, 2013) and may depend on individual differences in baseline impulsiveness (Morrison et al., 2014). Future-oriented behavior is also conceptually linked to sustainability because pro-environmental behavior requires resisting immediate temptations (like indulging in a long shower or going by car) in order to achieve long-term pro-environmental goals benefitting future generations (Weber, 2017).

To investigate whether mindfulness-based training promotes pro-environmental behavior via strengthening prosociality and/or future-orientation, we conducted a pre-registered study where mindfulness-naïve participants performed decision tasks measuring pro-environmental, prosocial, and future-oriented preferences before and after a mindfulness or control training (pre-test/post-test design). We hypothesized mindfulness (relative to active control) training to increase preferences for pro-environmental outcomes (hypothesis 1). Moreover, as potential mediators of the influence of mindfulness on pro-environmental behavior, we expected the mindfulness training to strengthen also prosociality in social decision making (hypothesis 2) and explored potential intervention effects on future orientation in an intertemporal decision task.

We measured pro-environmental preferences with two experimental tasks: an environmental decision task and an environmental donation task. In the environmental decision task, participants made choices between a sustainable (reducing carbon emission) and an unsustainable option (monetary bonus for the participant with less or no reduction of carbon emission). In the environmental donation task, participants could donate money to different environmental organizations. Contrary to previous mindfulness studies assessing sustainability with self-report questionnaires (Geiger et al., 2019), these tasks allowed testing the impact of mindfulness on decisions involving real-world implications for one's own benefits and environmental consequences.

Materials and Methods

Participants

Eighty-six participants were recruited through the participant pool of the Munich Experimental Laboratory for Economic and Social Sciences at the Ludwig Maximillian University of Munich. During the recruitment participants were informed that we would be testing the influence of health awareness on decision-making and avoided mentioning "mindfulness" or "meditation" in the study description. Four participants were excluded due to lack of attendance in the post-test session or incomplete training performance (> 4 missed training sessions). Therefore, the final sample included eighty-two participants ranging from 18 to 35 years (mean age = 23.3, ranging from 18-35 years, 63 women, 19 men), with 40 in the control group (mean age = 23.4 years, 31 women, 9 men) and 42 in the mindfulness group (mean age = 23.2 years, 32 women, 10 men). Participants were mostly university students. Exclusion criteria were prior mindfulness experience (i.e., any meditation or mindfulness experience in the past 3 years), and history of psychiatric or neurological diseases. Prior to participation, participants gave written informed consent. The study was approved by the ethics committee of the Ludwig Maximillian University of Munich (31_Soutschek_b), performed in accordance with the Declaration of Helsinki and preregistered on OSF (https://osf.io/3wbs4).

Study design and procedures

The study followed a pre-test/post-test design where participants were pseudorandomly assigned to either the mindfulness or the control group. The first group completed a mindfulness training and the latter a health enhancement training, which were both conducted online and lasted thirty-one days. The training included daily fifteen-minute sessions that could be completed on a smartphone or computer. The daytime and location of the training were chosen by the participants. Before (pre-test) and after (post-test) the training, participants completed computer-based tasks in the lab measuring pro-environmental, prosocial, and future-oriented preferences as well as questionnaires assessing participants' mindful state and sustainable attitudes (Figure 1).

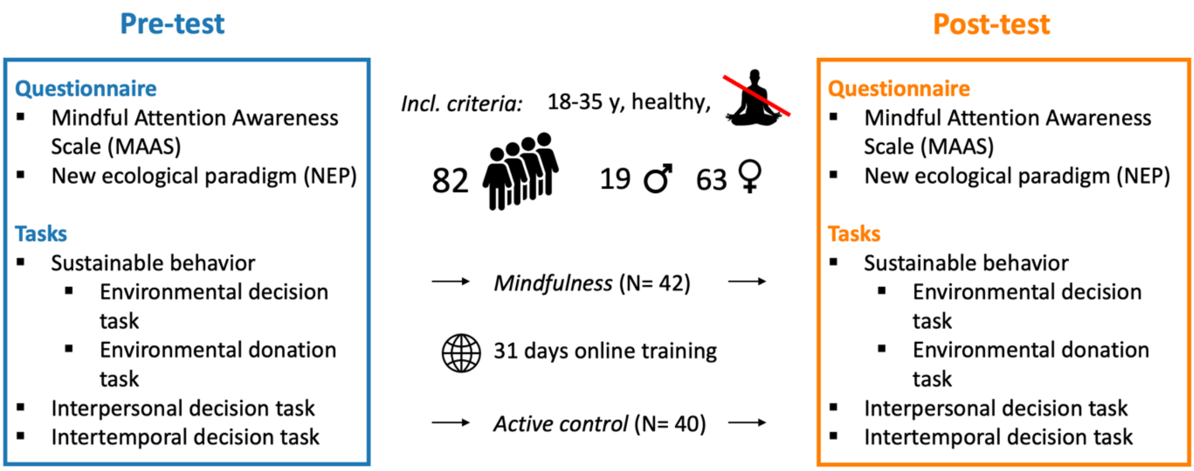

Figure 1. Experimental Design. The experimental group completed a 31-day online mindfulness training, while the active control group undertook a health enhancement training. Before and after the training, participants completed questionnaires assessing their mindful attention awareness state (MAAS) and environmental attitudes (NEP). Additionally, they completed two tasks: an environmental decision task and an environmental donation task as measures of pro-environmental behavior as well as an interpersonal decision task and an intertemporal decision task as measures of prosociality and future orientation, respectively.

Mindfulness training. We used an adapted version of an online training (in German) that had been implemented in past studies (Bremer, Wu, Mora Álvarez, Hölzel, Wilhelm, Hell et al., 2022; Mora Álvarez, Hölzel, Bremer, Wilhelm, Hell, Tavacioglu et al., 2023). The training involved daily active exercises presented in various formats such as videos, audio, or texts. During thirty-one days, different meditation techniques were repeated: 1) traditional methods such as breathing meditation, body scan, and body sensation, in total nine sessions, 2) meditations targeting emotions (e.g., loving-kindness), in total four sessions and 3) sessions focused on metacognitive aspects such as open awareness and seating in silence, in total six sessions. The remaining days included videos describing psychological processes applied during mindfulness like being in the present moment, communicating mindfully, or contemplating who you are. While the original version of the training largely focused on attention to body sensations, we modified it to strengthen the balance between different kinds of meditations. In particular, we changed the order of the meditations to have diversity throughout the training, erased the walking and hearing meditation, and added instead more meditation sessions focussing on metacognitive aspects, such as awareness.

Control training. The active control training (adopted from Bremer et al. 2022 (Bremer et al., 2022)) included health enhancement topics such as sleep hygiene, stress management, or dietary advice and contained informative videos, audio, and texts extracted from popular science broadcasting formats.

Behavioral assessments

Environmental decision task. In the environmental decision task (adapted from Berger and Wyss, 2021 (Berger & Wyss, 2021)), participants chose between options with different consequences for their monetary payoff and the environment. The sustainable option was not associated with a monetary reward for the participants but with a reduction of a certain amount of carbon dioxide emission (ranging from -0.1 to -50kg). In contrast, the unsustainable option included a monetary reward for the participant (1 to 10 €) but a lower reduction of carbon dioxide emission (ranging from 0 to -10 kg) than the sustainable option (Figure 2A). Thus, in this task participants were confronted with a conflict between their selfish payoff and beneficial consequences for the environment. The choice options were randomly presented on the left or right screen side and participants selected their preferred option by pressing the corresponding arrow key (left or right). It is important to emphasize that the chosen options had real consequences for participants' payoff and the environment. Participants were informed before the start of the task that one of the trials would be randomly selected at the end of the experiment and the chosen amount of money was added to participants' payment. For choices that included a carbon dioxide reduction, we bought CO_2 certificates of the displayed amount and destroyed them to take them out of the market, thereby removing them from the European Emissions Trading System and reducing real-life CO_2 emissions. We informed participants about this procedure before the task and emphasized they should take every choice seriously because all trials were equally likely to be selected after the experiment. We moreover informed participants that carbon dioxide is an important contributor to climate change and we translated the amount of reduced carbon dioxide emissions into the number of kilometers an average car has to drive to emit the given amount of carbon dioxide to help participants to better understand the real-world consequences of their choices. In addition, participants were given some references to help them understand the magnitude of the kg amounts. For example, they were informed that an average German emits between nine to ten tons of CO_2 per year or that a flight from Munich to Rome emits around 140 kg of CO_2.

Environmental donation task. As a further measure of pro-environmental preferences, participants also performed a donation task where they could donate an amount of money between 0-10 € to an environmental organization. Participants were informed that they could receive €10 from us and that one trial could be randomly selected at the end of the experiment. The chosen amount of money would be donated, while the remaining non-donated portion of the 10 € endowment would be added to their final payoff. The amount participants were willing to donate had to be indicated on an 11-point rating scale from 0-10 € (Figure 2B). The task included a total of four trials with four different environmental organizations. Before the task participants received an overview of the goals and values of each organizations. The following four organizations were included: WWF (World Wide Fund For Nature), NABU (Naturschutzbund Deutschland), BUND (Bund für Umwelt und Naturschutz Deutschland), and Primaklima.

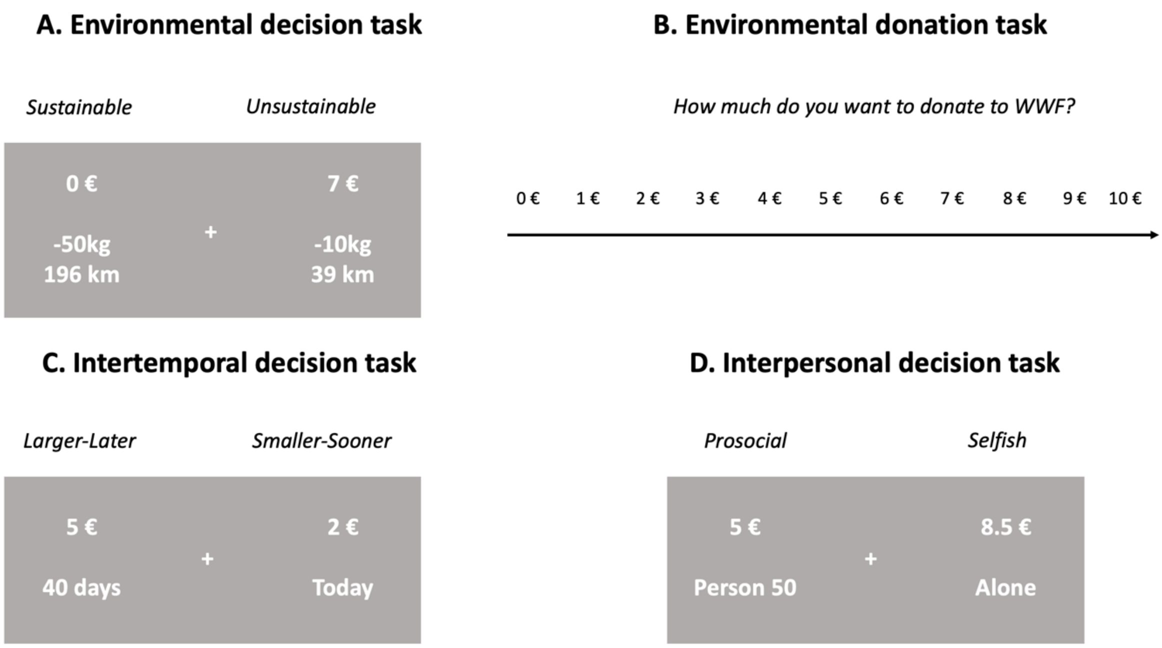

Figure 2. Illustration of decision tasks. Two tasks measured pro-environmental behavior: (A) In the environmental decision task, participants chose between a sustainable option (no reward but higher carbon dioxide reduction) and an unsustainable option (reward with a small or no carbon dioxide reduction). (B) In the environmental donation task, participants had to indicate how much money they would like to donate to a specific environmental charity, for example the WWF, on a rating scale. Moreover, (C) the intertemporal decision task required choices between larger-later and smaller-sooner rewards, whereas (D) the interpersonal decision task required choices between a prosocial option (sharing money with another person) and a selfish option (keeping money for oneself).

Intertemporal decision task. As a measure of future-oriented preferences, we administered an intertemporal choice task which required participants to make choices between smaller immediate and larger later monetary rewards. The smaller immediate rewards ranged from 0.5 to 4.5 € in steps of 0.5 (nine immediate reward levels), whereas the larger later reward was fixed to 5 €, with the temporal delay varying from 2 to 360 days (six delay levels) (Figure 2C). The choice options were randomly presented on the left or right screen side and participants selected the preferred option by pressing the left or right arrow key for the option presented on the left or right screen side, respectively.

Interpersonal decision task. In this task (Jones & Rachlin, 2006; Soutschek et al., 2016), we first asked participants to imagine a scale ranging from 1 to 100 representing the closeness of their relationships to other individuals in their lives (i.e., social distance). The number ”0” referred to themselves, “1” to someone very close to them (e.g., their mother), “50” to someone they have seen repeatedly, but do not know their name, and “100” to a stranger on the street. Participants were asked to avoid thinking about relationships that caused negative feelings. During the task, participants then decided between a selfish option involving an amount of money for themselves only and a prosocial option where they shared the money with another individual at varying social distances. The reward of the selfish option ranged from 5 to 10 € in steps of 0.5. In the case of the prosocial option, both the participant and the other person received 5 €, and we used the social distances of 1, 5, 10, 20, 50, and 100 (Figure 2D). Again, the decisions were indicated with the right and left arrow keys, and the screen presentation sides of both options were counterbalanced.

Control measures. To measure the effectiveness of the mindfulness training, we used the Mindful Attention Awareness Scale (MAAS) (Brown & Ryan, 2003; Carlson & Brown, 2005), which is a validated self-report questionnaire for participants' mindfulness state (i.e., their ability to stay present in their daily life experiences). Moreover, participants also completed the Positive and Negative Affect Schedule (PANAS) test (Watson, Clark, & Tellegen, 1988) to control for training effects on mood. We also used a computer-based version of the digit span backward task as a measure of working memory capacity. Lastly, we controlled for side effects of mindfulness by using a German version of the Meditation-

Related Adverse Effects Scale (Britton, Lindahl, Cooper, Canby, & Palitsky, 2021; Settgast, Ziebell, & Kübler, 2023). Lastly, to measure participants' sustainable attitudes, we implemented the New Ecological Paradigm (NEP) questionnaire (Dunlap et al., 2000), which consists of 15 statements about the relationship between humans and the environment. We used the NEP sum score for statistical analyses.

Statistical analyses

Statistical analyses were conducted with R version 4.3.2. We analyzed data in the decision tasks both with model-free and model-based (drift diffusion modelling (DDM)) analyses. For the model-free analyses, we conducted generalized linear mixed models (GLMMs) that regressed binary choices in the pro-environmental, intertemporal, and interpersonal decision tasks on fixed-effect predictors for Group (0 = control, 1= mindfulness), Session (0= pre, 1= post) and the interaction using the function glmer in the lme4 package. Session was also modelled as random slope in addition to participant-specific random intercepts. Similarly, we also analyzed log-transformed reaction times in these tasks with the lmer function and the additional predictor Choice as well as all interaction effects.

In addition, for both the interpersonal and intertemporal choice tasks, we calculated hyperbolic discount functions which indicate how the subjective values of shared and delayed rewards decline with increasing social distance or temporal delay, respectively. We used the hBayesDM package in R to estimate hyperbolic discount parameters separately for the pre-test and post-test data, assuming a standard hyperbolic discount function:

$$SV = \frac{reward\ magnitude}{1+k \times social\ distance\ /temporal\ delay} \tag{1}$$

where SV is the discounted subjective value of the shared or delayed reward and k is an individual-specific constant that quantifies the degree of hyperbolic discounting ("discount factor”). We converted subjective values into binary choices using a softmax function with the inverse temperature parameter β_{temp}:

$$P(choice\ of\ shared\ or\ delayed\ reward) = \frac{1}{1+\exp\left(-\beta_{temp}\times(SV - selfish\ /immediate\ reward)\right)} \quad (2)$$

We estimated the parameters k and β_{temp} in a hierarchical Bayesian fashion (2 chains with 4,000 samples, the first 1000 samples were used as burn-in) and log-transformed the resulting individual parameter estimates for the statistical analysis.

For the environmental donation task, the digit span task, as well as the MAAS and NEP questionnaires, we conducted linear regressions (function lmer) where the dependent variable was predicted by fixed-effect predictors for Group, Session, and the interaction term in addition to participant-specific random intercepts. We note that all findings based on general linear regressions were robust to using non-parametric rather than parametric regression models. For the meditation-related adverse effects, we used a chi-square test for binary data (adverse effect present vs. absent) to determine whether adverse effects occurred more often in the mindfulness than in the control group.

In addition to the model-free analyses, we analyzed data in the decision tasks with exploratory (not pre-registered) hierarchical Bayesian drift-diffusion models (DDMs) using the JAGS software package (Hornik, Leisch, Zeileis, & Plummer, 2003). JAGS utilizes Markov Chain Monte Carlo sampling to estimate the DDM parameters ν (drift rate), α (decision boundary), ζ (starting bias), and τ (non-decision time) (Wabersich & Vandekerckhove, 2014). The lower and upper decision boundaries were associated with unsustainable and sustainable choices, respectively, in the environment decision task, with selfish versus prosocial choices in the interpersonal decision task, and with choices of immediate versus delayed rewards in the intertemporal decision task. Following previous procedures (Soutschek & Tobler, 2023), we assumed that the speed of the accumulation process (drift rate ν) is given by a linear combination of the individually weighted influences of reward magnitudes and action costs (i.e., carbon dioxide emission, social distance of recipient, or delay of reward delivery). We also modelled how the mindfulness and control interventions changed the accumulation process in the post-test relative to the pre-test. For example, in the environment decision task the drift rate ν was given by the following equation:

$$\nu = \beta_1(\text{Reward}) + \beta_2(\text{Session}\times\text{Reward}) + \beta_3(CO_{2diff}) + \beta_4(\text{Session}\times CO_{2diff}) \quad (3)$$

Here, Reward is the monetary reward associated with the unsustainable option, CO_{2diff} is the difference in CO_2 emission reduction between the sustainable and the unsustainable option. For the interpersonal and intertemporal decision tasks, we modified equation 3 by replacing Reward and CO_{2diff} with the differences in reward magnitudes and social distances/temporal delays between the choice options.

We modelled training effects also on all other DDM parameters. For example, the training effect on the starting bias parameter (and analogously for the decision boundary and non-decision time) was given by:

$$\zeta = \beta_5 + \beta_6(\text{Session}) \quad (4)$$

To investigate group differences between DDM parameters, we modelled both individual and group-level parameters separately for the mindfulness and the control group in a hierarchical Bayesian fashion. Individual parameters were assumed to be normally distributed around group-level parameters. To test for significant group differences, we computed the differences between the posterior parameter distributions of the group-level parameters for the session effects (which capture the difference between post-test and pre-test parameter estimates) in the mindfulness and the control group. If the 95% highest density interval ($HDI_{95\%}$) of this difference did not entail zero, the group difference was considered statistically significant. We excluded trials with unreasonable fast decision times below 250 ms (Westbrook, Van Den Bosch, Määttä, Hofmans, Papadopetraki, Cools et al., 2020). As priors, we assumed non-informative uniform priors over plausible parameter ranges and estimated parameters by computing two chains with 20,000 samples (burning = 15,000). $\hat{R}$ was below 1.01 for all parameter estimates, indicating model convergence.

Results

Mindfulness training increased participants' mindful state

As a sanity check, we first assessed whether the mindfulness training enhanced participants' mindful state compared to the control training as measured with the MAAS. The mindfulness training increased mindfulness scores compared to the control training, $\beta = 0.29$, $t(80) = 2.31$, $p = 0.024$. A post-hoc analysis revealed an increase in mindfulness scores in the mindfulness group from the pre-test to the post-test, $\beta = 0.30$, $t(41) = 2.80$, $p < 0.01$, whereas the control group showed no significant change, $\beta = 0.01$, $t(39) = 0.16$, $p = 0.87$. In contrast, we found no significant training effects on positive, $\beta = -0.22$, $t(80) = 1.43$, $p = 0.16$, or negative mood (measured with the PANAS), $\beta = -0.18$, $t(80) = 1.12$, $p = 0.27$, or on working memory capacity, $\beta = 0.11$, $t(80) = 0.34$, $p = 0.74$. The treatment groups also showed no significant differences in age, $t(78) = 0.31$, $p = 0.76$, or gender, $t(80) = 0.14$, $p = 0.89$, and participants in the mindfulness group did not report more adverse effects (MRAES questionnaire) than the control group, chi square test: $\chi^2(1) = 2.35$, $p = 0.13$. Thus, any potential training effects on the decision tasks cannot be explained by such confounding variables but are likely to result from the increased mindfulness in the mindfulness compared with the control group.

Mindfulness training increased preferences for unsustainable rewards

In the environmental decision task, we tested our hypothesis that the mindfulness training increases sustainable choices. The interventions differently affected choices in the post-test relative to the pre-test, Group × Session: β = -0.68, z = 2.36, p = 0.019. To resolve this interaction, we conducted separate GLMMs for each training group: the mindfulness training decreased sustainable choices in the post-test compared to pre-test session, Session: β = -0.79, z = 3.92, p < 0.01, while the control training did not show significant effects, Session: β = -0.06, z = 0.29, p = 0.78 (Figure 3A). Thus, contrary to our hypothesis, the mindfulness intervention reduced rather than increased preferences for sustainable outcomes. To explore whether the unexpected direction of this effect could be explained by individual differences in participants' baseline pro-environmental behavior, mindful state, or gender we added in separate models the mean percentage of sustainable choices from the pre-test, the difference in MAAS score (pre- minus post-test), and gender to the model described above, but the Group × Session interaction remained significant when controlling for individual differences in baseline pro-environmental behavior, β = -0.66, z = 2.16, p = 0.03, difference in mindful state, β = -0.59 , z = 2.02 , p = 0.04 , and gender, β = -0.69, z = 2.40, p = 0.02 , and was not significantly modulated by baseline sustainability, β = 0.24, z = 0.69, p = 0.49, difference in mindful state, β = 0.46, z = 1.10, p = 0.27 , or gender: β = 0.2 , z = 0.76, p = 0.45 Thus, the unexpected effect of the mindfulness training on pro-environmental choices cannot be explained by individual differences in pro-environmental preferences, mindful state , or gender.

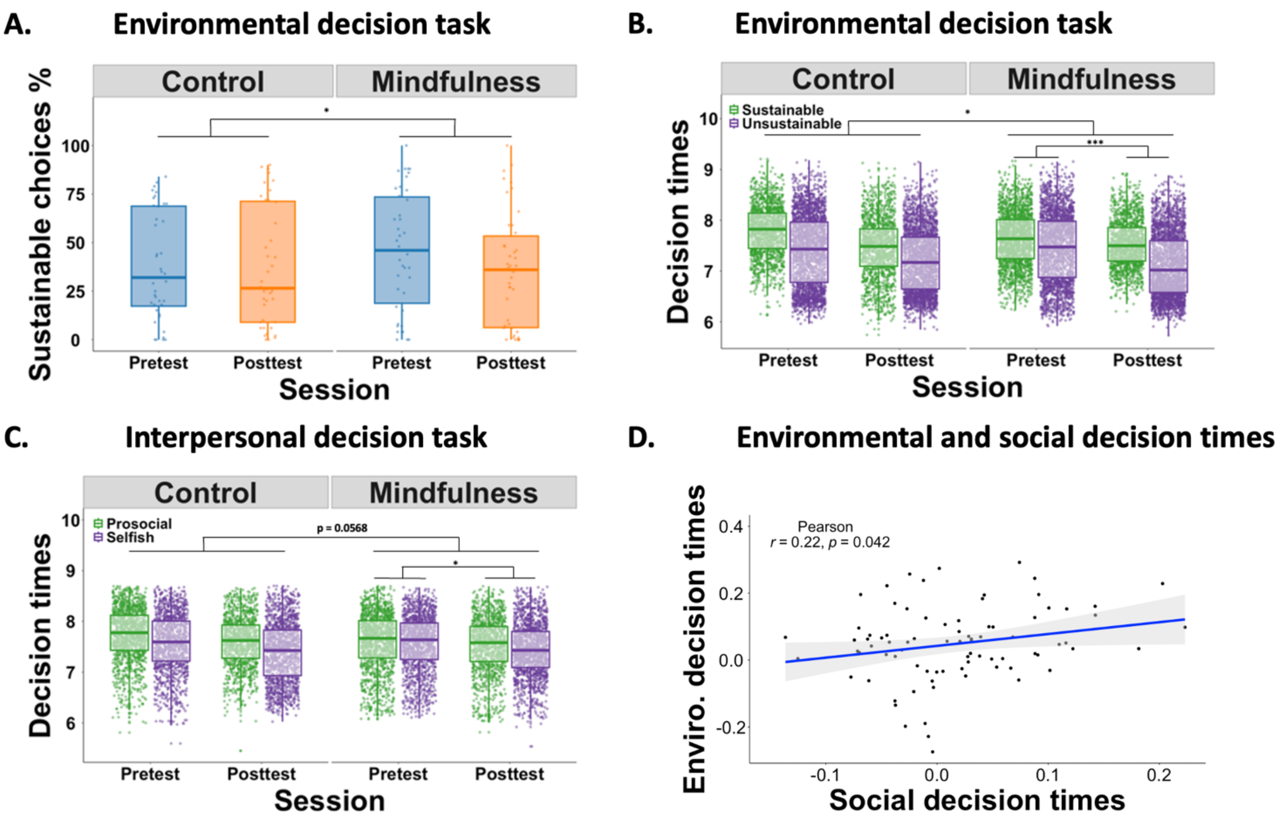

Figure 3. Mindfulness effects on the environmental decision task (A-B) and interpersonal choice (C) task. The mindfulness training, relative to the control training, (A) reduced sustainable choices in the post-test (orange) compared with the pre-test (blue), and (B) increased the decision time for unsustainable (purple) relative to sustainable (green) choices. (C) The mindfulness training also enhanced the decision time for selfish (purple) relative to social (green) choices, and this effect tended to be stronger in the mindfulness compared with the control group. Lastly, (D) the mindfulness effects on decision times in the pro-environmental and interpersonal decision task were positively correlated.

In addition to binary choices, we also analyzed decision times as a measure of the strength of participants' preference for sustainable over unsustainable options (with stronger preferences being indicated by faster decision times (Krajbich, Bartling, Hare, & Fehr, 2015)). The trainings differentially affected post-test relative to pre-test decision times for sustainable versus unsustainable choices, Group × Session × Choice: $\beta = 0.08$, $t(68)= 2.50$, $p = 0.01$. Separate GLMMs for each group suggested that the mindfulness training increased decision times for unsustainable relative to sustainable choices in the post-test relative to the pre-test, Session × Choice: $\beta = 0.09$, $t(32) = 4.66$, $p < 0.001$, whereas we observed no significant effects for the control training, $\beta = 0.01$, $t(35) = 0.28$, $p = 0.78$ (Figure 3B). Taken together, the mindfulness training, compared with the control training, increased the preference for unsustainable relative to sustainable outcomes.

To corroborate the finding that mindfulness training strengthens the preference for unsustainable options, we analyzed data in the environmental decision task also with hierarchical Bayesian DDMs. DDMs explain observed choices and decision times via an evidence accumulation process, where individuals accumulate evidence for the options from the starting point ζ until the strength of the accumulated evidence surpasses the decision boundary α. We assumed that the velocity ν of the accumulation process depends on the weighted influences of the rewards and reduction of carbon dioxide emissions on the choice process. Posterior predictive checks comparing simulated decision times (based on estimated DDM parameters) with observed decision times suggested that our model provided a reasonable account of the empirical data (Figure 4A). As to be expected, both the mindfulness and the control group accumulated evidence faster towards the unsustainable option the higher participants' payoff in the unsustainable option (mindfulness group: $HDI_{mean} = -1.12$, $HDI_{95\%} = [-1.44; -0.81]$; control group: $HDI_{mean} = -1.31$, $HDI_{95\%} = [-1.66; -0.99]$) as well as the smaller the difference in carbon dioxide emission reduction between the options (mindfulness group: $HDI_{mean} = -0.90$, $HDI_{95\%} = [-1.15; -0.47]$; control group: $HDI_{mean} = -0.77$, $HDI_{95\%} = [-1.06; -0.47]$). When we tested for significant training effects on DDM parameters, we found that the mindfulness intervention significantly shifted the starting point of the accumulation process towards the unsustainable option in the post-test relative to the pre-test, $HDI_{mean} = -0.05$, $HDI_{95\%} = [-0.08; -0.01]$, and this effect was significantly stronger than in the control group, $HDI_{mean} = -0.08$, $HDI_{95\%} = [-0.12; -0.03]$ (Figure 4B). In contrast, we observed no significant group differences between the influences of reward, HDI_{mean} = -

0.17, $HDI_{95\%}$ = [-0.61; 0.29], and of carbon dioxide emission on the drift rate, HDI_{mean} = 0.18, $HDI_{95\%}$ = [-0.14; 0.51], as well as on decision boundaries, HDI_{mean} = -0.05, $HDI_{95\%}$ = [-0.28; 0.20], and non-decision times, HDI_{mean} = -0.01, $HDI_{95\%}$ = [-0.14; 0.11]. Thus, the DDM analysis replicates the finding that the mindfulness training increased the preference for unsustainable options and provides insights into the subcomponent of the choice process that was altered by the mindfulness intervention.

In contrast to the environmental decision task, there were no significant training effects in the environmental donation task, β = 0.15, $t(80)$= 0.43, p = 0.67, or in pro-environmental attitudes measured by the NEP scale (Dunlap et al., 2000), β = -0.003, $t(80)$= 0.06, p = 0.96. The latter suggests that mindfulness training did not affect self-reported pro-environmental attitudes despite lowering choice-revealed preferences for sustainable outcomes in the environmental decision task.

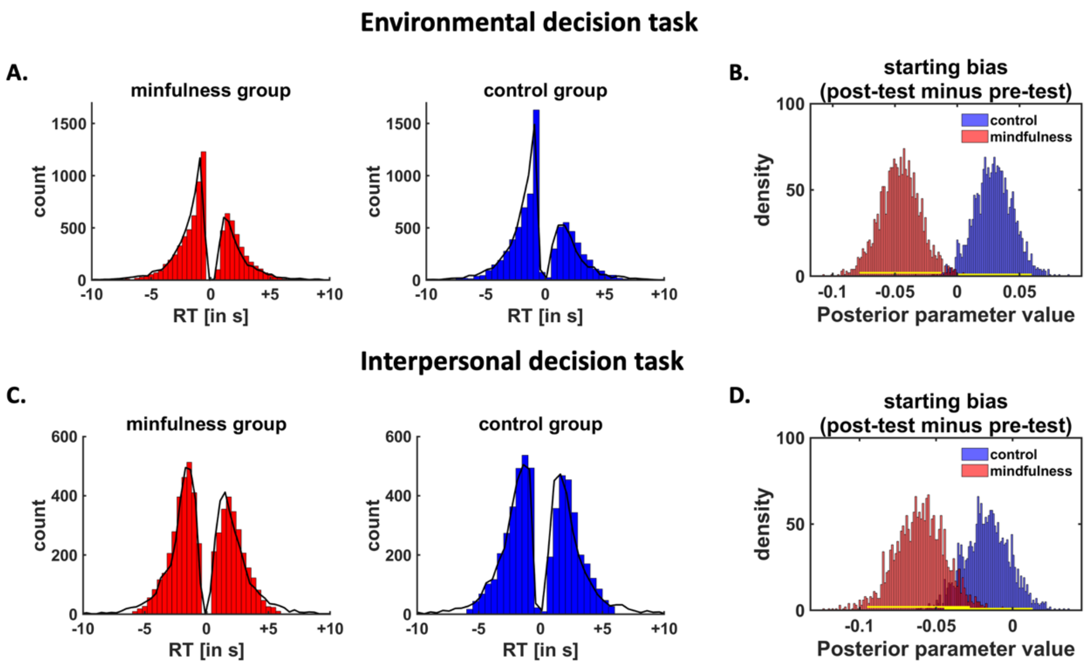

Figure 4. Illustration of the posterior predictive check and drift diffusion model results for the environmental decision task and interpersonal decision task. For the posterior predictive check,

simulated reaction times (based on estimated drift diffusion model parameters) were compared with observed decision times in the mindfulness and control group (A,C). The mindfulness training shifted the starting bias parameter towards unsustainable choices (lower decision boundary) in the environmental decision task (B) and towards selfish choices (lower decision boundary) in the interpersonal decision task (D) in the post-test relative to the pre-test.

Mindfulness training changed social but not future-oriented preferences

The unexpected direction of the impact of the mindfulness training on sustainability raises the question as to how the stronger preference for unsustainable options in the mindfulness group can be explained. Sustainable decisions are conceptually linked to prosocial and future-oriented preferences (Ericson et al., 2014; Thiermann & Sheate, 2020; Weber, 2017). Given the unexpected training effects on sustainability, we reasoned that (contrary to our original hypothesis) the mindfulness intervention might increase the preference for selfish or immediate options in the interpersonal and intertemporal decision tasks, respectively. Baseline preferences for sustainable rewards (pre-test) were significantly correlated with pre-test choices in the interpersonal, $\rho = 0.59$, $p < 0.01$, but not in the intertemporal decision task, $\rho = 0.049$, $p = 0.66$. In neither of these tasks, we observed significant training effects (Group × Session interactions) on binary choices, both $z < 0.07$, both $p > 0.94$, or on hyperbolic discount parameters, all $t < 0.49$, all p > 0.62. However, an analysis of decision times in the interpersonal decision task suggested that the trainings tended to have dissociable effects on post-test relative to pre-test decision times for prosocial versus selfish choices, Group × Session × Choice: $\beta = 0.05$, $t(64) = 1.94$, $p = 0.057$ (Figure 3C). Separate GLMMs for each group suggested that the mindfulness training increased decision times for prosocial relative to selfish choices in the post-test relative to the pre-test, Session × Choice: $\beta = 0.04$, $t(33) = 2.06$, $p = 0.047$, whereas the control training showed no effect, $\beta = -0.01$, $t(32) = 0.56$, $p = 0.58$. Thus, in analogy to the findings for the environmental decision task, the mindfulness training tended to increase the preference for selfish rewards in the interpersonal decision task. To identify whether there is a correlation between the mindfulness effects on decision times in the environmental and the interpersonal decision task, we correlated the model parameters capturing the training effects on decision times in these tasks, which revealed a small to moderate correlation, r = 0.22, p = 0.042 (Figure 3D). This suggests that stronger training-induced changes in interpersonal decisions were also associated with more pronounced training effects on sustainable decisions.

In analogy to the sustainability task, we again fitted Bayesian DDMs to the data in the interpersonal decision task and the posterior predictive checks in this task also suggested that our model provided a reasonable account of the empirical data (Figure 4C). Again, the mindfulness training affected the starting bias parameter (shifting the bias towards the selfish option), HDI_{mean} = -0.06, $HDI_{95\%}$ = [-0.09; -0.03], and this effect was significantly stronger in the mindfulness compared with the control group, HDI_{mean} = -0.04, $HDI_{95\%}$ = [-0.09; -0.00] (Figure 4D). The starting bias parameter in the baseline pre-test session was significantly correlated between the environmental and the interpersonal decision task, r = 0.41, $p < 0.001$, and also the training effects on the starting bias showed a trend-level positive correlation, r = 0.19, p = 0.08. The mindfulness training, relative to the control training, also significantly increased the decision boundary parameter, HDI_{mean} = 0.25, $HDI_{95\%}$ = [0.08; 0.43], suggesting that participants made more cautious decisions after the mindfulness training (i.e., accumulated more evidence before making a choice). No further parameter showed significant training effects in the interpersonal decision task. In the intertemporal decision task there were no significant differences in DDM parameter estimates between the mindfulness and the control group (all $HDI_{95\%}$ included zero). Taken together, the DDM and the model-free analyses provide converging evidence for stronger preferences for unsustainable and selfish rewards after the mindfulness compared with the control intervention.

The significant training effects on pro-environmental and interpersonal decisions raises the question as to whether the impact of the mindfulness training on pro-environmental preferences can be statistically explained by the training effects on social preferences. To test for such a mediation effect, we regressed individual parameters capturing the training effect on the starting bias in the pro-environmental decision task on predictors for Group (mindfulness versus control) and individual parameters for the training effect on the starting bias in the interpersonal decision task. While the effect of Group remained significant, $z = 4.60$, $p < 0.001$, bias parameters from the interpersonal decision task did not significantly explain variance in the pro-environmental decision task, $z = 0.33$, $p = 0.74$. Moreover, also the non-significant Sobel test (measuring the influence of the indirect mediation path) provided no evidence for a mediation effect, $p = 0.74$. Thus, our data do not support the assumption that mindfulness training affected pro-environmental preferences by increasing selfishness in interpersonal decisions.

Discussion

The goal of the present study was to test whether mindfulness enhances pro-environmental preferences via strengthening prosociality or future orientation. Contrary to our original hypotheses, the mindfulness training reduced preferences for sustainable outcomes in the environmental decision task (hypothesis 1) and prosocial outcomes in the interpersonal decision task (hypothesis 2) in both model-free and model-based analyses. In the model-free analyses, negative influences of mindfulness on pro-environmental preferences were evidenced by training effects on both choices and decision times, with longer decision times (indicating weaker preferences (Krajbich et al., 2015)) for sustainable versus unsustainable options after the mindfulness training. Our hierarchical Bayesian DDMs moreover provided insights into the subcomponent of the decision process underlying these effects: the mindfulness training shifted the starting point of the evidence accumulation process towards non-sustainable options without affecting the evaluation of reward magnitudes or action costs. Note though that we observed no training effects on the environmental donation task, potentially due to the limited number of trials in this task (only four donations compared with the 100 decisions in the pro-environmental decision task). In any case, our findings challenge theoretical accounts according to which mindfulness should be linked with stronger pro-environmental preferences (Ericson et al., 2014; Geiger et al., 2019). While this hypothesis was mainly based on correlative evidence (Geiger et al., 2019), intervention studies observed no direct mindfulness effects on self-report measures of pro-environmental behavior (Geiger et al., 2020). Eliciting pro-environmental preferences with a decision task involving real consequences for decision makers and environment, we show that a mindfulness intervention may even lower the preference for pro-environmental outcomes.

Interestingly, the mindfulness intervention unexpectedly also enhanced the preference for selfish over prosocial rewards in the interpersonal decision task (hypothesis 2). This finding appears to be at variance with a recent meta-analysis suggesting a positive connection between mindfulness and prosocial behavior (Donald et al., 2019). There are several possible explanations for this discrepancy: First, the negative results on sustainable and social behavior could in theory be attributed to the duration of the training, which assumes that a training length of thirty-one days (and only 15 mins a day) might be too short for the acquisition of relevant mindfulness skills. However, previous studies provide no evidence for an u-shaped relationship between training length and training effects on pro-environmental or prosocial preferences (Donald et al., 2019; Riordan et al., 2022). Second, previous mindfulness studies on prosociality mainly relied on self-report measures (Donald et al., 2019) or hypothetical scenarios (Berry, Cairo, Goodman, Quaglia, Green, & Brown, 2018), contrary to our task where sharing involved real monetary consequences for the participants and the benefitted others. Interestingly, one study reported mindfulness to increase acceptance rates for unfair offers in the ultimatum game (Kirk, Gu, Sharp, Hula, Fonagy, & Montague, 2016), which was interpreted as increased cooperativeness, although accepting unfair offers in the ultimatum game maximizes also a decision maker's selfish payoff; this, in turn, is consistent with our findings where mindfulness training strengthened the preference for options with larger selfish rewards. Taken together, the meta-analytical evidence for mindfulness effects on prosociality should be interpreted with caution, given the small number of experimental (compared with self-report) measures of prosociality involving real consequences for self and others. This is consistent with another meta-analysis (Kreplin, Farias, & Brazil, 2018), which previously questioned the beneficial effects of mindfulness interventions on prosocial behavior by showing that the effects of mindfulness trainings varied depending on the type of prosocial behavior studied (i.e., aggression, compassion, empathy, prejudice, or connectedness). Beneficial mindfulness effects were limited to compassion and empathy and were only observed in studies with methodological limitations, such as exclusively using passive controls and the mindfulness teachers being co-authors of the papers. It is further worth noting that the influence of mindfulness on social preferences may depend on personality variables like as how separate individuals perceive themselves from the others (Poulin, Ministero, Gabriel, Morrison, & Naidu, 2021). To summarize, we emphasize that our findings should not be misinterpreted as evidence that mindfulness generally promotes selfish or unsustainable behavior; instead, they suggest that the influence of mindfulness interventions on these variables may strongly depend on the employed outcome measures and the training characteristics (Schindler & Friese, 2022).

Prosocial and pro-environmental preferences were significantly correlated in the baseline pre-test session and also the intervention effects on these preferences tended to covary. While this supports the hypothesized link between pro-environmental and prosocial behavior (which so far relied only on self-report questionnaire measures (Pfattheicher et al., 2016)), it is important to note that we observed no evidence for a significant mediation effect. In other words, the current data do not allow concluding that the mindfulness training reduced pro-environmental preferences via increasing selfishness. Instead, the significant correlation but lack of a mediation effect speaks in favor of a third variable that was affected by the training and resulted in the observed training effects on pro-environmental and prosocial preferences. Mindfulness training was suggested to reduce habitual behavior (Ericson et al., 2014), but the current data provide no evidence that pro-environmental and pro-social decisions might represent the habitual responses in the current tasks (as participants chose the pro-environmental and pro-social options in only 42% and 50% of all pre-test decisions, respectively). We also observed no significant training effects on mood or working memory capacity, which were linked to pro-environmental and prosocial choices (Ericson et al., 2014; Langenbach, Berger, Baumgartner, & Knoch, 2020; Schulz, Fischbacher, Thöni, & Utikal, 2014). A further potential explanation for the correlated mindfulness effects on pro-environmental and social preferences is that mindfulness reduces feelings of guilt. According to Baumgartner et al. 2021, individuals who reported guilt after having been warned about the limited availability of resources were more likely to minimise resource depletion (pro-environmental decision) (Baumgartner, Lobmaier, Ruffieux, & Knoch, 2021). Likewise, another study showed that guilt increased cooperation in a social dilemma game that focused on shared electricity usage at home (Skatova, Spence, Leygue, & Ferguson, 2017). The mindfulness effects on both pro-environmental and prosocial preferences in our study might thus be related to reduced feelings of guilt (Frank, Fischer, Stanszus, Grossman, & Schrader, 2021), though this explanation remains speculative given that our study included no measure of guilt. We therefore recommend future studies to measure mindfulness effects on feelings of guilt associated with unsustainable choices. Moreover, a recent study suggests that the mindfulness effects depend on the specific aspect of the training, for instance, completing a module focused on compassion and loving kindness meditation, resulted mostly in higher compassion, whereas attention improved most after attention training (Trautwein et al., 2020). While our training involved only few sessions focusing on the relationship of the participant with others, trainings in other studies put more weight on such social aspects of mindfulness (Weng, Fox, Shackman, Stodola, Caldwell, Olson et al., 2013). In fact, mindfulness trainings focusing on self-centered aspects resulted in less pro-environmental intentions, while mindfulness interventions focusing on social or biospheric contents enhanced pro-environmental intentions (Tang, Geng, Schultz, Zhou, & Xiang, 2017). Given that most of our mindfulness exercises focused on self-centered contents, a mindfulness training focusing on social or biospheric contents might strengthen instead of weaken pro-environmental and prosocial preferences (Dahl, Lutz, & Davidson, 2015; Dorjee, 2016). Thus, we recommend to increase the number of meditation sessions targeting prosocial activities such as loving kindness and to include more nature components to the training, either in the training itself, for instance by including natural sounds or introducing reflection tasks related to participants` connections with nature, or even leading the mindfulness exercises in nature. This is supported by Barbaro et al. 2016 who posited that the connectedness to nature might mediate the relationship between mindfulness and pro-environmental behavior (Barbaro & Pickett, 2016) , but this too remains speculative given that we did not assess individual differences in connectedness to nature. Lastly, it might be beneficial to understand who benefits the most of the mindfulness intervention. Therefore, we recommend future studies to identify participants who are more responsive to mindfulness training related to environmental behavior by considering inter-individual differences, such as socio-economic status, individual stress-level or personality traits, which have been shown to predict individuals preference for a mindfulness type (De Vibe, Solhaug, Tyssen, Friborg, Rosenvinge, Sørlie et al., 2015; Tang & Braver, 2020). While the current data cannot provide a conclusive answer to the question of why the mindfulness intervention reduced pro-environmental and prosocial preferences, they nevertheless provide evidence that mindfulness might not necessarily lead to more pro-environmental behavior, contrary to theoretical assumptions.

Our study revealed no mindfulness effects on future-oriented preferences measured with the intertemporal decision task, which may be unsurprising given the inconsistent mindfulness effects on time preferences in previous studies (Hendrickson & Rasmussen, 2013; Morrison et al., 2014; Smith, Panfil, Bailey, & Kirkpatrick, 2019). Here too, heterogeneity in administered tasks, specific contents of the mindfulness training, and baseline time preferences (participants chose the larger-later option in 75% of all baseline decisions, leaving little room for training effects to further increase patience) may play a crucial role for determining the influence of a mindfulness intervention on time preferences.

Taken together, we provide evidence that a mindfulness intervention can reduce pro-environmental and prosocial preferences and that the influences of mindfulness on these preferences might be correlated. This challenges existing theories about the positive impact of mindfulness on pro-environmental and prosocial behavior and suggests that the effects of mindfulness on sustainable and social behavior might be more complicated than previously assumed based on correlative evidence. The current findings moreover advance our understanding of the psychological mechanisms underlying pro-environmental decision by showing that these appear to be more strongly linked to prosociality than to future orientation. These insights into the psychological determinants of pro-environmental decision may deepen the understanding of the reasons why humans often fail to act sustainably despite their best intentions and pave the ground for designing interventions for promoting sustainability.

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Data availability statement

The behavioral raw data supporting the findings of this study and data analysis code are available on Open Science Framework under the following link (https://osf.io/dmrtn/).

Additional information

Competing interests statement

The authors declare to have no competing interests.

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3. Chapter II: Environmental and social decisions share neural mechanisms

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Environmental and social decisions share neural mechanisms

Zarah Le Houcq Corbi[1], Didem Taşkıran[1], and Alexander Soutschek[1]

[1]Department of Psychology, Ludwig-Maximilians-Universität München, Munich

Author contributions:

ZLHC and AS designed research; ZLHC and DT performed research; ZLHC and DT analyzed data; ZLHC and AS wrote manuscript with contributions from DT; all authors approved the final manuscript version

Corresponding author:
Zarah Le Houcq Corbi
Department for Psychology
LMU Munich
Leopoldstr. 13, 80802 Munich, Germany
Email: zarah.lehoucq@psy.lmu.de

Abstract

Previous evidence suggests a link between pro-environmental decisions and prosociality, but it remains unknown whether pro-environmental and prosocial decisions rely also on common neural mechanisms. Here, we tested the hypothesis that the neural correlates of pro-environmental decisions overlap with brain regions involved in prosociality - including the temporoparietal junction (TPJ) - but not in future orientation. To test this hypothesis, we used functional magnetic resonance imaging on 35 healthy participants performing pro-environmental, prosocial, and future-oriented (intertemporal) decision tasks. As expected, environmental and social decision-making showed overlapping neural activation in regions belonging to the mentalizing network, including the TPJ, whereas we observed no shared activation between environmental and intertemporal decisions. In addition, the TPJ moderated the attitude-behavior gap: increasing TPJ activation was associated with lower attitude-behavior gaps. Taken together, our findings provide insight into the neuro-cognitive processes of pro-environmental decision-making by suggesting that environmental decisions share neural mechanisms with social preferences and by elucidating the role of the TPJ in the attitude-behavior gap.

Keywords: fMRI, pro-environmental behavior, prosociality, future orientation, attitude-behavior gap.

Introduction

Climate change is a substantial challenge in our society, with individual consumption contributing up to 60% of the total greenhouse gas emissions (Ivanova et al., 2016). Therefore, understanding the neuro-cognitive mechanisms underlying individuals' pro-environmental behavior is crucial for creating successful interventions and policies. On the psychological level, pro-environmental behavior was linked to prosociality and future orientation (Pfattheicher et al., 2016; Weber, 2017). Consistent with this, previous neuroscientific studies revealed that pro-environmental behavior is related to activation in brain regions that are also involved in prosocial and future-oriented decision making, including the prefrontal and parietal cortex (Baumgartner et al., 2019; Bellucci, Camilleri, Eickhoff, & Krueger, 2020; Carter, Meyer, & Huettel, 2010; Guizar Rosales et al., 2022; Langenbach et al., 2022; McClure et al., 2004; Rilling & Sanfey, 2011; Strombach et al., 2015; Van Overwalle, 2009; Wesley & Bickel, 2014). However, no previous study has directly tested whether pro-environmental decision-making relies on brain mechanisms involved in social or future-oriented decisions. To fill this gap, the current study employed functional magnetic resonance imaging (fMRI) to compare the neural correlates of pro-environmental, social, and future-oriented decisions. In addition, we aimed to investigate whether the brain mechanisms underlying prosociality and future orientation contribute to the so-called attitude-behavior gap. The attitude-behavior gap refers to the phenomenon that, although most people acknowledge the seriousness of climate change and show positive attitudes towards sustainability, they rarely act upon these attitudes (Kollmuss & Agyeman, 2002). Determining the neural mechanisms underlying this attitude-behavior gap may improve our understanding of why people often fail to act in accordance with their pro-environmental attitudes.

Prosociality was hypothesized to foster pro-environmental behavior because acting pro-environmentally requires people to weigh their selfish interests against preserving natural resources, which primarily benefits others and in particular future generations (Gladwin et al., 1995). This notion is supported by empirical evidence showing a positive correlation between self-reported pro-environmental attitudes and compassion, with the latter being related to prosociality (Batson & Shaw, 1991; Eisenberg & Miller, 1987; Pfattheicher et al., 2016). In line with this, we recently showed that pro-environmental decisions positively correlate with prosocial decisions in experimental tasks with real-world consequences (Le Houcq Corbi, Koch, Hölzel, & Soutschek, 2024). However, we observed no evidence for an association between pro-environmental and future-oriented decisions (Le Houcq Corbi et al., 2024), contrary to theoretical claims according to which pro-environmental behavior should relate to future-orientation (Weber, 2017). These accounts relied on the intuition that pro-environmental behavior requires restraining from immediate temptations (like indulging in a long shower or going by car) to achieve long-term pro-environmental goals (Weber, 2017). The finding that pro-environmental decisions correlate with prosocial but not future-oriented behavior raises the question as to whether, on the neural level, pro-environmental decisions involve brain regions implementing prosociality rather than regions linked to future orientation.

A brain region that plays a key role in prosocial decisions is the temporo-parietal junction (TPJ). The TPJ was shown to promote prosocial over selfish behavior by enabling decision-makers to shift their perspective to the needs of others (Christian et al., 2023; Hutcherson et al., 2015; Soutschek et al., 2016; Strombach et al., 2015; Van Overwalle, 2009). In line with the hypothesized link between pro-social and pro-environmental decisions, excitatory brain stimulation of the TPJ resulted in higher frequency of pro-environmental choices, revealing a causal contribution of the TPJ to pro-environmental decision-making (Langenbach et al., 2022). Pro-environmental decisions were further related to the dorsolateral (DLPFC) and dorsomedial prefrontal cortex (DMPFC) (Baumgartner et al., 2019; Guizar Rosales et al., 2022). Both of these regions are also involved in social decision-making (Bellucci et al., 2020; Christian, Kaiser, Taylor, George, Schütz-Bosbach, & Soutschek, 2024; Christian & Soutschek, 2022; Hill, Suzuki, Polania, Moisa, O'doherty, & Ruff, 2017; Knoch, Pascual-Leone, Meyer, Treyer, & Fehr, 2006), though at least the DLPFC was also associated with future orientation in intertemporal choice (McClure et al., 2004; Yang, Völlm, & Khalifa, 2018). Taken together, the existing neural evidence supports the view that overlapping brain regions might be involved in pro-environmental and prosocial decisions.

A further goal of our study was to investigate whether brain mechanisms related to pro-sociality and future orientation moderate the attitude-behavior gap. While previous research suggests that future-oriented individuals tend to display behaviors that are better aligned with their attitudes (Gu, Jiang, Zhang, Sun, Jiang, & Du, 2020), a recent review highlights social cognition to be the most important factor for the attitude-behavior gap in pro-environmental decision-making (Grandin et al., 2021). It therefore seems plausible to assume that brain mechanisms associated with prosociality, rather than future orientation, moderate the attitude-behavior gap. Given the TPJ's key role in social decision-making (Christian et al., 2023; Hutcherson et al., 2015; Soutschek et al., 2016; Strombach et al., 2015; Van Overwalle, 2009), we hypothesize that the TPJ will modulate the attitude-behavior gap, with higher TPJ activation predicting a stronger alignment between individuals' pro-environmental attitudes and pro-environmental decisions (smaller attitude-behavior gap).

To test our hypotheses, participants performed in the MRI scanner a pro-environmental decision task – the environmental donation task – as well as an interpersonal decision task and an intertemporal decision task as measures of prosociality and future orientation, respectively. We expected to replicate our previous behavioral findings that pro-environmental preferences are more strongly correlated with social compared to future-oriented preferences (hypothesis 1). This should be mirrored on the neural level by an overlap between the neural correlates of pro-environmental and social decisions (including the TPJ), whereas we expected to see no overlap between pro-environmental and intertemporal decisions (hypothesis 2). Lastly, we expected TPJ activity to moderate the attitude-behavior gap (hypothesis 3). As hypothesized, our results showed a correlation between pro-environmental and social decisions, an overlap between the neuronal correlates of environmental and social decisions, and a moderating influence of TPJ activation on the attitude-behavior gap. Together, our findings deepen our understanding of the neural mechanisms underlying environmental decisions.

Materials and Methods

Participants

Forty-two participants were recruited, and seven participants had to be excluded due to either premature termination of the study or technical issues. The final sample included thirty-five participants (mean age = 26.2 years; standard deviation = 2.74 years; 11 females, 24 males). Participants were mostly university students and had normal or corrected-to-normal vision, no history of psychological or neurological disorders, and were screened for fMRI participation criteria. Before participation, the participants gave written informed consent. The study was approved by the ethics committee of the Ludwig Maximillian University of Munich (46_Soutschek_a). Participants were compensated with 30€ plus a decision-dependent bonus of up to 10€ (see below).

Stimuli and task design

The study was divided into two parts, the first taking place outside the scanner, where participants completed the self-reported sustainability questionnaire, practiced the tasks performed in the scanner, and performed the CO_2 emission task (which was executed only outside the scanner). During the second part, participants performed an environmental donation task, an interpersonal decision task, and an intertemporal decision task inside the fMRI scanner.

In the *environmental donation task*, participants had to decide between a sustainable and an unsustainable option. Participants were informed that they could receive €10 from us in addition to their payment. The sustainable option entailed a variable split from this €10 endowment between the participant and a donation to an environmental organization (e.g., €4 for the participant, €6 for the organization). In contrast, if participants chose the unsustainable option, they would receive the total amount of €10, and no money would be donated to an environmental organization (Figure 1A). Before starting the task, the participants were given short descriptions of the goals and values of the environmental organizations, which were extracted from the official websites of each organization. The following six organizations were included: WWF (World Wide Fund For Nature), NABU (Nature And Biodiversity Conservation Union), BUND (Bund für Umwelt und Naturschutz Deutschland, German for "German Federation for the Environment and Nature Conservation"), Primaklima, Rewilding Europe, and Environmental Action Germany. To ensure that the descriptions were read and understood, the participants were given a set of multiple-choice questions about the organizations outside the scanner. In this and all other tasks performed in the scanner, the options were displayed for 5 seconds and randomly presented on the left or right side of the screen (Figure 1D); participants had to indicate their choices by pressing the corresponding key (left or right) on an MRI-compatible button box. Following a choice, the option turned red until the end of the stimulus presentation time. Jittered inter-trial intervals, derived from a Poisson distribution (mean = 3s, minimum = 0.5s), were used to separate the trials.

In the *interpersonal decision task* (Jones & Rachlin, 2006; Soutschek et al., 2016; Strombach et al., 2015), participants were asked to imagine a scale ranging from 0 to 100, which indicated the degree of closeness between them and other people in their lives (i.e., social distance). On this scale, "0" represented the participant, "10" a person they were very close to (e.g., their mother), "50" a person they encountered repeatedly but did not know their name, and "100" a total stranger they could run across on the street. During the task, participants chose between a selfish option where only the individual with closer social distance (i.e., themselves or a close other at social distance 10 or 20) would receive a monetary reward and a prosocial option where a fixed amount of 10 euros was split equally between a person with a close social distance and another person at a higher social distance (e.g., "8.5 euros for participant" versus "5 euros for both the participant and the person at social distance 50", Figure 1B). The reward of the selfish option ranged from 5 to 10 € in steps of 0.5 and we used the social distances of 0, 10, or 20 for close distances and 1, 10, 20, 50, and 100 for higher distances. Stimulus timing and key-response assignment (left and right key for option presented on left and right screen side, respectively) were identical to the environmental donation task.

In the *intertemporal decision task*, participants chose between a larger-later (LL) and a smaller-sooner (SS) reward (e.g., "5 euros in 40 days" versus "2 euros today", Figure 1C). The larger reward was fixed at 5 euros and was delivered at a delay ranging from 10-360 days, whereas the smaller reward ranged from 0.5-5 euros (in steps of 0.5) and was delivered at a delay of 0-90 days. Stimulus timing and key-response assignment (left and right key for option presented on left and right screen side, respectively) were identical to the environmental donation task.

In the scanner, participants performed a total of five runs, each run including three miniblocks for each task with six trials per miniblock, resulting in a total of 90 trials for each task. The task order of the mini blocks was pseudo-randomized across all runs.

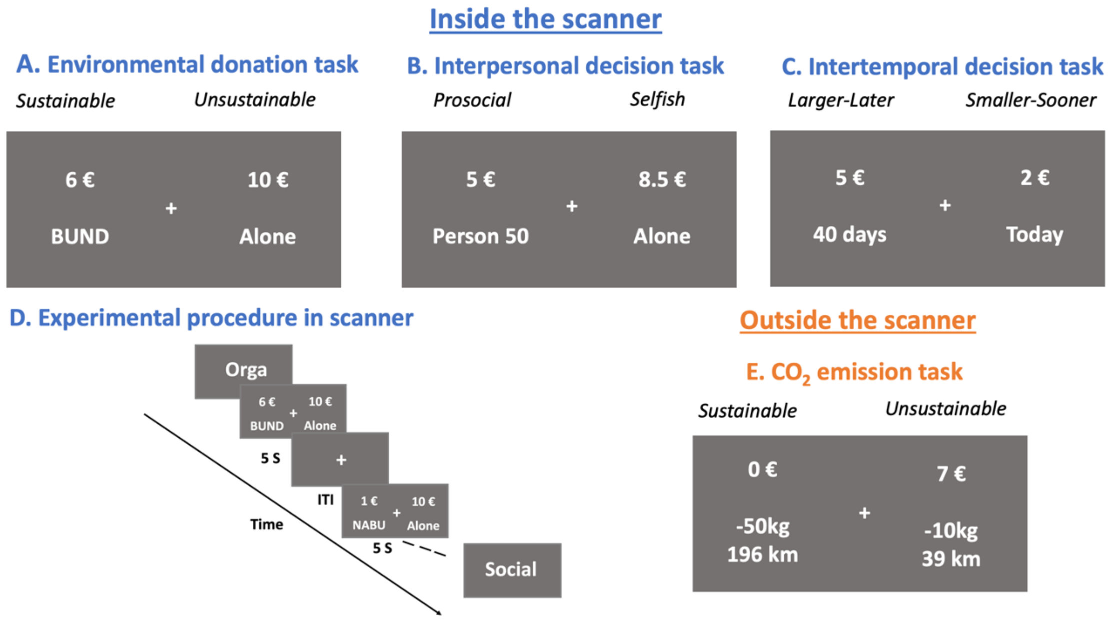

Figure 1. Illustration of decision tasks and experimental procedure inside the scanner (A-D), and the behavioral decision task outside the scanner (E). Inside the fMRI, participants performed (A) the environmental donation task, where they chose between a sustainable option (donating money to an environmental organization) and an unsustainable option (keeping the money to themselves), (B) the interpersonal decision task, which required choices between a prosocial option (sharing money with another person) and a selfish option (keeping money to themselves or someone close), and (C) the intertemporal decision task that required choices between larger-later and smaller-sooner rewards. (D) On each trial, the options for the corresponding task (A-C) were displayed for five seconds, during which participants had to indicate their response. Trials were separated by jittered inter-trial intervals. Participants performed a total of five runs, each with three mini-blocks for the three tasks. At the start of a miniblock, the upcoming task was briefly announced by a task cue (e.g. "Social"). (E) Outside the scanner, participants conducted the CO_2 emission task (E), where they decided between a sustainable option (reducing CO_2, but no reward) and an unsustainable option (reward, but lower amount of CO_2 reduced).

In addition, participants performed a *CO_2 emission task* outside the scanner (Figure 1E). In this task (Berger & Wyss, 2021), participants faced conflicts between gaining no monetary reward but reducing larger amounts of CO_2 emission (1-50 kg) (sustainable option) versus gaining various monetary rewards (1-10 euros) while reducing smaller amounts of CO_2 (0-10kg) (unsustainable option). As for the tasks in the scanner, options were randomly displayed on the left or right screen side; participants chose their preferred option by pressing the corresponding left or right arrow key. To illustrate to participants the real-world consequences of their choices, the amounts of reduced CO_2 emissions were translated into the number of kilometers an average car has to drive to emit the given amount of CO_2. In addition, participants were given some references to help them understand the magnitude of the kg amounts. For example, they were informed that a flight from Munich to Rome emits around 140 kg of CO_2. Decisions had real consequences for participants' payoff and the environment, since for choices including a CO_2 reduction, we bought CO_2 certificates for the selected amount and destroyed them, thereby removing them from the European Emissions Trading System and reducing real-life CO_2 emissions.

At the end of the experiment, one trial was randomly selected from the environmental donation task, intertemporal decision task, and CO_2 emission task. Participant's responses in the chosen trial determined whether the money was donated to the respective organization, the participant received an extra monetary reward (in the moment or in the future), or a CO_2 certificate was purchased. Unbeknownst to participants, the interpersonal decision task could not be included in the random selection due to data protection issues.

Self-reported sustainability. To evaluate participants' pro-environmental attitudes, we used the well-established New Environmental Paradigm (NEP) scale which includes statements about the human-environment relationship (Dunlap et al., 2000).

MRI data acquisition

Images were acquired using a Siemens Magnetom Prisma 3 T scanner with a 64-channel head coil at the NeuroImaging Labor at the City Centre Campus of LMU Munich, Germany (NICUM). Across five runs, T2*-weighted echo-planar images (EPIs) were obtained by using a blood-oxygen-level-dependent (BOLD) contrast with a repetition time of 1 s. 48 slices were acquired with the following parameters; echo time = 30 ms; field of view = 240 mm, slice thickness = 3 mm, interslice gap = 0.3 mm. In addition, T1-weighted structural images (voxel size = 0.8 mm) were acquired from each participant. High-resolution structural scans were coregistered to their mean EPIs and averaged together to allow anatomical localization of the functional activations at the group level.

The stimuli were projected onto a screen at the back of the MRI machine and were presented to the participants via a mirror that was attached to the head coil. For the stimulus presentation, Matlab (MathWorks) and the Cogent Toolbox (Cogent, http://www.vislab.ucl.ac.uk/Cogent/) were used. Participants gave responses with their index and middle fingers using a button box placed under their dominant hand. Participants' head movements in the scanner were minimized with pads.

Data analysis

Behavioral analysis. Behavioral analyses were conducted with R version 4.3.2. To test for the hypothesized correlations between environmental, social, and intertemporal choices, we computed Spearman rank-order correlations between mean choices in these tasks. To compare the correlation coefficients, we used the Fisher's Z transformation approach. To replicate our previous finding that pro-environmental choices show a stronger correlation with prosocial than with intertemporal choices (Le Houcq Corbi et al., 2024), we employed one-tailed tests.

Imaging analysis. Analysis of neuroimaging data was conducted with SPM12 in Matlab (www.fil.ion.ucl.ac.uk/spm). Participants' functional images underwent motion correction, unwarping, slice-timing correction (temporally corrected to the first image), and co-registration with the anatomical image. After segmentation, we spatially normalized the data into standard MNI space. Lastly, a 6 mm FWHM Gaussian kernel was used to smooth the data, and a high-pass filter (filter cutoff = 128 seconds) was applied.

For the first-level analysis, we conducted two separate general linear models (GLMs). GLM-1 included separate onset regressors for the environmental donation task, intertemporal decision task, and interpersonal decision task (irrespective of the chosen option), whereas GLM-2 included separate onset regressors for each choice type: larger-later, smaller-sooner, sustainable, unsustainable, prosocial, and selfish decision. The duration of the onset regressors was defined as the decision time in the given trial. In all models, we included 6 movement (3 translation and 3 rotation) parameters as covariates of no interest. We convolved regressors with the canonical hemodynamic response function implemented in SPM.

For the first-level analysis at the task level, we computed the following participant-specific contrasts comparing activation between tasks in GLM-1: (i) environmental donation task > intertemporal decision task, (ii) interpersonal decision task > intertemporal decision task, and iii) environmental donation task > interpersonal decision task, and the corresponding reversed contrasts. At the choice level (GLM-2), we computed participant-specific contrasts comparing activation between choices: (i) larger-later > smaller-sooner, (ii) sustainable > unsustainable, iii) prosocial > selfish, and the corresponding reversed contrasts. For the second-level analysis, we then entered the contrast images into a between-participant, random effects analysis and performed whole-brain second-level analyses with one-sample *t*-tests. For these analyses, we report results that survive whole-brain family-wise error (FWE) corrections at the cluster level ($p < 0.05$; cluster-inducing threshold $p < 0.001$ uncorrected). The individual voxel threshold for the figures was set at $p < 0.001$, with a minimal cluster extent of $k \geq 20$ voxels. Results are reported in the MNI coordinate system.

To determine brain regions that are activated during both environmental and social decisions, we performed a conjunction analysis for the two contrasts “environmental donation task > intertemporal decision task” and “interpersonal decision task > intertemporal decision task” on the second level (voxel threshold was set at $p < 0.001$ uncorrected, minimal cluster size $k \geq 20$ voxels).

Lastly, to determine whether the TPJ modulates the attitude-behavior gap, we first extracted participant-specific parameter estimates from the significant TPJ cluster for the contrast “environmental donation task > intertemporal decision task” using the Marsbar toolbox (Brett, Anton, Valabregue, & Poline, 2002). Next, we conducted generalized linear mixed models (GLMMs) that regressed binary choices in the environmental donation task and CO_2 emission task on fixed-effect predictors mean NEP questionnaire scores (self-reported pro-environmental attitudes), participant-specific TPJ activation, and the interaction term in addition to participant-specific random intercepts.

Results

Environmental choices are associated with social but not with future-oriented preferences

We first aimed to replicate our previous findings that environmental choices correlate with social but not future-oriented decisions (Le Houcq Corbi et al., 2024). Also in the current sample, environmental donations showed a positive correlation with social choices, Spearman’s $\rho = 0.3$, $p = 0.04$, but not with future-oriented choices, Spearman’s $\rho = -0.2$, $p = 0.86$ (Figure 2). When directly comparing these correlation coefficients, the correlation of pro-environmental choices with prosocial choices was significantly stronger than with future-orientation decisions, $z = 2.0$, $p = 0.02$. This replicates our previous findings of a stronger link between pro-environmental and prosocial decisions compared to future-oriented decisions.

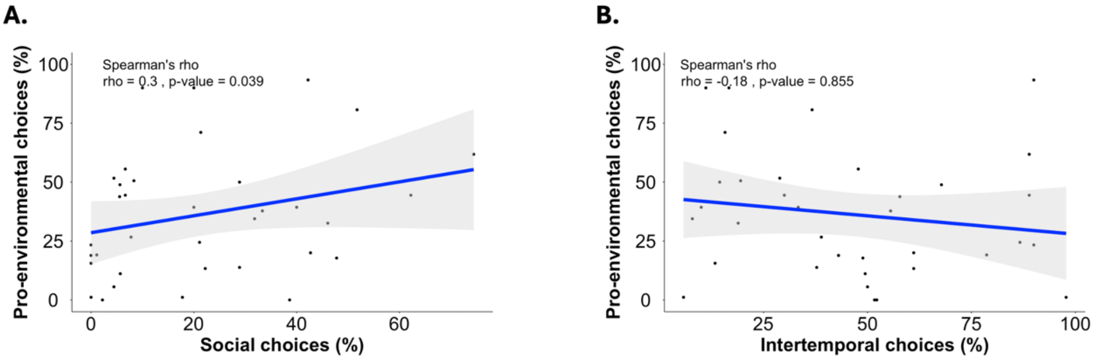

Figure 2. Correlations between mean choices in the environmental donation, interpersonal decision, and intertemporal decision task. Environmental choices were significantly correlated with social choices, but not with intertemporal choices.

Neural correlates of environmental, social, and future-oriented decisions

Based on these behavioral findings, we next asked whether the closer association between pro-environmental and prosocial compared to future-oriented decisions is also reflected at the neural level. When we tested for brain regions showing stronger activation during environmental compared with intertemporal choices (GLM-1), we found significant clusters in the bilateral TPJ, precuneus, anterior cingulate cortex, DMPFC, and right insula, FWE-corrected at cluster level, all $p < 0.03$ (Table 1, Figure 3). In contrast, intertemporal compared to environmental decisions yielded stronger activation only in the posterior parietal lobe, FWE-corrected at cluster level, $p = 0.03$ (Table 1). A similar result pattern emerged when we compared interpersonal with intertemporal decisions: we observed higher activation in the precuneus, bilateral TPJ, bilateral DLPFC, and right cerebellum, FWE-corrected at cluster level, all $p < 0.02$ (Table 1, Figure 3). In contrast, no regions showed enhanced activation for intertemporal compared with interpersonal decisions (Table 1). Furthermore, environmental compared with social choices showed higher activation in the left temporal fusiform gyrus and left TPJ, FWE-corrected at cluster level, all $p < 0.05$, whereas social compared to environmental choices showed stronger activation in the bilateral DLPFC, parietal cortex, right precentral gyrus and left cerebellum FWE-corrected at cluster level, all $p < 0.02$. However, when we assessed whether activation in these tasks depended on the chosen option (i.e., sustainable versus unsustainable, prosocial versus selfish, and larger-later versus smaller-sooner option; GLM-2), we observed no significant effects (all $p > 0.42$, FWE-corrected at cluster level). Taken together, the current findings suggest that several regions, including the TPJ, show enhanced activation during both environmental and social decisions compared to intertemporal decisions.

Next, we assessed whether the neural correlates of environmental and social decisions overlap. As hypothesized, the conjunction analysis revealed clusters in the bilateral TPJ as well as in the precuneus, and anterior cingulate cortex, FWE-corrected at cluster level, all $p < 0.01$ (Table 2, Figure 3). This suggests that overlapping brain regions correlate with environmental and social decisions, mirroring our results on the behavioral level.

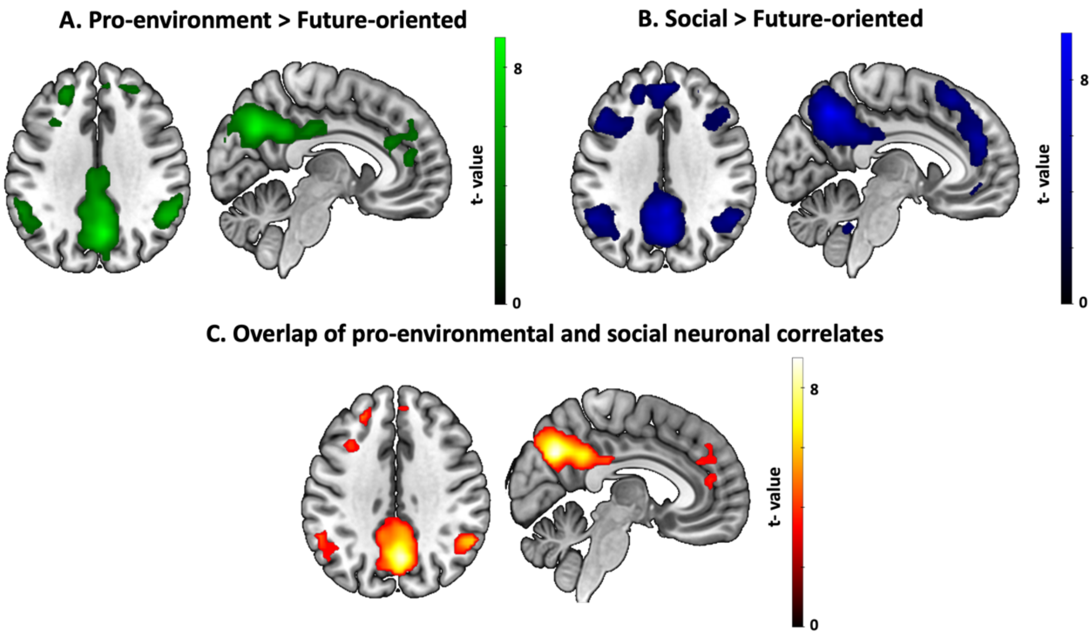

Figure 3. Neuronal correlates of (A) environmental > intertemporal decision-making, (B) social > intertemporal decision-making, and (C) the overlap between these contrasts. All figures are based on the threshold $p < 0.001$ uncorrected.

Right TPJ modulates the attitude-behavior gap

Given the TPJ's role for both environmental and social decision-making, we tested whether individual differences in right TPJ activation moderated the relationship between pro-environmental attitudes (measured with the NEP questionnaire) and pro-environmental choices. For this purpose, we extracted individual parameters estimates from the right TPJ cluster for the contrast environmental donation task > intertemporal decision task. We then regressed binary pro-environmental choices in the environmental donation task on NEP scores, TPJ parameter estimates, and the interaction term. TPJ activity negatively correlated with sustainable versus unsustainable decisions in the environmental donation task, $\beta = -0.55$, $z = 2.02$, $p = 0.04$, suggesting that the TPJ showed stronger activation during environmental decisions in individuals with a higher frequency of non-sustainable compared to sustainable choices. Consistent with our moderation hypothesis, TPJ activation also moderated the influence of pro-environmental attitudes on sustainable decisions, $\beta = 1.01$, $z = 3.15$, $p = 0.002$ (Figure 4A): Enhanced TPJ activation during environmental decisions was associated with stronger, more positive alignment between attitudes (NEP score) and pro-environmental choices, which indicates a weaker attitude-behavior gap. Strikingly, we observed a moderating influence of TPJ activation also when we assessed pro-environmental decisions via the CO_2 emission task that was performed outside the scanner and has weaker conceptual links to social decisions than the donation task as it measures the trade-off between rewards and lowering CO_2 emissions. In analogy to the environmental donation task, increasing TPJ activation was associated with stronger alignment between participants' attitudes and decisions to reduce CO_2 emissions, $\beta = 0.74$, $z = 2.21$, $p = 0.03$ (Figure 4B). Together, the current results provide evidence that TPJ activation during environmental choices moderates the attitude-behavior gap.

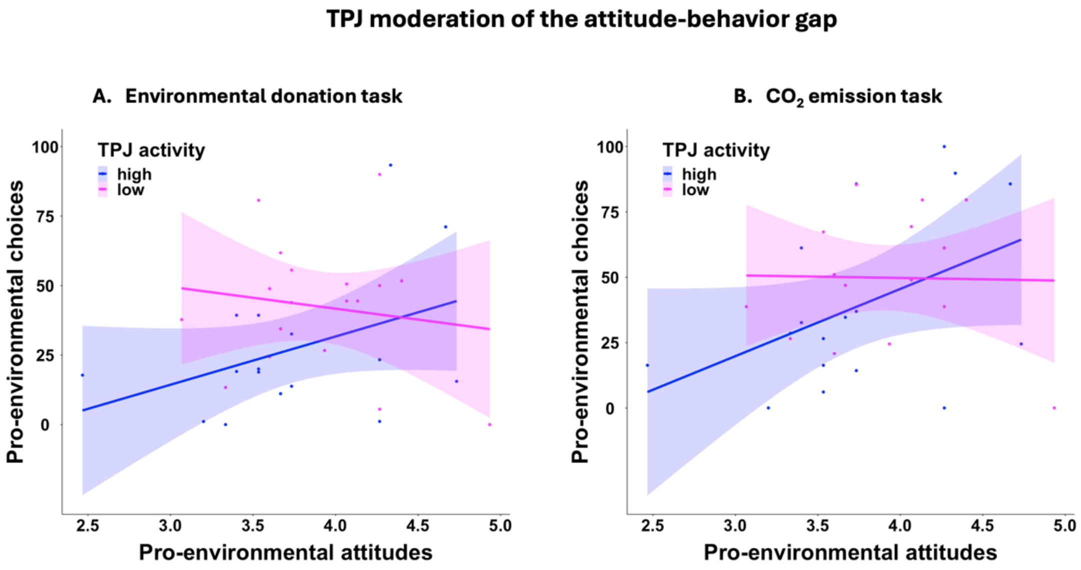

Figure 4. The TPJ moderates the attitude-behavior gap in both (A) the environmental donation task and (B) the CO_2 emission task. Increasing TPJ activation during environmental decisions was associated with stronger, more positive relationships between pro-environmental attitudes (NEP scores) and pro-environmental decisions. For illustration purpose, we split the sample into low and high TPJ activation groups at the median. *TPJ = temporo-parietal junction.

Discussion

The development of policies and strategies for promoting environmentally conscious lifestyles may benefit from a better understanding of the neuro-cognitive mechanisms underlying pro-environmental behavior. Here, we provide both behavioral and neural evidence that environmental preferences are more closely linked to prosocial than to future-oriented preferences. On the behavioral level, we replicated our previous findings that pro-environmental decisions show a significantly stronger correlation with prosocial decisions than with future-oriented decisions (Le Houcq Corbi et al., 2024). Importantly, this association between environmental and social decision-making was also reflected on the neural level: Environmental compared to intertemporal decision-making correlated with enhanced activation in the DMPFC, precuneus, and TPJ, and the latter two regions showed overlapping activation during social compared to intertemporal choices. In contrast, no brain region exhibited increased activation during intertemporal compared to social decision-making. Furthermore, intertemporal compared to environmental decisions showed enhanced activation in the posterior parietal lobe, and environmental compared to social choices were associated with activation in the left TPJ and fusiform gyrus. Taken together, the behavioral and neural findings suggest that environmental decisions are more closely related to prosociality than to future orientation. As caveat, we note that these results are based on comparisons between task-related activations. We observed no significant choice-dependent (i.e., sustainable versus unsustainable choices) activations in the environmental donation task. While the current findings do not allow concluding that the observed TPJ and precuneus clusters are related to sustainable rather than unsustainable choices, they nevertheless support our hypothesis that environmental decisions correlate with activation in brain regions involved in social decision-making. Our results are thus consistent with theoretical accounts positing a relationship between pro-environmental and social choices (Pfattheicher et al., 2016), but do not support alternative accounts assuming a link between pro-environmental and future-oriented decision-making (Weber, 2017).

The current findings moreover provide insights into the neural mechanisms underlying the attitude-behavior gap in pro-environmental decision-making. The TPJ moderated the strength of the relationship between pro-environmental attitudes and pro-environmental decisions, with increasing TPJ activation being associated with smaller attitude-behavior gaps (i.e., stronger correlations between attitudes and pro-environmental choices). This effect was also observed in another pro-environmental decision task conducted outside the scanner, where participants faced non-social trade-offs between selfish rewards and CO_2 reduction, such that the TPJ activation in the moderation analysis was independent of the choices made in this task. Given the role of the TPJ in perspective-taking – the ability to adopt the viewpoint of others (Frith & Frith, 2006) – we speculate that individuals with stronger TPJ activation during environmental decisions might better align their attitudes and behavior due to simulating the consequences of their decisions for the environment and others. We also found that lower TPJ activation was associated with more pro-environmental choices independently of an individual's attitude. This might imply that highly pro-environmental individuals do not need to recruit perspective-taking processes in the TPJ to simulate the consequences of their decisions as they might experience little conflict between selfish and pro-environmental options. Taken together, our results highlight the role of the TPJ in moderating the attitude-behavior gap in two distinct pro-environmental tasks.

Our results inform neural models of environmental decision making. First, our findings on the TPJ's contribution to environmental decisions are corroborated by a recent brain stimulation study which demonstrated that excitatory stimulation of the TPJ results in more pro-environmental choices (Langenbach et al., 2022). Here, we go beyond these previous findings by showing that the TPJ subregion involved in environmental decisions also contributes to social decisions and moreover moderates the attribute-behavior gap. Furthermore, our fMRI results showed task-related activation during pro-environmental decision-making in the DMPFC, which is in line with previous correlative studies that suggested associations between DMPFC cortical thickness and individual differences in pro-environmental behavior (Guizar Rosales et al., 2022). While previous evidence provided mixed results regarding DLPFC involvement in pro-environmental decisions (Baumgartner et al., 2019; Guizar Rosales et al., 2022; Langenbach et al., 2019; Wyss et al., 2024), there is thus increasing evidence that pro-environmental preferences may relate to regions belonging to the mentalizing network like DMPFC and TPJ.

In summary, the present study provides behavioral and neuroimaging evidence for a close relationship between pro-environmental and social preferences. We show that the TPJ, a key node in the network underlying social cognition, modulates the attitude-behavior gap. Our findings contribute to the understanding of the neuro-cognitive mechanisms underlying pro-environmental decision-making and shed light on the reasons why people frequently fail to adopt sustainable lifestyles. In a broader context, the results point out that interventions and policies aimed at advancing sustainability should prioritize social factors over future-oriented strategies.

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Data availability statement

The behavioral raw data are available on Open Science Framework under the following (https://osf.io/krxe4/). Imaging data will be available upon reasonable request.

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Tables

Table 1. Anatomical locations and MNI coordinates of the peak activations for pro-environmental, social, and future-oriented decision-making. We report activations surviving whole-brain FWE correction at cluster level ($p < 0.05$) with a minimal cluster extent of k ≥ 20 voxels.

Hem = Hemisphere (L = left, R = right); BA = Brodmann area

			MNI Coordinates				
Region	Hem	BA	X	Y	Z	k	T
Environmental > ITC							
Precuneus cortex	R	7	5	-66	33	1047	9.14
Temporoparietal junction	R	39	56	-51	30	373	6.81
Temporoparietal junction	L	39	-61	-42	27	451	5.92
Anterior cingulate cortex	L	32	-13	42	12	405	5.93
Dorsomedial prefrontal cortex	R	9	23	45	27	147	4.82
Insula	R	13	-28	9	-12	91	5.19
ITC > Environmental							
Posterior parietal lobe	R	7	26	-60	48	94	4.55
Social > ITC							
Precuneus cortex	L	7	-7	-60	45	1298	9.8
Temporoparietal junction	R	39	53	-54	30	283	6.11
Temporoparietal junction	L	39	-37	-54	45	642	7.98
Dorsolateral prefrontal cortex	R	8	41	21	48	295	6.33
Dorsolateral prefrontal cortex	L	8	-31	15	54	1602	6.87
Cerebellum	R		32	-72	-33	117	5.36
ITC > Social							
-							
Environmental > Social							
Temporal fusiform cortex	L	37	-31	-42	-18	118	5.93
Temporoparietal junction	L	40	-61	-39	27	73	4.57
Social > Environment							
Dorsolateral prefrontal cortex	L	6	-25	3	54	203	7.28
Superior parietal lobe	L	39	-31	-57	48	293	7.05
Posterior parietal lobe	R	7	32	-72	45	229	6.17
Precentral gyrus	R	6	47	3	33	213	5.99
Cerebellum	L		-4	-75	-21	130	5.88
Precuneus cortex	L	7	-7	-57	45	167	5.76
Dorsolateral prefrontal cortex	R	6	29	6	57	113	4.82

Table 2. Anatomical locations and MNI coordinates of the conjunction analysis based on the results drawn from the contrast environmental donation task > intertemporal decision task and interpersonal decision task > intertemporal decision task. We report activations surviving whole-brain FWE correction at cluster level ($p < 0.05$) with a minimal cluster extent of k ≥ 20 voxels.

Hem = Hemisphere (L = left, R = right); BA = Brodmann area; ITC = Intertemporal decision task.

			MNI Coordinates				
Region	Hem	BA	X	Y	Z	k	T
Environmental > ITC ^ Social > ITC							
Temporoparietal junction	R	39	56	-51	30	172	6.81
Temporoparietal junction	L	39	-58	-51	30	153	5.89
Precuneus cortex	R	7	5	-66	33	834	9.14
Anterior cingulate cortex	L	32	-13	42	15	206	5.88

4. General discussion

The main aim of this dissertation was to elucidate the underlying mechanisms of pro-environmental behavior. Through a combination of behavioral and neural methodologies, this dissertation tested how mindfulness influences pro-environmental behavior and provided empirical insights into interrelationships among pro-environmental, prosocial, and future-oriented behaviors at both behavioral and neural levels. In addition, findings contributed to the understanding of the neural mechanisms of the attitude-behavior gap. The section below summarizes the main findings and conclusions of the projects described in this dissertation. Following this, I delve into the theoretical and practical implications of the findings, outline the methodological limitations, and propose directions for future research.

4.1 Summary of findings

4.1.1 Mindfulness training reduces the preference for sustainable outcomes

In the first study, we investigated the modulatory effect of mindfulness training on pro-environmental behavior (H1). Additionally, we investigated the link between pro-environmental, prosocial, and future-oriented choices at a behavioral level (H2). Lastly, since mindfulness has also been connected to these behaviors, we tested the roles of prosociality (H3a) and future orientation (H3b) as potential mediators in the mindfulness-environmental link to further elucidate how mindfulness influences pro-environmental choices. We employed a pre-post-test design in which healthy, meditation-naive participants engaged in tasks measuring pro-environmental, prosocial, and future-oriented behavior. Over 31 days, participants underwent either mindfulness training or active control training between sessions. Contrary to previous theoretical and correlative accounts, mindfulness training reduced, instead of increased, pro-environmental and social preferences, and we did not observe any mindfulness effect on future orientation (Ericson et al., 2014; Geiger et al., 2019). Moreover, our findings revealed a positive correlation between baseline pro-environmental and prosocial choices but not with future-oriented outcomes, and the effects of mindfulness intervention on pro-environmental and prosocial behavior were also correlated. However, prosocial behavior did not mediate the relationship between mindfulness and pro-environmental behavior. Overall, our results underscore a stronger empirical connection between pro-environmental and social outcomes compared to future orientation. Yet, they indicate that prosocial behavior alone does not fully explain the link between mindfulness and pro-environmental behavior.

4.1.2 Environmental and social decisions share neural mechanisms

In the second study, we investigated the neuronal mechanisms underlying pro-environmental behavior (H1). Given the roles of prosociality and future orientation in this behavior, we compared their neuronal correlates with those of pro-environmental behavior within a single study —a novel approach not previously explored but essential for clarifying their intricate relationships (H2)(Gladwin et al., 1995; Pfattheicher et al., 2016; Weber, 2017). Additionally, to further characterize the neuronal mechanisms of pro-environmental behavior, we aimed to determine whether prosocial and future-oriented behavior influence the attitude-behavior gap (H3), a term used to describe the inconsistency between people's attitudes and their actual behavior (Kollmuss & Agyeman, 2002). We employed task-dependent fMRI methods on 35 healthy participants who completed pro-environmental, prosocial, and future-oriented tasks inside the scanner, along with a questionnaire assessing pro-environmental attitudes. Our findings revealed higher activation in the DMPFC, TPJ, and precuneus for pro-environmental behavior. Moreover, this study replicated the behavioral correlation between pro-environmental and prosocial choices observed in the mindfulness study and demonstrated that these behavioral findings are mirrored at a neural level. Specifically, we observed an overlap between pro-environmental and prosocial behavior in the TPJ, as hypothesized, along with activation in the precuneus and ACC. Lastly, the TPJ – a brain region associated with prosocial behavior (Christian et al., 2023; Hutcherson et al., 2015; Rilling & Sanfey, 2011; Strombach et al., 2015; Van Overwalle, 2009) – modulated the attitude-behavior gap, with higher TPJ activation reducing the gap between attitudes and behavior and lower activation resulting in overall more environmental choices, independently of participants' attitudes. To sum up, the second project offers insights into task-related brain activation during pro-environmental behavior. In addition, it builds upon the findings of the first study by revealing that the behavioral correlation between pro-environmental and prosocial behavior persists at a neuronal level. Lastly, the project provides initial evidence of the role of the TPJ in the attitude-behavior gap.

In summary, the dissertation uses a multidisciplinary approach to shed light on the underlying mechanism of pro-environmental **behavior**. First, we provide initial evidence of the potential adverse effects of mindfulness training on pro-environmental behavior. Furthermore, we offer compelling evidence of a strong interconnection between pro-environmental and prosocial behavior at behavioral and neuronal levels. Overall, these results underscore the complexity inherent to this behavior.

4.2 Theoretical implications

The two projects of this dissertation investigated the underlying neurocognitive mechanism of pro-environmental behavior. For this purpose, we tested the modulatory effect of mindfulness on pro-environmental preferences, investigated the relationship between pro-environmental, prosocial and future-oriented behavior at both behavioral and neuronal levels, and lastly tested whether the neuronal mechanisms underlying prosocial or future-oriented behavior impact the attitude-behavior gap. The first study determined mindfulness training to reduce pro-environmental and social preferences – instead of increase as previously hypothesized – and unveiled a behavioral link between pro-environmental and social choices (Ericson et al., 2014). Our second study further supported these behavioral findings by identifying shared neuronal mechanisms between pro-environmental and prosocial behavior. Additionally, the fMRI study determined the TPJ, which is associated with social decisions (Christian et al., 2023; Hutcherson et al., 2015; Rilling & Sanfey, 2011; Strombach et al., 2015; Van Overwalle, 2009), to modulate the attitude-behavior gap. Along with this empirical evidence, the findings also present theoretical implications.

Although past theoretical and correlational research suggested mindfulness to enhance pro-environmental behavior, we provide evidence that mindfulness training reduced pro-environmental preferences (Ericson et al., 2014; Geiger et al., 2019). It's worth highlighting that previous correlational studies positively linking mindfulness to pro-environmental behavior were based on dispositional mindfulness (i.e., individuals' general state of mindfulness awareness), whereas the effects of mindfulness-based interventions (i.e., mindfulness practices aimed at enhancing dispositional mindfulness) on pro-environmental behavior are still unclear (Geiger et al., 2020; Geiger et al., 2019; Ray et al., 2021; Riordan et al., 2022). Our mindfulness training also diminished social preferences, which is in contrast with previous meta-analytical findings linking dispositional and interventional mindfulness to higher prosocial behavior (Donald et al., 2019). In contrast, no significant mindfulness effect was observed on future-orientated outcomes, which aligns with previous findings that were inconclusive (Hendrickson & Rasmussen, 2013; Morrison et al., 2014). While several factors could account for our negative results (please refer to the main manuscript for more details), I argue that a key factor may be the use of a generalized mindfulness training approach rather than focusing on specific social components such as loving-kindness meditations and environmental elements like implementing natural sounds into the content. In line with this, a recent intervention study observed that meditations accompanied by natural sounds, compared to spa-like sounds, were related to higher connectedness to nature, which partially mediated the mindfulness-environmental link (Ray et al., 2021). These effects could be even more significant if mindfulness exercises are conducted in natural settings (Ray et al., 2021). Furthermore, to better understand how mindfulness affects pro-environmental behavior, it might be worthwhile to investigate how distinct components of mindfulness—attention regulation, body awareness, emotion regulation, and changes in self-perspective—influence pro-environmental preferences (Hölzel et al., 2011). Research has highlighted that these components may affect behavior in distinct ways (Hölzel et al., 2011). Using tools like the Five Facet Mindfulness Questionnaire (FFMQ), which encompasses various facets of mindfulness, could provide deeper insights compared to more generalized measures like the Mindful Attention Awareness Scale (MAAS) used in our study (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Carlson & Brown, 2005). Although these components are interconnected, identifying which ones predominantly influence pro-environmental behavior could enhance our understanding of the mechanisms linking mindfulness to pro-environmental behavior and thus better comprehend how pro-environmental is promoted. Interestingly, our findings that mindfulness negatively impacts pro-environmental and prosocial behavior align with theories claiming that contemporary mindfulness strengthens self-focused behavior compared to traditional Buddhist training (Monteiro, Musten, & Compson, 2015). Specifically, they argue that non-religious mindfulness programs often neglect the moral and ethical aspects crucial to the original practices. Therefore, modern mindfulness might paradoxically reinforce individuals' sense of self rather than help them transcend it (Monteiro et al., 2015).

Moreover, environmental and social choices were correlated, whereas no association with future-oriented outcomes was observed. These findings align with prior theoretical and empirical studies highlighting a link between pro-environmental and prosocial behavior (Gladwin et al., 1995; Pfattheicher et al., 2016). However, they contradict theories suggesting pro-environmental behavior and future orientation to be related (Weber, 2017). In contrast, prosocial behavior did not act as a mediator in the mindfulness-environmental relationship. The baseline correlation between pro-environmental and social choices, but lack of mediation by prosocial behavior in the mindfulness-environmental link, suggests that mindfulness training affects environmental decisions through distinct mechanisms that do not involve social preferences, advocating for the presence of a third variable influencing this relationship. Potential candidates are guilt feelings, previously associated with increased pro-environmental behavior (Baumgartner et al., 2021; Frank et al., 2021; Shipley & Van Riper, 2022; Skatova et al., 2017) or connectedness to nature, which has been shown to partially mediate the relationship between mindfulness-based interventions and self-reported pro-environmental behavior (Ray et al., 2021).

In summary, these findings inform theoretical models by acknowledging possible reverse mindfulness effects on pro-environmental behavior. It's important to note that our study does not seek to dismiss previous research showing a positive impact of mindfulness. Rather, our results offer complementary insights by demonstrating that adverse effects may also exist. Furthermore, our behavioral data underscore a strong correlation between pro-environmental and prosocial behavior, but not with future-orientation. This suggests that prosocial behavior plays a crucial role in influencing pro-environmental decisions, potentially more so than future-oriented preferences. However, the absence of mediation by prosocial behavior in the mindfulness-environmental relationship indicates that social decisions alone do not fully elucidate how mindfulness affects environmental decisions. This underscores that while prosocial behavior is necessary, it may not be sufficient for fostering pro-environmental choices, implying that other factors are also needed. This is in line with the model proposed by Kollmuss and Agyeman, which posits that pro-environmental behavior is influenced by a variety of factors, suggesting that theoretically, several factors should be targeted simultaneously (rather than just one) to promote pro-environmental behavior (Kollmuss & Agyeman, 2002). At a more practical level, this is supported by a review highlighting that combining interventions targeting different aspects is more effective than a single intervention alone (Rau, Nicolai, & Stoll-Kleemann, 2022). Thus, our results highlight the importance of exploring multiple pathways to promote pro-environmental behavior. As a caveat, our results are correlational; thus, they do not conclusively rule out future orientation as a potential factor for pro-environmental behavior. While our findings suggest that future orientation might be less significant than prosocial behavior, further research is needed to causally compare pro-environmental, prosocial, and future-oriented preferences. Taken together, in a broader context, our results emphasize that pro-environmental behavior is influenced by numerous factors, highlighting its multidimensionality and contributing to a deeper understanding of its mechanisms (Larson, Stedman, Cooper, & Decker, 2015).

The second project replicated the behavioral environmental-social link and provided neuronal evidence of this relationship by determining shared neuronal mechanism between pro-environmental and prosocial behavior. Environmental choices showed task-related activation in the DMPFC and TPJ. The latter was also activated during social decisions and modulated the attitude-behavior gap. These results are in line with another neuroscientific study that showed brain stimulation over the right TPJ to increase pro-environmental choices

(Langenbach et al., 2022). Our findings further elucidate the role of the TPJ in pro-environmental behavior by determining its activation during both pro-environmental and social decisions and identifying its contribution to the attitude-behavior gap. Higher TPJ activity appeared to reduce the attitude-behavior gap, fostering more aligned environmental choices, while lower TPJ activity was related to higher environmentally friendly behaviors irrespective of attitudes. The TPJ is crucial for perspective-taking, enabling individuals to adopt others' viewpoints (Frith & Frith, 2006). We speculate that participants with higher TPJ activation during environmental decisions might have engaged in perspective-taking. They might have mentally simulated their decisions' environmental and social consequences, which could have facilitated the alignment between attitudes and behavior. In contrast, highly environmentally conscious individuals might not have heavily relied on TPJ processes to simulate outcomes, possibly due to minimal conflict between self-centered and environmentally friendly options. It is important to note that this is just one potential explanation, as TPJ has been associated with different roles beyond perspective-taking, such as overcoming egoism bias to facilitate prosocial choices (Strombach et al., 2015). In fact, overcoming the temptation to maximize personal payoff has shown a similar TPJ activation pattern to our findings: higher TPJ activation occurred when the temptation to make selfish choices was high (i.e., high conflict), whereas lower activation was related to little conflict (Strombach et al., 2015). This alternative explanation could reflect the need to overcome the self-benefit bias to preserve resources for future individuals. Moreover, TPJ has also been related to non-social behaviors such as delay discounting and attentional re-orientation (Chang, Hsu, Tseng, Liang, Tzeng, Hung et al., 2013; Soutschek, Moisa, Ruff, & Tobler, 2020; Soutschek et al., 2016; Van Overwalle, 2009). Thus, our results do not allow us to determine which specific mechanism was implemented. Nonetheless, they provide initial insights into the neural correlates underlying the attitude-behavior gap. The findings demonstrate differential modulation by the TPJ depending on individuals' attitudes, offering novel insights into this challenging phenomenon.

Next, our fMRI-task-related findings determined brain activation during environmental decisions in the DMPFC, consistent with previous studies relating the cortical thickness of the DMPFC with individual differences in pro-environmental behavior (Guizar Rosales et al., 2022). Interestingly, a recent functional fMRI study connected both brain regions by identifying that the TPJ and DMPFC - both part of the social network - seem to interact (Baumgartner et al., 2023). Thus, based on our results and previous research, there is increasing evidence that pro-environmental preferences might be associated with brain regions related to the social network, including DMPFC and TPJ. In contrast, the role of DLPFC – a brain region related to prosocial as well as future-oriented behavior (Bellucci et al., 2020; McClure et al., 2004; Yang et al., 2018) – in pro-environmental behavior is still inconclusive. While correlational neuronal data revealed an association between pro-environmental behavior and DLPFC (Baumgartner et al., 2019; Guizar Rosales et al., 2022), brain stimulation studies have not reached a consensus on its causal role (Langenbach et al., 2019; Wyss et al., 2024).

Taken together, our findings emphasize the potential adverse effects of mindfulness on pro-environmental behavior and provide evidence of a closer connection between pro-environmental and social choices, at a behavioral and neuronal level, than with future-oriented outcomes. This suggests that some factors might be more relevant to pro-environmental behavior than others, as proposed by previous research (Grandin et al., 2021). Additionally, the dissertation addresses the challenge of the attitude-behavior gap by demonstrating the role of the TPJ in bridging this gap, with findings showing that higher activation in this region might align attitudes and behaviors. This offers a potential explanation for why individuals' attitudes do not always translate into corresponding behavior. Overall, this dissertation highlights the complex and multifaceted nature of pro-environmental behavior, underscoring the need to address multiple facets to promote such behavior.

4.3 Practical implications

The results of this study enhance our understanding of the neurocognitive mechanisms underlying pro-environmental behavior. Beyond the theoretical insights already discussed, these findings could have practical applications. Although our findings primarily contribute to fundamental research and may not solve climate change on their own, I believe our behavioral and neural insights offer a unique contribution to interdisciplinary sustainability efforts. While our results may not directly translate into immediate applications such as intervention development or policymaking, they challenge current practices and might provide valuable insights to inform and inspire future efforts.

At a practical level, our adverse effects of mindfulness on pro-environmental behavior do not advocate for the immediate adoption of mindfulness as an intervention. However, these results should not be interpreted as evidence that mindfulness inherently reduces pro-environmental behavior; instead, they highlight the need for further research before drawing any definitive conclusions. In fact, research investigating mindfulness and pro-environmental behavior is still in its early stages (Geiger et al., 2019; Van Dam et al., 2018). Implementing pro-environmental interventions in real-world contexts often requires years of research (IPCC, 2014). Nevertheless, it has been previously argued that relying solely on mindfulness practices as an intervention for broader societal change should be approached with caution (Ray et al., 2021). Even if mindfulness did positively impact pro-environmental behavior, as stated by other studies (Geiger et al., 2019), accessibility to formalized meditation programs is often restricted. Thus, the impact would be limited to a small cohort. Therefore, these programs might not be able to drive the broad societal change in mindfulness and pro-environmental behavior necessary to address climate change. Instead, integrating mindfulness practices into existing societal campaigns that engage larger audiences could be more effective (Ray et al., 2021).

Based on both projects, we concluded that pro-environmental preferences, at both a behavioral and neuronal level, are more closely related to social preferences than future-oriented outcomes. Our results reinforced this link by showing that the TPJ, a brain area associated with prosocial behavior (Rilling & Sanfey, 2011; Van Overwalle, 2009), modulates the attitude-behavior gap, with higher activity reflecting a smaller gap. Our findings are primarily behavior-oriented rather than policy- or intervention-based, limiting our ability to directly translate them into policymaking or strategy development. Nevertheless, our multidisciplinary results suggest that policies and interventions might benefit from simultaneously addressing environmental and social issues. This aligns with recent findings suggesting that policies are most effective when they address both the impacts of climate change and the equity concerns of citizens, such as the distributional effects on lower-income households (Dechezleprêtre, Fabre, Kruse, Planterose, Chico, & Stantcheva, 2022). Moreover, the IPCC 2022 report has newly emphasized the importance of social aspects in climate mitigation, noting that attention to equity can support deeper mitigation and potentially accelerate the process (IPCC 2022). Consequently, policies that integrate both social and environmental considerations are likely to enhance the acceptability of environmental measures. Similarly instead of urging individuals to think about future consequences, focusing on the social aspects of pro-environmental behavior may be more effective for intervention development. For example, one study found that interventions leveraging social influences at the workplace are particularly successful in encouraging employees to save energy (Staddon, Cycil, Goulden, Leygue, & Spence, 2016).

Overall, our research highlights the multifaceted nature of pro-environmental behavior and the significance of incorporating other behaviors when developing interventions or policies to promote pro-environmental behavior, with prosocial behavior being particularly relevant. Recent studies advocate for a broader approach to sustainability, recognizing the importance of not only addressing emission goals but also meeting social needs and fostering economic growth in developing countries (Rau et al., 2022). This aligns with the Brundtland report's emphasis on the interconnectedness of environmental protection, social equity, and economic development (Keeble, 1988). Addressing these aspects together is essential for achieving long-term sustainable goals and well-being.

4.4 Methodological limitations and future studies

The two projects in this dissertation use a combination of behavioral measurements and fMRI methods to investigate the neurobiological mechanisms underlying pro-environmental behavior. While behavioral and neuroscientific methods each offer unique insights into the choice patterns and neuronal processes associated with this behavior, it is crucial to acknowledge their respective limitations.

In our first project, we used mindfulness training to modulate pro-environmental behavior. Here, we aimed to bolster methodological rigor by increasing our sample size to 90 participants, implementing both mindfulness and active control trainings, and incorporating experimental tasks to measure behavioral changes. However, our study design and training protocols revealed some limitations. First, both trainings were performed online, and we monitored participants' completion by using an online platform that allowed us to track whether participants adhered to the trainings in the specified timeframe. However, we could not verify that participants actively engaged with the exercises rather than merely letting the videos run, relying on participants' honesty and self-reporting for this aspect. Second, four participants were excluded from the study due to incomplete training, potentially introducing bias and limiting the generalizability of our findings. Next, to ensure unbiased group assignment, participants were randomized based on their chosen attendance days: those attending on day one were allocated to the mindfulness group, those on day two to the control group, and day three included a mix of participants. This allocation method was overseen by an impartial individual to maintain researcher blinding. However, it should be noted that computerized randomization was not employed in this process. Lastly, a significantt limitation of our study was the lack of consideration for participants' sociocultural backgrounds. This factor has been shown to impact the effects of mindfulness and is crucial for ensuring participant diversity, thereby enhancing the generalizability of our results (Henrich, Heine, & Norenzayan, 2010; Kirmayer, 2015).

Moreover, while task-related fMRI offers valuable insights into the neuronal mechanisms of behavior, it is crucial to recognize its limitations. The primary limitation is that the results of the fMRI methods are based on correlational observations. Often, it is assumed that changes in neuronal activity measured by fMRI directly correspond to task engagement. This claim suggests that when a specific brain region becomes active during a task, there would theoretically be a rise in the firing rate of specialized neurons associated with the participant's behavior (Logothetis, 2008). However, as Logothetis (2008) noted, this is not always the case. Therefore, while we can infer a timely correlation between brain activation and task execution, we can not conclude whether the task elicits neuronal spiking. Based on our results, we can determine that the DMPFC, TPJ, and precuneus clusters are linked to pro-environmental choices compared to intertemporal ones. However, we cannot infer that the behavior itself activates these regions. Our conclusion is limited to the observation that these brain regions were active during the environmental donation task compared to the intertemporal choice task. Further methods like brain stimulation would be needed to test their causal relationship with pro-environmental behavior. Indeed, it has been emphasized that multimodal approaches are essential for gaining a comprehensive understanding of the neuronal mechanisms underlying behaviors (Logothetis, 2008). Similarly, our findings on the shared neuronal mechanisms between environmental and social decisions are also correlational. To establish a causal relationship between pro-environmental and social decisions, future research should employ brain stimulation methods or a combination of fMRI and brain stimulation on one of the overlapping regions, for instance, TPJ, to see if the stimulation affects both behaviors.

In conclusion, like any research method, the techniques employed in this dissertation present limitations and results need to be interpreted accordingly. Nevertheless, our results contribute to a better understanding of the mindfulness-environmental link and mark a significant stride in comprehending the connection between pro-environmental and prosocial behavior at both behavioral and neuronal levels. Lastly, they shed light on the neuronal mechanism associated with the attitude-behavior gap.

5. Conclusion

In conclusion, this dissertation aimed to provide deeper insights into the neurocognitive mechanisms underlying pro-environmental behavior. First, our findings challenge previous theoretical accounts by suggesting potential reverse effects of mindfulness on pro-environmental and prosocial behavior (Ericson et al., 2014). Next, through a multidisciplinary approach, this dissertation unveiled a more pronounced link between pro-environmental and prosocial behavior than with future orientation. This relationship is further corroborated by the involvement of the TPJ (which is related to prosocial behavior (Van Overwalle, 2009)) in the attitude-behavior gap. At a more practical level, our first project does not support mindfulness as an effective intervention for promoting pro-environmental behavior, however I argue that further research is needed before drawing definitive conclusions. Lastly, the multidisciplinary evidence on the connection between pro-environmental and prosocial behavior suggests that integrating environmental and social aspects in political and interventional approaches could yield more effective outcomes than focusing exclusively on environmental concerns.

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Author contributions

Chapter I: Mindfulness training reduces pro-environmental preferences

The author of this dissertation designed the research, programmed the tasks, collected the data, performed data analysis, interpreted the results, created plots (except Figure 4), and wrote the manuscript.

Alexander Soutschek contributed to designing the research, assisted with data collection and data analysis, contributed to the interpretation of results, supervised the experiment, created Figure 4, and wrote the manuscript.

Kathrin Koch contributed to the research design and provided comments on the manuscript.

Britta Hölzel contributed to the research design and provided comments on the manuscript.

Munich, 05.07.2024

Zarah Le Houcq Corbi　　Alexander Soutschek

Kathrin Koch　　Britta Hölzel

Chapter II: Environmental and social decisions share neural mechanisms

The author of this dissertation designed the research, programmed the tasks, collected the data, performed data analysis, interpreted the results, created plots, and wrote the manuscript.

Alexander Soutschek designed the research, assisted with data collection and data analysis, contributed to the interpretation of results, supervised the experiment, and wrote the manuscript.

Didem Taşkıran assisted with data collection and data analysis and provided comments on the manuscript.

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Zarah Le Houcq Corbi　　Alexander Soutschek　　Didem Taşkıran

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