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Opinion

Effortless training of attention and self-control: mechanisms and applications

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For the past 50 years, cognitive scientists have assumed that training attention and self-control must be effortful. However, growing evidence suggests promising effects of effortless training approaches such as nature exposure, flow experience, and effortless practice on attention and self-control. This opinion article focuses on effortless training of attention and self-control. We begin by introducing our definitions of effortful and effortless training and reviewing the growing literature on these two different forms of training. We then discuss the similarities and differences in their respective behavioral outcomes and neural correlates. Finally, we propose a putative neural mechanism of effortless training. We conclude by highlighting promising directions for research, development, and application of effortless training.

Highlights

A long-held belief in cognitive science is that training attention and self-control must recruit effort. Therefore, various effortful training programs such as attention or working memory training have been developed to improve attention and self-control (or executive function). However, effortful training has limited far-transfer effects.

A growing literature suggests a new way of effortless training for attention and self-control. Effortless training – such as nature exposure, flow experience, and effortless practices – has shown promising effects on improving attention and self-control.

Effortful training requires cognitive control supported by the frontoparietal network to sustain mental effort over the course of training. Effortless training engages autonomic control with less effort, and is supported by the anterior and posterior cingulate cortex, striatum, and parasympathetic nervous system (PNS).

Improving attention and self-control

Attention is foundational to our conscious experience and adaptation to the external environment. Self-control is also vital to human adaptability and success in school, work, and health [1,2]. Consequently, improving attention and self-control has been the focus of many cognitive training programs. Many of these are **effortful training** (see Glossary) programs that require sustained mental effort and cognitive control throughout training to achieve the desired outcome. However, recent work shows that it is possible to train attention and self-control effortlessly [3–5]. Such **effortless training** may provide powerful tools for enhancing and maintaining these critical capacities in the general population. Growing evidence suggests that effortless training of attention and self-control engages the anterior and posterior cingulate cortex (ACC and PCC), striatum, and parasympathetic nervous system (PNS) [6–10]. To facilitate future research and applications, we propose a neural mechanism of effortless training encompassing these regions.

Attention can be subdivided into alerting, orienting, and executive attention functions, which are thought to be supported by distinct brain regions and neurotransmitters [11–13]. Among the three attention networks, executive attention (also known as effortful control in the developmental literature) has attracted particular research interest. Executive attention involves monitoring and resolving conflicts among thoughts, feelings, and actions, and thus is heavily involved in subserving crucial executive functions and self-control. Self-control is the ability to regulate one's cognition, emotion, and voluntary behavior in accordance with internal goals [1,2]. Conceptually, exercising self-control often requires the involvement of executive attention. Indeed, both executive attention and self-control have overlapping brain circuits, including the ACC/adjacent medial prefrontal cortex (PFC) (Brodmann areas 24, 25, 32, 11) and lateral PFC (Brodmann areas 45, 46, 9, 10), further indicating the closely intertwined relationship of these two constructs [6,11].

Self-control failures are common in everyday life, and many of these have been said to arise from 'ego depletion' [7]. However, a growing number of studies demonstrate that beliefs about willpower, self-affirmation, mood, and incentives can also affect self-control [3]. These findings

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suggest that self-control depletion is a motivation-driven and attention-driven process [4,14]. A recent multilaboratory replication showed a small and significant ego depletion effect [15], whereas another preregistered multilaboratory project did not find any evidence for a depletion effect [16]. However, exploratory analyses on the full sample (i.e., ignoring preregistered exclusion criteria) detected a significant effect, suggesting that this multisite replication was inconclusive [16]. Taken together, the performance decline after initial exertion – when it is evident – is often modest in size, and may be due to reduced attention and/or motivation to exert further control [4,14]. It should be noted that one's attention capacity is also limited; thus, if one pays attention to one thing, one cannot pay full attention to others. This raises an important question about how to train attention and self-control effectively to improve their capacities.

Effortful versus effortless training

Cognitive scientists have generally assumed that training attention and self-control must be effortful [17]. This assumption has led to the development of different effortful training programs such as vigilance training [18,19], attention training [20,21], and working memory training [22,23]. These programs typically involve computerized paradigms used to improve attention, working memory, and self-control (or executive function). In particular, these adaptive training programs involve task repetitions with increasingly demanding levels of task difficulty and effort, which require cognitive control supported by the frontoparietal network to sustain mental effort over the course of training [21–23]. These programs are designed to improve cognitive performance and ameliorate behavioral problems such as attention deficit hyperactivity disorder [22]. However, findings are mixed regarding the efficacy of training (e.g., working memory training, attention training). Results show mainly selective benefits in task-related attention or working memory performance but no significant gains in other cognitive skills and domains, suggesting limited far-transfer effects [18–20,23–26].

Must training of attention and self-control be effortful? According to the **process model of self-control**, self-control can become more effortless when using strategies to prevent the experience of temptation or avoid conflict in advance [4,5]. For example, a person could avoid the meat section and only visit the vegetable section at the grocery store, a dieter could ask the waiter not to bring around the dessert cart, and if a person's spouse loves cookies and keeps them at home, the person could place them out of sight to resist the temptation. The process model illustrates various strategies such as situation selection and modification to help reduce/eradicate temptation and avoid conflict [3–5]. However, it is almost impossible to avoid or prevent self-control conflicts completely. Moreover, conflict avoidance is effortful, and sustaining avoidance requires additional inhibition of impulsive behavior [3,4]. Research has shown that experiential avoidance is linked to a wide range of behavioral problems and disorders and can be harmful in the long run [27–30].

Studies dating from the 1970s have suggested that effort can be equated with attention, and that effort/attention is a special case of sympathetic dominance of the autonomic nervous system (ANS); it is associated with an increase in metabolic activity in the brain [17]. However, growing evidence from behavioral, physiological, and neuroscience research indicates that effort cannot be equated with attention (see [31] for more details). For example, attention can also occur under parasympathetic dominance and is likely to be experienced as effortless [8,10,31]. From an effort perspective, then, there are two types of attention. One is associated with sympathetic dominance (e.g., control, tonic alertness) that handles the demands of cognitive tasks and is experienced as effortful, whereas the other is related to parasympathetic dominance (e.g., monitoring, phasic alertness) and effortlessness [8–10,13,31–33]. Therefore, training programs of attention and self-control can also be effortless when exercising effortless attention.

Glossary

Attention balanced state (ABS): a state in which there is no effort to control or manipulate stimuli or objects; instead, individuals gently and naturally observe their own awareness and accept the ongoing experience as it is. ABS is effortless and maintains the balance of attention and control.

Automaticity: the ability to carry out tasks in an automatic and effortless manner after successful learning and practice.

Effortful training: training programs that use task repetitions, such as attention or working memory, with increasingly demanding levels of task difficulty and mental effort to achieve desirable outcomes. The programs are typically computerized, and often require cognitive control supported by the frontoparietal regions of the brain to maintain mental effort over the course of training.

Effortless training: training programs that engage minimal mental effort and involve effortless practices or experiences, such as nature exposure and flow experience. The programs engage autonomic control with minimal mental effort, which is supported by the anterior and posterior cingulate cortex (ACC and PCC), striatum, and parasympathetic nervous system.

Flow experience: the complete and effortless concentration or absorption in what one is doing; one is fully immersed in a feeling of energized focus, full engagement, and enjoyment in the process of ongoing activity. Flow experience can be achieved or trained through most autotelic activities that have clear goals and balance the difficulty of the challenge with the skills of the individual. These activities include, but are not limited to, complete absorption and engagement in listening to or playing music, gaming, or reading a book. During flow states, individuals often lose track of time and are unaware of anything else.

g ratio: relative myelin thickness, which is calculated as the ratio of the axon caliber (diameter) to the fiber caliber (total diameter of axon plus its myelin sheath).

Integrative body–mind training (IBMT): a type of effortless training that stresses no effort to control or manipulate thoughts and feelings, but emphasizes an awareness of the natural state of body and mind, and accepts whatever arises in one's awareness at

Effortless training refers to practices that involve minimal mental effort or effortless experiences such as **nature exposure** and **flow experience** [6,10,34–37]. Recent behavioral evidence indicates that reduced control and effort can enhance cognitive performance [38], suggesting promising effects of effortless training on cognition (Box 1). Effortless training changes brain and bodily states effortlessly and is different from effortful training, which involves cognitively demanding tasks or processes to achieve benefits. Effortless training engages autonomic control with less effort and is supported by parts of the ACC, striatum, and PCC [6,8,39–41] (see details in the section 'Neural mechanisms of effortless training').

As shown in a series of randomized controlled trials (RCTs) using **integrative body-mind training (IBMT)** [6,8,39,42], effortless training is often accompanied by enhanced parasympathetic activity indexed by lower heart rate and skin-conductance response (SCR), greater belly respiratory amplitude, or/and high-frequency heart-rate variability (HRV). Similarly, nature exposure, a form of effortless training or experience, is associated with increasing parasympathetic regulation that supports reduced stress and anxiety, improved attention restoration, and cognitive function [36,43–45]. Moreover, flow experience is also related to greater parasympathetic activity such as greater high-frequency HRV [34,46]. However, flow experience is often induced by diverse tasks in different contexts. Therefore, different stages of flow experience may involve distinct ANS biomarkers [34].

Another key distinction between effortful and effortless training is the state of attention. In effortful training, attention is often fully devoted to the task at hand and requires all attentional resources.

each moment. IBMT originated from ancient Eastern contemplative traditions such as traditional Chinese medicine and Zen. Series of randomized controlled trials indicate that brief IBMT improves attention and self-control, and induces neuroplasticity in the ACC, PCC, and striatum through central and autonomic nervous system interaction.

Nature exposure (or experience): one type of effortless experience which includes individuals' perceptions and/or interactions with stimuli from the natural world through a variety of sensory modalities; experience can occur through conditions of real contact, window views, representations (e.g., landscape photographs), or simulations (e.g., virtual reality).

Nondual awareness: an effortless experience without subject–object dualistic structure; it is different from meditation techniques that require effort to maintain the state. The experiencer–object relationship makes the experience dual or nondual, rather than the nature of the object experienced. Nondual awareness can be experienced in a more unitary way during absorption states with minimal effort.

Process model of self-control: a model which posits that impulses are response tendencies that develop over time, which begin with the situation and end with a response tendency.

Soto Zen meditation: a type of effortless meditation with no objects, anchors, or content to focus on during the practice. The key is being aware of the stream of thoughts and allowing them to arise and pass away naturally without interference.

Transcendental meditation: a type of effortless meditation that repeats a simple mantra (a meaningless sound) during practice, which requires minimal effort and does not involve focused attention to the mantra. Instead the mantra becomes secondary in experience and ultimately disappears with practice, while self-awareness becomes more primary.

Box 1. Behavioral effects of effortless training

Mounting evidence has indicated beneficial effects of effortless training on attention and self-control, as well as certain aspects of cognitive and affective functions. We provide a selective review of representative evidence on training-related behavioral improvement.

For effortless mindfulness and meditation training, enhancement in critical aspects of executive functions or self-control has been well documented. For instance, executive attention (i.e., executive control), the ability to monitor and resolve conflicts, has been consistently detected in novice meditators [51,109,110]. Similarly, an early study comparing effortless and effortful mindfulness techniques showed superior performance in sustained attention of unexpected stimuli in the effortless group of long-term meditators [111]. Most effortless mindfulness training emphasizes effortless attention and nonreactive monitoring, and awareness of ongoing experiences such as bodily sensations or thoughts, which inevitably engage attention and self-control capacities [10,56]. Not surprisingly, there have been studies showing enhanced mood, attention, and working memory after training. Interestingly, a collection of reviews and empirical work also suggests that effortless mindfulness practices and training can have a far-transfer effect on creativity [110,112]. In particular, the improvement in creativity is theorized to be accomplished through increased divergent thinking [110], which is not trained in effortless training or practices.

Similar cognitive outcomes have been reported in other effortless training or experiences such as nature exposure. Specifically, individuals exhibited improvements in attentional control following nature exposure relative to urban exposure, as well as in related domains such as working memory and cognitive flexibility [113,114]. The far-transfer effects of nature exposure are apparent in this form of training, even though the experience does not engage these cognitive processes at all. Current theories for explaining the benefits of nature exposure are that attention is restored and replenished and that stress is reduced during exposure, thereby leading to improvement in cognitive performance [113]. Finally, flow experience, which involves effortless concentration, is another type of effortless experience that induces improvement in sustained attention task performance, such that individuals who had more state-like flow experience during a task made fewer commission errors [115].

Based on our review of behavioral effects, a converging mechanism of effortless training and experiences seems to be the ability to induce state-related changes in body and mind [21,116], as well as in multiple brain networks [21,116], which altogether cultivate optimal mental and physiological states that contribute to these behavioral effects, particularly far-transfer effects to domains beyond those specifically trained or engaged during the training or experiences. Currently, research on the duration of effortless training-related behavioral effects is limited, with some evidence showing long-lasting effects [39,117,118]. Thus, it is possible for effortless training to induce long-term learning just like effortful training [119] when individuals continue their effortless practices to translate state-related changes into more stable and long-lasting trait-like changes [117,118].

By contrast, effortless training is characterized by an **attention balanced state (ABS)**, which is shared by various effortless training approaches [6,9,47]. ABS can be perceived as a type of metacognitive monitoring that is nonpropositional and has a unique emphasis on effortlessness in the use of attention for monitoring and meta-awareness [48]. Specifically, ABS involves no effort to control or manipulate stimuli or objects; instead, individuals naturally observe their own awareness and accept the ongoing experience as it is [6,10,48]. ABS contrasts with our typical attention state which is often propositional, clinging to or suppressing our mental states and behaviors through effort and control. It changes our tendency to avoid (or resist) dislikes and cling (or attach) to likes. Therefore, ABS initiates new conditioning to guide our attention through an open, soft, and flexible mode [6]. With practice, effortless attention may become the new attention habit [6,31]. Some researchers have used different terms to describe the effortless state, such as effortless mindfulness and pure awareness, which can all be experienced directly through a variety of effortless practices [49,50]. Table 1 summarizes the key differences between effortful and effortless training.

Neural mechanisms of effortless training

Mental processes of effortless training involve the automatic detection and allocation of appropriate effort, attention, energy, and resource to effortlessly monitor and regulate global neural dynamics, homeostasis, ongoing performance, and experience. The state is indexed by ABS and skill **automaticity** [6,8]. Therefore, we speculated that the ACC-PCC-striatum (APS) circuit supports effortless training and its related processes (Figure 1).

To clarify the neural mechanisms underlying effortless training, we consider studies that mainly employed randomized designs and effortless training approaches. These include IBMT, **transcendental meditation (TM), Soto Zen meditation**, and **nondual awareness** practices that use minimal effort and effortless strategies. Although training techniques are diverse, they share a focus on effortless training, and thus might be expected to engage similar brain systems [6,8,50,51].

ACC

To achieve ABS in effortless training, global and dynamic monitoring of ongoing internal and external experiences is needed. However, the monitoring process in effortless training should not be equated with effortful control processes. In fact, monitoring and control processes usually recruit different levels of effort. Monitoring processes, such as conflict and error detection (e.g., phasic alertness), are often associated with the ACC. By contrast, more lateral frontal areas such as the dorsal lateral prefrontal cortex (dlPFC) are usually involved in the actual control operations such as working memory [12,52]. Although the ACC is also involved in these effortful-related tasks, it is likely to play an effort valuation and allocation role that determines how much effort to exert, as shown by most effort-based decision-making studies [53,54]. Relatedly, in a case study, a patient had a large left-hemisphere frontal lesion including the ACC but could perform effort-based tasks such as the Stroop task. However, the patient had no subjective

Table 1. Comparison of effortful and effortless training

Effortful training	Effortless training
Frontoparietal regions	ACC, PCC, striatum
Sympathetic dominance	Parasympathetic dominance
Rigid and fixated attention mode	Open, soft, and flexible attention mode
Continuous effort on the object(s)	Rest, as innate awareness effortless

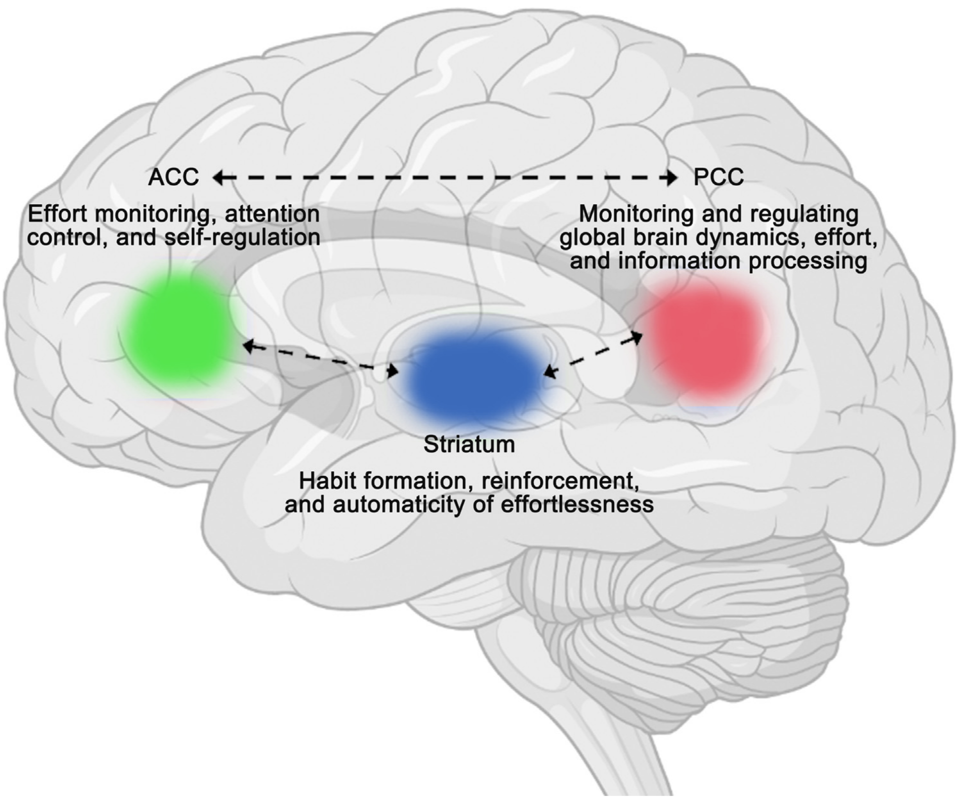

Figure 1. Core brain regions and their functions during effortless training. Three colored areas represent the anterior cingulate cortex–posterior cingulate cortex (ACC–PCC)–striatum (APS) and their corresponding functions during training. The broken line arrows indicate that these regions actively communicate with each other during effortless training.

feeling of difficulty or effort, such as perceiving incongruent trials as more difficult than congruent trials, and also did not show any change in SCR, an index sensitive to effort and control. By contrast, healthy participants experienced increases in subjective effort and control in a Stroop task, which were correlated with higher SCR. These results suggest that ACC plays an important role in monitoring and the valuation of mental effort and control, and may serve as a neurobiological basis for effortless-related processes [55].

Examining the literature on effortless training programs, the same brain region emerges. IBMT, a type of effortless mindfulness training, stresses no effort to control or manipulate thoughts and feelings but instead encourages an awareness of one's natural state of mind and acceptance of whatever arises in one's awareness at each moment. When we gently and naturally observe our awareness, our attention is not focused on any particular objects (e.g., thoughts, emotions, sensations). Instead, our awareness – which includes not only the observer but also the content being observed – gradually and naturally merges (i.e., nondual awareness) [6,8]. IBMT shares key components with other forms of effortless training that engage effortless practices [6,8,39]. Our series of RCTs of IBMT indicate that, compared with relaxation training, short-term IBMT increases brain activity in the ACC, PCC/precuneus, insula, and striatum, as well as indices of parasympathetic activity [6,8,39,42,56]. These results suggest that effortless practices such as IBMT can be learned in a short time, and are generally supported by enhanced parasympathetic activity of ANS regulation and the ACC [6,42]. Similarly, a recent 10-year longitudinal study of

IBMT also showed the same parasympathetic dominance and ACC participation during and after long-term effortless practice [39].

In mindfulness meditation, practitioners often start with more effort and control, as indicated by enhanced dlPFC activation, but then gradually use more of a monitoring strategy with less or minimal effort to maintain the meditative states that primarily engage the ACC [10,56,57]. These findings suggest that mental training has different stages, such that effort and control usually decrease with skill levels or effortless strategies [6,56].

What would happen if mental training started with minimal effort and maintained effortlessness throughout practice? We found that 2–4 weeks of IBMT (10–20 half-hour sessions) led to higher fractional anisotropy in white matter pathways surrounding the ACC [58,59]. We speculated that the change in white matter occurred as a result of the increased frontal theta following effortless training [42,60]. For instance, in electroencephalograph (EEG) studies of IBMT, compared with relaxation training, 1–2 weeks of IBMT increased both theta and alpha activity in the ACC. Moreover, frontal-midline ACC theta power correlated with greater parasympathetic activity [6,42].

We further tested the role of frontal theta by using optogenetics to produce increased output from the ACC over 20 half-hour sessions in mice [61]. The mice exposed to near theta rhythms (1 and 8 Hz stimulation) showed a lower **g ratio**, indicating improved myelination of pathways close to the ACC in comparison to those far from theta stimulation. The mice showed no change in their motor behavior during the passive stimulation, suggesting that the stimulation did not cause any change in effort when it was presented. However, following near theta stimulation the mice showed lower levels of fear or anxiety when given the chance of choosing a dark or light portion of the box in comparison to controls. These results indicate that frontal theta may induce both white matter change and reduced negative emotion. Moreover, the brain and behavioral changes did not require any effort from the mice. Several studies have also shown that brief exposure to theta from scalp electrodes or auditory input can improve attention and memory, perhaps through enhanced long-term potentiation [62–64].

Evidence from other effortless practices corroborates the important role of ACC in maintaining ABS. Nondual awareness refers to an effortless state without subject–object dualistic structure and differs from some meditation techniques that require effort to maintain the meditative state [65]. One EEG study analyzed alpha, beta, and gamma in four types of meditation, including nondual awareness. During meditation sessions, the study team detected increased gamma in the ACC, precuneus, and superior parietal lobule, and increased beta in the insula that may be related to nondual awareness [66]. However, they did not explore theta or delta activity [66]. In a carefully designed study distinguishing nondual awareness from an effortful meditative state, higher EEG power of theta, alpha, and delta in brain midline areas (ACC and PCC/precuneus) and other areas were detected during the nondual state compared with the effortful meditation state. By contrast, higher power of gamma was found in the effortful meditation state than in the nondual state [50]. Taken together, effortless training seems to be associated with more theta and alpha activity in the ACC and PCC/precuneus.

Growing evidence also shows that ACC and its subdivisions – such as dorsal ACC (dACC) or anterior mid-cingulate cortex (aMCC) – serve as key regions of the multimodal integration network and the large-scale allostatic/interoceptive system [67,68]. This integration guides the nervous system towards allocating the optimal amount of effort to achieve a goal, monitoring and regulating internal states of the body to prepare for action. The ACC estimates future energy or metabolic needs, as well as the value of effort required for potential behaviors [68]. Together, although global brain activity reduces during effortless training, the ACC seems to be actively engaged to monitor, regulate, and maintain the effortless state.

PCC

PCC is a key hub of the default mode network. It is associated with information processing and is implicated in a diverse range of functions such as self-awareness, attention allocation, adaptive behavior, cognitive processes, and emotion regulation [40,41,69,70]. In studies of effortless training, our RCTs show that 1–4 weeks of IBMT improves PCC activity, metabolism, white matter connectivity, and gray matter volume when compared with an active control (relaxation training) [6,40]. Similarly, structural neuroimaging studies show increased gray matter density in PCC for novices following a period of meditation and increased PCC volume in long-term expert meditators relative to controls [71,72].

TM uses a repeated simple mantra that requires minimal effort to become skillful in the short term; it is different from focused attention meditation which uses more effort in the early stage and takes a longer time to grasp [73,74]. One study compared two groups with 1 month and 5 years of TM practice [75]. The two groups reported similar effortless experiences, consistent with prior results between novice and expert TM subjects [73,76]. Moreover, the two groups showed similar EEG patterns: more theta and alpha activity in the PCC and adjacent precuneus during rest and TM practice [75]. Similarly, long-term Soto Zen meditators using no effort to focus strategy also showed more brain theta activity relative to a control group [77]. Although nondual awareness is not yet fully understood, some studies have provided preliminary evidence toward a better understanding of effortless training. One fMRI study suggested that the neural correlates of nondual awareness are associated mainly with the precuneus network, adjacent to the PCC [49,78]. Relatedly, increased PCC activity is associated with distancing, one of the mindfulness skills that emphasizes the experience of presence without judgment [79], consistent with recent meta-analyses showing that the PCC is one of the main regions implicated in the upregulation and downregulation of emotion [80–82]. Moreover, the PCC/precuneus also participate in conscious awareness, which may explain why enhanced interoceptive awareness is often observed following mindfulness [56,83,84]. Taken together, a recent review article suggested a new function of the PCC, which involves monitoring and regulating global brain dynamics, effort, performance, and resources [85].

The PCC has very high levels of metabolic consumption, indicating an important role in global information monitoring and processing. For example, aging and aging-related cognitive decline, and disorders such as mild cognitive impairment and Alzheimer's disease, are associated with deficits in global information processing, which are often accompanied by decreased PCC activity and metabolism (e.g., glucose metabolic rate) [86,87]. By contrast, high-performing elderly participants have greater gray matter in the PCC, indicating a putative biological signature of optimal aging [88]. During cognitively demanding tasks or meditation training that requires a considerable amount of effort, PCC typically shows deactivation [56,85,89]. By contrast, effortless meditation training shows increased PCC/precuneus activity and PCC gray matter volume [39,42,75]. Relatedly, the default mode network, which encompasses the PCC, is associated with the development of automaticity [90,91] and automated information processing [92], such that increased functional activity/connectivity involving the default mode network is observed during these automated or likely effortless processes. Finally, research in non-human primates and humans using diffusion imaging has shown that the PCC is connected to the ventromedial PFC, such as ACC through the cingulum bundle [93,94], suggesting that the ACC and PCC interact to serve the monitoring and regulating role during effortless training.

Striatum

Research has shown that the striatum is associated with multiple functions such as reward processing, learning success, automaticity, habit formation, and intrinsic motivation [95–97]. A review article concluded that increased striatum activity is associated with enhanced learning during effortful working memory training, and that striatum activity before training predicts the amount of transfer after training [22].

Automaticity is the ability to carry out tasks or actions in an automatic and effortless way after successful learning and practice. A task-related global reduction and a shift in activation from cortical to subcortical areas are often observed once automaticity has been achieved [98]. In a study that compared the pattern of activation during the performance of an unpracticed and a practiced task, the PFC/ACC were activated during the performance of the unpracticed task, whereas activation shifted to the insula in the practiced task [99]. The insula has extensive interconnections with subcortical regions, particularly with the basal ganglia/ striatum. This change in activation may be due to the increasing automaticity associated with the practiced task which results in a reorganization of functional associations [99]. Other studies also showed similar results [100–102]. For instance, during learning and the acquisition of automaticity, global reduction occurred but no reduction in activation of basal ganglia (particularly the striatum) was detected, indicating the role of the striatum in automaticity [101]. Together, these findings suggest that different brain structures are involved during automatic and controlled processing, with effortfully controlled processing likely relying on cortical regions such as the PFC, but effortlessly automatic processing and behavior likely relying more on subcortical regions, namely, basal ganglia and particularly the striatum [98]. It is important to note that the striatum is composed of three nuclei (caudate, putamen, nucleus accumbens), each of which has been shown to be associated with effortless processes. However, whether these have distinct or specific roles in effortless training warrants further investigation.

Based on the existing literature, we propose the ACC, PCC, and striatum as key neural correlates of effortless training. We further propose that the insula serves a primary role in switching between learning and automaticity to support automatic and effortless behavior, consistent with other studies showing that the insula is related to state switching and other functions [56,103,104]. Finally, it is worth noting that other higher cortical areas may also be involved in effortless processes, and this requires further investigation. Our proposed neural correlates of effortless training serve as the first step in moving forward the research on effortless training and its mechanisms.

Concluding remarks

Training effortless attention and self-control is possible and appears to be supported by the APS circuit and the PNS. Trying not to try is the spirit of effortless training, which can be attained through appropriate practices. However, research on effortless training is still in its infancy (see Outstanding questions). Although we have described the main neural substrates involved in effortless training, we need to better understand their precise mechanisms and dynamics during effortless processes. Additionally, we need to understand how to effectively apply effortless training to improve performance and promote health and wellbeing. Finally, other less effortful and effective training approaches that focus on different domains – such as emotion regulation [105–107] and physical health [108] – require further investigation. Different effortless training approaches may share an overlapping neural mechanism that supports effortlessness, but each may involve neural mechanisms that are unique to the particular training approach.

Outstanding questions

Short-term effortless training can induce changes in the brain's gray and white matter, but how does effortless training lead to these rapid changes? Does it induce such rapid changes by engaging both self-control and reward systems?

Are there any differences in training effects between short-term and long-term effortless training? In general, training effects are dose-dependent, but different effortless techniques may differentially contribute to the extent of benefits gained from training.

People respond to training differently; are there any individual differences in the effects of effortless training? How can the responders and nonresponders of effortless training be characterized? What are the driving factors (e.g., genes, brain function and/or structure, or physiological markers) that may constrain or facilitate the effects of effortless training?

What are the roles of subdivisions of the ACC, of subdivisions of the PCC, and of the subregions of the striatum in effortless training? What are the dynamic and causal relationships among the ACC, PCC, and striatum during effortless training?

How can effortless training be taught effectively? How can effortless training be translated into daily life to improve performance and induce behavior change or habit formation? How can effortful and effortless training be combined to potentially further enhance training outcomes?

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Declaration of interests

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