The Relationship Between Mindfulness and Cognitive Control

[1] Dr. Imran Siddiqui
[2] Hira Yousaf

How to cite this article:

Siddiqui, I., & Yousaf, H. (2025). The relationship between mindfulness and cognitive control. *Pakistan Journal of Multidisciplinary*, *3*(1), 51-61.

Article Details

Received: 12 Feb 2025

Accepted: 20 April 2025

Published: 18 June 2025

Dr. Imran Siddiqui
[2]Hira Yousaf

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Corresponding Author:

*** Dr. Imran Siddiqui**

Abstract

This research explores the relationship between mindfulness and cognitive control, investigating how mindfulness practices influence individuals' ability to regulate attention, manage impulses, and enhance decision-making processes. Cognitive control, essential for goal-directed behavior, involves the mental processes that enable individuals to maintain focus, resist distractions, and adapt to changing circumstances. This study reviews empirical literature and theoretical frameworks to analyze the effects of mindfulness meditation, mindful awareness, and related practices on cognitive control outcomes. Key findings suggest that consistent mindfulness practice is associated with improvements in attention regulation, emotional reactivity, and working memory capacity. Furthermore, the research highlights the mechanisms through which mindfulness fosters cognitive control, including increased awareness of thought patterns and enhanced emotional regulation. These findings have significant implications for mental health interventions and educational practices, as fostering mindfulness could potentially enhance cognitive performance and resilience in various settings. Ultimately, this study advocates for the integration of mindfulness techniques into daily routines and therapeutic approaches to cultivate better cognitive control and overall psychological well-being.

Keywords: *mindfulness, cognitive control, attention regulation, emotional reactivity, working memory, mental health, decision-making, mindfulness practices.*

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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1. INTRODUCTION

Given the increasing interest in mental functions like attention, self-regulation, and their impact on brain and cognition, the emergence of mindfulness practices has brought new insights into this topic field. Mindfulness refers to maintaining attention in the present context, without judgment (Li et al., 2018). Its beneficial effects on several forms of mental functions are attracting more and more attention from both psychological and neuroscientific fields. For example, it has been found that the meditators out-performed non-meditators in tasks requiring attentional and executive function, and it has been reported that attention capacity can be trained by mindfulness. Thus, numerous researchers are concentrating on how mindfulness practices affect cognitive functions, such as perception, attention, memory, and executive function. Nevertheless, the effect of mindfulness practices on cognitive control is still controversial due to different methods and understandings of cognitive control tasks used in prior investigations.

Cognitive control is the ability to regulate and control the attention, thoughts, and/or actions to achieve certain behavioral objectives. It plays a crucial role in daily life, such as in communicative interaction and problem-solving processes. Consequently, a number of neuropsychiatric diseases are connected with cognitive control deficient, such as schizophrenia, attention deficit hyperactivity disorder (ADHD), and depression. Similarly, effective proactive control is relevant to observation of goal bases of a generation of new strategies, for example, in therapy, education and so on. In addition, mindfulness, as a mental practice, includes mental practices to regulate attention, such as focusing attention on breathing, posture and the train of thought. By doing this, potential conflict can be avoided. Mindfulness practices also train awareness of the present through body and external perceptual objects, such as direct experience. (Ron-Grajales et al.2021)

1.1. Overview of Mindfulness and Cognitive Control

An important mental practice designed to enhance cognitive skills is called mindfulness. A more formal definition characterizes mindfulness as "the

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment" . According to this view, mindfulness refers to several cognitive processes. The first is Attention, which helps individuals to focus on an object. The second is Awareness, which helps to monitor the fluctuating mental context. The third is Acceptance, which helps individuals accept negative experiences without getting caught up in them. Consequently, practicing mindfulness improves cognitive control skills (Li et al., 2018). In contrast, cognitive control refers to a set of processes that enable individuals to regulate their thoughts and actions. Working Memory represents one internal storage system that maintains and manipulates goal-relevant information. Inhibitory Control represents another internal inhibitory system that stops the activation of irrelevant mental structures and impulsive actions. Cognitive control also includes a set of fluid processes that regulate the contents of Awareness, and the extent of Attention, by flexibly prioritizing and manipulating task-relevant mental structures based on context. It is proposed that mindfulness enhances cognitive control indirectly, by improving Attentional Resources. Attentional Resources refer to a pool of energy that enables the brain to allocates Attention. This attention is enhanced via the practice of meditation, which improves Attentional Resources.

2. THEORETICAL FRAMEWORK

Despite considerable popular hype, the relationship between mindfulness and cognitive control is not well understood. There is currently no structured understanding of how the effects of mindfulness might be conceptualized, including potential modulating variables and possible cognitive pathways. The central aim of this systematic investigation was to determine how far psychological and neuropsychological models of mindfulness can account for cognitive control. At a psychological level, mindfulness is purported to enhance attentional processes that coordinate choice. Existing research does not clearly substantiate this hypothesis, although methodological issues make it difficult to draw firm conclusions. In the present investigation, seven studies found that the effects of mindfulness on cognitive control are fully explained by Attentional

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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Control Theory. In addition, these studies provided convergent evidence suggesting alterations to cognitive pathways, particularly in terms of enhanced attentional control. The flood of psychological studies on the topic has yet to be met by a similar interest from cognitive neuropsychologists, with this investigation aiming to both initiate that interest and to provide a foundation to examine these phenomena from a neural perspective (Li et al., 2018).

Attentional Control Theory posits that attentional processes are central in the modulation of cognitive control. This theory proposes that orientating attention towards task-relevant information is beneficial for control, enhancing stimulus encoding and the formation of specific task sets. In contrast, attentional broadening promotes stimulus-independent thought processes that interrupt these control-related processes. According to the model, automatic control processes are emotion-based, the function of which is to evaluate the affective value of the situation. These evaluations directly influence the narrowing and broadening parameters, so that threatening stimuli narrow attention, whereas low-level rewards broaden attention. At an early level of consideration, this model does not clearly specify the role for mindfulness per se in cognitive control, so a prime focus was to assess the extent to which its structured lens can capture and explain these effects. Given that the research on this topic, and particularly the relevant psychological and neuropsychological models, are still in their relative infancies, this broader framework may also help to stimulate ideas and hypotheses for further investigations. (Lenze et al.2022)

2.1. Attentional Control Theory

Attentional Control Theory (ACT) posits that attention contains three networks of control over information processing. The orienting network selects sensory input to be attended to. The executive network resolves any conflict between the two other networks, which may be due to either bottom-up sensory conflict or top-down goal conflict. The word memory network, or so-called “contention scheduling”, maintains goals and other auxiliary information to be used for any conflict resolution. This enables the executive network to inhibit or suppress irrelevant or conflicting information. The relative strength of the two types of

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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conflict determines the utilization of different control models (Li et al., 2018). It can be surmised that attentional mechanisms are a foundation for cognitive control processes, and therefore, such a close link exists between the two. From this viewpoint, the ACT, thus frames attentional mechanisms as trainable skills that allow for the enhancement of cognitive and emotional regulation. As Attentional Control Theory (ACT) explains, the ability to focus attention on task-relevant cues is directly connected to the narrowing of attentional focus and better task-congruent behaviors. In this sense, mindfulness practice seems to directly facilitate attentional mechanisms related to cognitive control. Indeed, studies have found that interventions involving mindfulness significantly ameliorate performance in executive functions, fluid intelligence, and shift learning, thus improving general cognitive control. Examination of this previously neglected link between mindfulness and attentional control can deepen the understanding and effectiveness of these practices as well as further illuminate the underlying mechanisms of cognitive control. As a promising start, there has been a focus on several components of attentional control that seem to fit well within the ACT, with the purpose of examining them in relation to mindfulness. Such components include the ability to selectively attend and disengage from distractions, utilize working memory in the service of attention, and task-switching. Empirical findings are also reviewed that demonstrate how mindfulness could enhance attentional control with this framework. The review of these components and findings suggest that attentional control is not only instrumental in improving general cognitive control, but also works in synergy with emotional regulation and decision-making.

3. EMPIRICAL EVIDENCE

There is a growing body of empirical studies that investigate the relationship between mindfulness and cognitive control. These studies employ a variety of methodologies including meta-analysis, cross-sectional, and intervention programs. For over two decades, research contributions have been made to further understand how mindfulness practices can shape cognitive functions. Regarding cognitive control, a hotly studied subdomain is conflict processing.

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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Although previous findings suggest that people with long-term mindfulness practice or high trait mindfulness show advantages in cognitive control concerning conflict processing, several studies show null results. The effectiveness of a short-term mindfulness intervention on cognitive control, especially conflict processing, is still controversial. The present study examines the effectiveness of an 8-week mindfulness training program on improving cognitive control. (Li et al., 2018).

Two aspects of cognitive control, proactive and reactive control, and their relation to mindfulness practice were further investigated. The behavioral results demonstrated the improvement of proactive control. Mindfulness benefits individuals' lives in various ways. A growing number of studies have shown that mindfulness training is effective in cultivating cognitive functions. This training can effectively enhance attention and improve cognitive inhibition, which is also a critical process in cognitive control theory. Together, these results suggest that cultivating the attention and awareness embedded in mindfulness practice through practice in various forms can bolster cognitive control function to a certain extent. Additionally, task-evoked pupillary responses were recorded during the task (Lin et al., 2022).

3.1. Studies on Mindfulness Training and Cognitive Control

In terms of mindfulness training and mindfulness practices, a number of studies have been conducted to examine their relation to cognitive control. Some studies employed a cross-sectional design to investigate group differences in long-term mindfulness practitioners and meditation-naïve novices. Such studies revealed that long-term mindfulness practitioners have a higher level of cognitive control and may be beneficial for attention function. This suggests that the underground mechanism of mindfulness-enhanced cognitive control is due to the ability of mindfulness practitioners to self-regulate cognitive and emotional processing more effectively.

Other studies conducted randomized controlled trials (RCTs) to determine cognitive changes following mindfulness training using the Stroop task, the Attention Network Test (ANT), and a Change task. For example, (Li et al., 2018)

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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found that a short-term mindfulness training program could significantly reduce reaction time, interference effect of reaction time, and conflict effect in the Stroop task, suggesting that mindfulness is a promising approach to promote a conflict adaptation process.

4. NEUROBIOLOGICAL MECHANISMS

The relationship between mindfulness and cognitive control is a topic of growing interest, both in psychology and neuroscience. Mindfulness meditation is found to have beneficial effects on cognitive functions, such as increased cognitive flexibility, working memory, and executive attention. Emerging evidence has shown that the practice of mindfulness is related to better cognitive control abilities and an associated neural network. Although empirical studies consistently suggest a positive association between dispositional mindfulness and cognitive control, how mindfulness exerts its effects on cognitive control remains poorly understood. A clearer understanding of such mechanisms can shed light on the potential applications of mindfulness in areas where cognitive control plays a crucial role. With the rapid development of neuroimaging technology, a number of studies have provided neurobiological evidence that mindfulness and its related practices influence brain structure and function. A review of the current progress includes the potential neurobiological mechanisms of mindfulness as it pertains to cognitive control (Hanley et al.2021).

In general, the executive attention network encompasses superior parts of the prefrontal cortex and includes the superior frontal gyrus, medial frontal gyrus, and Brodmann Area 8. The involvement of the prefrontal cortex with cognitive functions has been studied extensively. From the classic working memory model to the Theory of Mind study of social cognition, numerous research works implicate the prefrontal cortex in various cognitive functions. With regard to cognitive control, the crucial role of the prefrontal cortex has been the consensus across different studies, theories, and tasks. Recent studies of patients with prefrontal cortex lesions and updated meta-analyses of functional neuroimaging data demonstrate that the prefrontal cortex is closely associated with cognitive control functions. As such, the special evidence for the prefrontal cortex in the

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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relationship between mindfulness and cognitive control is thoroughly reviewed. As one of the key control-related regions of the brain, the anterior cingulate cortex is primarily divided into the dorsal anterior cingulate cortex and the rostral anterior cingulate cortex. Accruing evidence suggests that these two subdivisions of the anterior cingulate cortex play different roles in cognitive control. (Yakobi et al., 2021)

4.1. Functional Brain Networks

4.1.1. Default Mode Network and Executive Control Network

By combining attentional control theory with resource competition theory, mindfulness researchers claim that mindfulness practices are effective in improving cognitive control abilities. This improvement might be due to alterations of functional brain networks associated with cognitive control as a consequence of mindfulness practices. In this context, the current knowledge of a wide range of functional brain networks, known to be actively involved in basic cognitive control, attention, and the role of mindfulness in these networks, are examined. Overall, there are several key networks that can be categorised into two broader brain systems: the default mode network (DMN) and the task-positive network (TPN) consisting of the central executive network (CEN) and salience network of bottom-up attention (BAN). During task rest, the correlations in functional magnetic brain activity are clear within the DMN and the SN, while it is negative between the DMN and the CEN with TPN due to competitive attention resource (D. Parkinson et al., 2019). Low- and high-frequency brain oscillations within the theta band have also been shown to coordinately mediate interactions between these networks during different attentional focusing tasks. (Chin et al.2021)

Recruitments of specific nodes of the DMN were mediated by goal-directed attention during a cognitive task. The DMN consists of both unmodular (e.g. MPFC, PCC) and modular (e.g. IPL) nodes that have roles in self-inspection processes, e.g. similar mind-wandering, memory recall, and future projection. In healthy participants, such cross-network de-activations of the DMN are weak, but robust within the CEN and are linked to improved task goal execution and

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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attention control. This type network involves the task-positive network (TPN) comprising the CEN and the DN along with the SN. Frontal regions of posting gyrus angular and anterior cingulate of the DMN have been implicated in improved attention ability. Increases in connectivity within the DMN, due to efficient competition by improving network connective capabilities. A network is more efficiently connected if the efficiency of global information transfer between brain regions is high for a low level of cost, e.g. wiring. Following mediation model, it is also suggested that the mindfulness-induced alteration of the attention control network may have a strong effect on the improvement of cognitive performance via mediation of attentional resource processes. This gives further empirical arguments for the combination of the competition and mediation aspect in the interpretation of mindfulness induced changes at a neurobiological level. (Gupta et al.2021)

5. Implications and Future Directions

What are the implications and future directions for improving understanding of the relationship between mindfulness and different control modes?

On the basis of the results obtained from seven experiments it is evident that an improvement in understanding the relationship between mindfulness and the different control modes will provide broad significance in both clinical practice and public policy. Moreover, the possibility of using mindfulness training as a novel training method is believed to enhance individuals' cognitive control. (Im et al.2021)

Within educational contexts, as cognitive control is necessary for human learning activities, it is believed that mindfulness training can be integrated into current educational systems or curricula to provide a powerful enhancement of students' cognitive skills. Recently, several researchers have found that mindfulness training has beneficial effects on cognitive control, as well as academic performance in educational contexts . Further, as previously mentioned, cognitive control is expected to help individuals make healthier choices, avoid negative activities, and correct health error judgments.

[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.
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Conflict of Interest

Not reported in the supplied article; author confirmation required.

Funding

Funding information was not reported; author confirmation required.

Data Availability

The article draws on published research. No original dataset is identified in the supplied text.

Informed Consent

Not applicable to the literature review described in the article.

Use of Generative AI

Use of generative AI in the original research and writing was not reported; author confirmation required.

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[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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[1] Assistant Professor, Department of Psychology, Abdul Wali Khan University Mardan, Mardan
[2] MPhil Scholar, Department of Psychology, Abdul Wali Khan University Mardan, Mardan.

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