Metacognitive Mechanisms of the Attentional Training Technique

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Abstract

The Attentional Training Technique (ATT) has been shown to enhance attentional control and reduce maladaptive cognitive patterns but lacks a well-defined computational explanation. This paper applies a metacognitive skill model within the ACT-R cognitive architecture to clarify the procedural mechanisms underlying ATT. Grounded in proceduralization theory, we propose that ATT transforms declarative attentional strategies into automatic procedural skills, enhancing metacognitive control and emotional regulation. This framework advances our understanding of the computational and cognitive mechanisms supporting ATT, its applications in psychotherapy, and the process of metacognitive skill learning.

Keywords: Attentional training technique; attention; metacognition; metacognitive skill; ACT-R; meditation

Introduction

Understanding the cognitive mechanisms underlying psychotherapeutic interventions is crucial for optimizing their efficacy and refining treatment strategies. The Attentional Training Technique (ATT) (Wells, 1990; 2019) has been shown to be effective in alleviating symptoms across various psychological disorders (Rochat, Manolov & Billieux, 2018). However, the computational and cognitive mechanisms that give rise to its effectiveness remain poorly understood. This paper investigates these mechanisms using the ACT-R cognitive architecture to provide a more precise account of these processes.

In their 2023 fMRI study, Jahn et al. stated, "Understanding the 'how' behind the Attentional Training Technique should lead to a better understanding of attentional control and metacognition in general and could eventually manifest in improved or even more specific treatment" (p.12). To this end, we aim to articulate the mechanisms of attentional training by applying a model of metacognitive skill that has been effectively used to explore related cognitive processes, including metacognitive sensitivity, emotional regulation, and attentional control (Conway-Smith, West, & Mylopoulos, 2023). Grounded in the principles of proceduralization, this model provides a computational framework for understanding how metacognitive skills develop and refine over time, offering a mechanistic account of how training enhances metacognitive monitoring and control.

This paper will help address Wells' (2019) call for a "stronger information processing theory" (p.13) to explain metacognitive control — its components, functions, and the types of metacognitive information involved in the preservation and disengagement of negative processing. A more precise theoretical account of the Attentional Training Technique's subcomponents may not only enhance its existing applications but also facilitate the development of more effective interventions.

This study addresses unanswered questions: What cognitive mechanisms underpin attentional control training? How does their enhancement reduce maladaptive patterns of thought and emotion? More broadly, we explore how intelligent systems may enhance their ability to monitor and regulate their own activity.

To address these questions, we first provide an overview of the Attentional Training Technique and its practical applications. Next, we outline key aspects of metacognition and the metacognitive skill model. We then apply this model to ATT to illuminate its constitutive mechanisms. Finally, we discuss how this refined explanation enhances our understanding of the cognitive processes that support emotional regulation and alleviate psychological symptoms.

Attentional Training Technique

Psychotherapeutic treatments in metacognitive therapy are grounded in the Self-Regulatory Executive Function (S-REF) model, which explains the role of strategic processes and metacognition in psychological disorders (Wells & Matthews, 1996). The S-REF model posits that maladaptive metacognitive beliefs and knowledge can trigger an adverse thought pattern known as the Cognitive Attentional Syndrome (CAS). CAS is a style of negative processing characterized by worry, rumination, and threat monitoring. It involves rigid, self-focused attention that amplifies negative emotions, leading to persistent self-preoccupation and distress. CAS is also associated with maladaptive coping strategies such as thought suppression, avoidance behaviors, and substance abuse (Wells, 2009).

The Attentional Training Technique (ATT) is designed to counteract CAS by enhancing metacognitive control and breaking cycles of negative thought (Knowles & Wells, 2018). ATT helps individuals disengage from persistent thought patterns, interrupt self-focused attention, and strengthen metacognitive awareness (Knowles et al., 2016; Nassif & Wells, 2014).

fMRI studies (Jahn et al., 2023) have linked ATT to improvements in attentional abilities and structural changes in the brain. However, researchers emphasize that the underlying cognitive mechanisms of ATT remain poorly understood, highlighting the need for a more detailed theoretical framework. This aligns with Wells' (2019) assertion that "a more detailed modeling of the metacognitive and cognitive architectures supporting self-regulatory processing is needed to advance the field" (p. 5).

Metacognition

We propose that the Attention Training Technique fundamentally relies on a form of automatized metacognition. The common conception of metacognition pertains to the monitoring and control of cognitive processes (Flavell 1979; Fleming, Dolan, & Frith, 2012). Metacognitive skill presupposes that the main components of metacognition, monitoring and control, can improve with practice. *Metacognitive control* concerns the active regulation of cognitive processes or states to either activate or suppress them (Proust, 2013; Wells, 2019). The control of one's own cognitive activity can involve a range of processes such as attention, emotion, planning, reasoning, and memory (Slagter et al., 2011; Efklides, Schwartz, & Brown, 2017; Pearman et al., 2020). *Metacognitive monitoring* refers to the ability to recognize and identify cognitive states. It involves the perception of internal mental properties such as thoughts and feelings in order to regulate those states or direct behavior.

There are at least two types of cognitive representations that engage in metacognitive monitoring and control processes — declarative knowledge and procedural knowledge. Metacognitive knowledge, or meta-knowledge, is considered a form of declarative knowledge (Schraw & Moshman, 1995; McCormick, 2003). Meta-knowledge takes the form of an explicit metarepresentation that is propositionally formatted and refers to a cognitive property, e.g.: "I am focused" (Shea et al., 2014; Proust, 2013). Metacognitive knowledge is considered distinct from metacognitive skill, as it does not automatically deploy metacognitive processes (Veenman & Elshout, 1999). Meta-knowledge is further distinguished from a metacognitive instruction, which specifies the mental action to be performed (Wells, 2019). A metacognitive instruction, or meta-instruction, prescribes a mental action directed toward controlling some cognitive process, e.g.: "Direct focus toward the present task."

The executing of metacognitive instruction is performed by way of procedural knowledge. Improvements in metacognition are said to involve the refining of procedural knowledge that people employ to monitor and control their own cognitive processes (Brown & DeLoache, 1978; Schraw & Moshman, 1995; Wells, 2019). The various realms of metacognitive skills can be understood as different domains of procedural knowledge (Veenman et al., 2005; Braithwaite, & Sprague, 2021). The dynamic role of declarative knowledge and procedural knowledge in metacognitive processes can be more clearly articulated within the ACT-R cognitive architecture.

ACT-R

Theories of metacognition have been modeled in the ACT-R cognitive architecture (Reitter, 2010; Anderson & Fincham, 2014). ACT-R instantiates decades of research on the computational mechanisms of human cognition. Its mandate is to depict the components necessary for human intelligence, which include working memory, perception, action, declarative memory, and procedural memory. These modules have been correlated with their associated brain regions, providing a neurobiologically grounded framework for investigating cognitive processes (Borst et al., 2015).

ACT-R distinguishes between declarative knowledge and procedural knowledge to explain the underlying components of skill learning, which accords with the literature on skill in philosophy and psychology (Squire, 1992; Christensen, Sutton, & McIlwain, 2016). Declarative knowledge is formatted propositionally and structured within semantic networks. Procedural knowledge is specified computationally as "production rules" which are a dominant form of representation within accounts of skill (Newell, 1990; Taatgen & Lee, 2003). Production rules, or "productions", transform information and change the state of the system to complete a task or resolve a problem. The building and refining of production rules are considered to be central to human intelligence and fundamental to cognitive skills (Anderson, 1993). Neurologically, production rules are associated with the 50ms decision timing in the basal ganglia (Stocco, 2018).

A production rule is modeled after a computer program instruction in the form of a "condition-action" pairing (Figure 1). It specifies a condition that, when met, performs a prescribed action. A production can also be thought of as an "if-then" rule. *If* the conditional side matches to a pattern in working memory, *then* it fires a prescribed action (Anderson, 1993; Stocco et al., 2021).

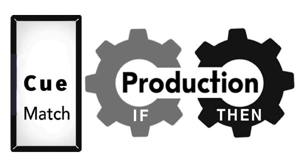

Figure 1. Production rules are formatted as an if-then rule, or condition-action pairing. *If* the condition side matches to the cue in working memory, *then* it fires an action.

This is clarified by noting that procedural knowledge (production rules) is generally not innate in humans. For example, a child must develop production rules to print their name (motor actions), perform mathematical calculations (cognitive actions), and regulate their focus (metacognitive actions). They must learn that conditions such as 'print name,' 'solve for x,' or 'pay attention' are paired with the appropriate action sequences. Once these actions are associated with the correct cues, practice is required to refine the supporting production rules and improve performance.

With sufficient practice, these productions become stored in procedural memory. When a relevant cue appears in working memory ('print,' 'calculate,' 'focus'), matching productions will activate and execute the correct actions. In this way, cues in working memory can trigger procedural knowledge across motor, cognitive, and metacognitive domains, and refined through a process of proceduralization.

Proceduralization

Proceduralization is a key concept in skill acquisition, describing the transition from explicit declarative knowledge to implicit procedural knowledge. Theories of skill learning characterize this process as moving from a declarative stage of rule-following to a procedural stage where performance becomes faster, more automatic, and more accurate (Dreyfus & Dreyfus, 1986; Kim & Ritter, 2015). Our account follows Fitts' (1964) skill acquisition model as computationally interpreted by Anderson (1982).

Proceduralization plays a central role in both physical skills, such as those in athletics (Beilock & Carr, 2001; Ford, Hodges & Williams, 2005), and cognitive skills, such as mathematics (Anderson, 1982; Taatgen & Lee, 2003). As declarative knowledge is retrieved and practiced, actions become faster, more automatic, and less error-prone. This occurs because procedural knowledge becomes directly associated with task-relevant cues, reducing reliance on slow declarative knowledge retrieval. Consequently, performance speeds up and working memory load decreases. Task refinement can also occur through mechanisms such as time-delayed learning, where faster productions are reinforced.

With sufficient practice, conscious control diminishes, and skill execution becomes automatized. Automatized skills operate largely outside of working memory, making them less perceivable to the performer (Beilock & Carr, 2004; Ford et al., 2005). When an appropriate cue appears, well-practiced motor, cognitive, and metacognitive skills activate automatically with minimal effort. We posit that this transition toward automaticity is a fundamental mechanism underlying the Attentional Training Technique.

Stages of metacognitive skill

Here we propose that proceduralization is key to understanding attentional training as a subdomain of metacognitive skill. Metacognitive proceduralization articulates a top-down mechanism by which human cognition becomes more skillful at monitoring and controlling its own processes, such as attention, emotion, and metacognitive sensitivity (Conway-Smith, West, & Mylopoulos, 2023; Conway-Smith & West, 2024). Explanations of metacognitive skill have also produced bottom-up models, where implicit processes learn by way of stored low-level feedback (Proust, 2013) such as metacognitive reinforcement learning (Krueger, Lieder & Griffiths, 2017).

Metacognitive proceduralization posits that the development of metacognitive skill develops from an initial stage of instruction-following to an advanced stage where performance largely relies on automatic procedural knowledge (production rules). In the later stages, monitoring and control processes are deployed quickly, more automatically, and require less working memory. This shift towards automatization not only enhances the efficiency of cognitive processes but also frees up cognitive resources, allowing for more complex and nuanced metacognitive operations.

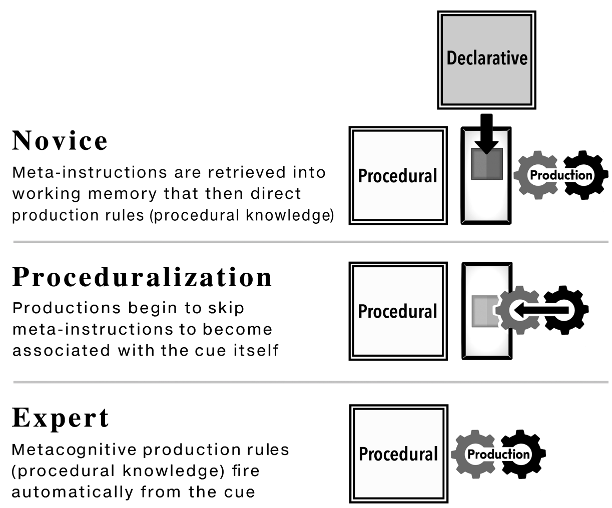

Figure 2. Three stages of metacognitive skill learning through proceduralization (Conway-Smith, West, & Mylopoulos, 2023).

According to the theory of metacognitive learning via proceduralization, a metacognitive practitioner progresses through three stages of training (Figure 2), which we propose as a structured framework for understanding the Attentional Training Technique.

Novice Stage. Training begins with meta-instructions that direct monitoring and control processes toward a specific target of focus (e.g., a visual point, physical area, or sound). These instructions are retrieved from declarative memory and executed as productions. Performance at this stage is slow, effortful, error-prone, and demands significant working memory resources.

Intermediate Stage. Through proceduralization, repeated practice refines meta-instructions into faster, task-specific production rules, reducing reliance on declarative knowledge. These specialized productions are rewarded and reinforced, allowing metacognitive performance to become quicker, more automatic, and less cognitively demanding.

Expert Stage. Meta-instructions are fully converted into procedural knowledge and stored in memory. Upon encountering a relevant stimulus (e.g., a cue to focus attention), production rules activate automatically, requiring minimal conscious effort. At this stage, metacognitive performance is fast, efficient, and highly automatic, demonstrating the hallmarks of expertise.

Empirical support for proceduralized attention

Empirical findings support the notion that attentional control can become proceduralized through training. For example, Ramamurthy and Blaser (2017) introduced the concept of "procedural attention" to describe the transition from deliberate to automatic attentional deployment. In their study, participants were instructed where and how to allocate attention, and with repeated practice, attention became automatically oriented toward those rehearsed locations. This was interpreted as evidence for an "offline" attentional selection mode, that is, cognitively unsupervised and automatic. The authors noted that this mode is "analogous to the procedural memory that guides skilled motor behavior" (p. 1).

Additional evidence for proceduralization comes from data consistent with the power law of skill acquisition. Logan (1988) operationalized automatization as a speed-up in reaction times (RTs) that follows a power function — characterized by rapid initial improvement followed by a gradual leveling off. This negatively accelerating learning curve has been widely observed in both motor and cognitive skill domains (Newell & Rosenbloom, 1981; Anderson, 1982).

Shin et al. (2015) provide evidence that attentional control improves with practice according to a power law. In a multi-session rapid serial visual presentation (RSVP) task, participants showed gains in target identification and reductions in attentional blink, both following a negatively accelerating curve typical of procedural skill learning. These findings suggest that attentional control, like other motor and cognitive skills, develops through structured practice and proceduralization.

Clarifying the Attentional Training Technique

Building on the theory of metacognitive learning via proceduralization, we apply this framework to identify the key features and stages of proceduralization in the Attentional Training Technique (ATT). This structured, computational approach characterizes how attentional control transitions from deliberate, declarative strategies to automatic processes.

Jahn et al. (2023) describe the ATT method as implemented via a standardized audio protocol based on the Metacognitive Therapy (MCT) manual (Wells, 2009). Participants receive instructions on directing their attention while listening to six simultaneous audio stimuli: a bell, traffic noise, birds, rushing water, crickets, and a ticking clock. Each 12-minute session consists of three phases: selective attention (focusing on one sound at a time), attentional switching (shifting between sounds), and divided attention (attending to multiple sounds simultaneously).

Participants practiced ATT twice daily for five days. By the study's conclusion, they exhibited improved metacognitive expertise, demonstrating faster and more accurate attentional control compared to a control group. This training trajectory mirrors the transition from effortful, declarative instruction-following to automatized proficiency — a hallmark of metacognitive proceduralization.

Jahn et al. (2023) suggest that the anterior cingulate cortex (ACC) plays a primary role in metacognitive development and the storage/execution of procedural knowledge for attentional control. While ACT-R traditionally attributes procedural execution to the basal ganglia, both regions likely contribute within a broader neural network governing metacognitive proceduralization. Here, we propose the ACC and basal ganglia operate in tandem, collectively supporting the automatization of attentional control processes in ATT.

Alternative explanations of attentional training have emphasized mechanisms such as reinforcement learning (Krueger et al., 2017) and predictive coding (Clark, 2015). While these accounts provide valuable perspectives, they do not fully explain the transition from controlled to automatic attentional regulation. Proceduralization uniquely captures how attentional skills become automatized through training, offering a more mechanistic account of skill acquisition in ATT.

Exit from maladaptive thoughts

Metacognitive proceduralization provides a framework for understanding how attentional control training mitigates symptoms of psychological disorders. The Self-Regulatory Executive Function (S-REF) model describes how disorders such as anxiety and depression involve perseverative negative thinking (e.g., worry, rumination), characterized by repetitive cognitive loops (Wells, 1995, 2000). Cognitive Attentional Syndrome

(CAS) exemplifies this process, where threat-related thoughts become self-reinforcing without a natural exit condition from the loop.

A computational perspective helps clarify how attentional training disrupts maladaptive cognitive cycles. In ACT-R, production rules (procedural knowledge) operate as condition-action pairs. If a condition in working memory is met, an action is executed. Through attentional training, production rules become more efficient at recognizing maladaptive thought patterns, facilitating disengagement.

This aligns with clinical insights on the importance of developing meta-awareness, or "identifying thoughts as thoughts" (Moore, 1996) — a crucial step in breaking repetitive negative thinking. For example, an individual prone to rumination may, through attentional training, develop automatized metacognitive productions that detect and disengage from intrusive thoughts, effectively providing an exit condition (Figure 3).

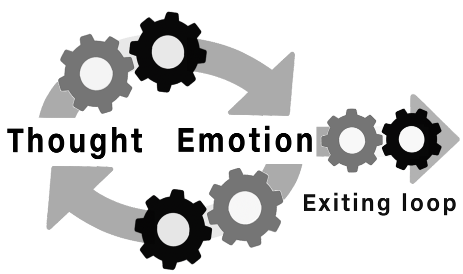

Figure 3: Maladaptive thought and emotional loops can persist without an exit condition. Attentional training develops production rules that recognize and disengage from these patterns, thereby exiting the loop.

Exiting negative emotions

Attentional training has been shown to reduce negative emotional patterns, yet the precise underlying mechanism remains unclear (Wadlinger & Isaacowitz, 2011; Wells, 2019). We propose that the same procedural mechanism that enables production rules to detect and disengage from maladaptive thoughts can also be applied to negative emotions.

This claim is supported by evidence that both declarative knowledge (propositional information) and emotions (non-propositional affective states) are represented as patterns of information within working memory and are accessible to production rules (West & Conway-Smith, 2019). As a result, attentional training fosters the development of production rules that recognize and disengage from negative emotional states, mirroring the mechanism by which it disrupts maladaptive thoughts. This process aligns with previous research suggesting that emotional regulation is supported by metacognitive proceduralization (Conway-Smith & West, 2024).

From a computational perspective, an exit condition from any cognitive loop is implemented through an exit production — a procedural rule that activates upon detecting a maladaptive emotional state. This shared mechanism suggests that metacognitive control over thoughts and emotions relies on a common process of proceduralization. As a result, attentional training provides an integrated framework for cognitive and emotional regulation, offering a mechanistic account of how structured interventions disrupt cycles of maladaptive thought and emotional reactivity.

Theoretical support for transfer effect

This analysis provides theoretical grounding for empirical findings that suggest attentional training skills are transferable — applicable across diverse tasks and cognitive domains (Ducrocq et al., 2016; Chua et al., 2021). Proceduralization helps explain this phenomenon by identifying the metacognitive informational units (i.e., production rules) that enable attentional skills to be generalized across contexts.

The role of production rules in skill transfer has been extensively studied, demonstrating their ability to facilitate both near and far transfer across cognitive domains (Singley & Anderson, 1989; Taatgen, 2013). From this perspective, attentional skills transfer when production rules become refined and automatized, allowing them to be triggered effortlessly in any context requiring attentional control. Once proceduralized, these skills stabilize focus across various tasks without requiring explicit instruction or deliberate cognitive effort.

Beyond attentional training, this framework suggests that metacognitive skill acquisition follows a generalizable learning trajectory, in which proceduralized attentional control becomes a core cognitive resource that can be redeployed across different domains, ranging from problem-solving and decision-making to emotional regulation and self-directed learning. This underscores the broader cognitive impact of attentional training beyond its immediate therapeutic applications.

Future Directions and Implications

Further empirical work is needed to test and refine this paper's claim that metacognitive proceduralization underlies the Attentional Training Technique (ATT).

First, model validation is critical. Task-based fMRI studies could examine whether attentional proceduralization involves activation in the anterior cingulate cortex and basal ganglia (Jahn et al., 2023). EEG markers may also reveal proceduralization-related changes analogous to those observed in motor and cognitive skill learning, including reduced frontal theta power and diminished prefrontal activation.

Second, the extent to which ATT produces domain-general versus task-specific improvements remains an open question. Clarifying this distinction will be essential for optimizing its application across clinical, educational, and high-performance contexts.

Third, integrating insights from metacognitive reinforcement learning (Krueger, Lieder, & Griffiths, 2017) may enhance the model's ability to represent the dynamics of proceduralization over time.

Fourth, future work could test the hypothesis that behavioral measures of attentional control — such as visual gaze stability, reaction time, and accuracy — follow a power law of learning, with rapid initial gains tapering off with continued practice.

Conclusion

This paper has provided a computational account of the metacognitive mechanisms underlying the Attentional Training Technique (ATT), offering a more precise characterization of how attentional control is proceduralized through structured training. By situating the Attentional Training Technique within the ACT-R cognitive architecture, we extend Wells' (2019) call for a more comprehensive metacognitive information-processing theory, refining our understanding of how metacognitive skills develop and automatize.

Through the application of a metacognitive skill model, we have demonstrated how proceduralization transforms attentional training from an effortful, declarative process into an automatic, self-regulating metacognitive skill. This transition is critical for enhancing attentional control, improving emotional regulation, and disrupting maladaptive cognitive loops characteristic of psychological disorders.

Beyond its clinical implications, this framework suggests that attentional skill training transfers across domains, with potential applications in education and high-performance training. A deeper computational understanding of metacognitive proceduralization can help develop more adaptive, scalable, and personalized interventions for cognitive and emotional self-regulation.

By mapping the metacognitive mechanisms underlying the Attentional Training Technique, we aim to support the development of more effective psychotherapeutic interventions and to advance the broader study of cognitive training, computational modeling, and applied metacognition.

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