Executive Function Plasticity: A Study on Task Switching Training

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Abstract

Task-switching training represents one approach to enhancing individual executive function. Researchers have utilized various task paradigms to conduct task-switching training. Empirical findings demonstrate that task-switching training can reduce switch costs and improve performance on other cognitive tasks, with training effects persisting for a certain duration. Nevertheless, some studies have failed to observe significant transfer or maintenance effects. Factors such as age, involvement of other executive components, cognitive flexibility, and strategies may moderate training efficacy. Task-switching training may enhance switching ability by improving individuals' capacity to resolve task-set conflicts, increasing engagement of the fronto-parietal brain network associated with task switching, and establishing bottom-up automatic control. Future research should standardize existing methodologies and procedures, examine task-switching training from the perspective of both integrated and fractionated structural characteristics of executive function, and explore more flexible training modalities, such as tDCS technology.

Full Text

Preamble

Plasticity of Executive Function: A Study of Task-Switching Training

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Abstract: Task-switching training represents one approach to enhancing individual executive functions. Researchers have employed various task paradigms to investigate task-switching training, with findings indicating that such training can reduce switch costs and improve performance on other cognitive tasks, with effects lasting for a certain period. However, some studies have failed to observe significant transfer or maintenance effects. Age, involvement of other executive components, cognitive flexibility, and strategy use may influence training efficacy. Task-switching training may improve shifting ability by enhancing conflict resolution between task sets, increasing engagement of the frontoparietal network associated with task switching, and establishing bottom-up automatic control. Future research should standardize existing methodologies and procedures, examine task-switching training from the perspective of both unified and separable executive function structures, and explore more flexible training methods such as tDCS technology.

Keywords: shifting; executive functions; task-switching training

Shifting, updating, and inhibition are considered three relatively independent central executive functions (Miyake & Friedman, 2012). Among these, shifting refers to the process of switching from one cognitive task to another, emphasizing the ability to flexibly transition between tasks, goals, or mental sets (Collette & Van, 2002). Jersild (1927) first employed the task-switching paradigm to investigate individual switching processes, finding that participants exhibited significantly longer reaction times when performing switch tasks compared to repeated tasks—a phenomenon known as time loss or "switch cost." Building on this foundation, increasing scholarly attention has focused on switching processes, with growing basic research examining switch costs and their origins, components of switching, processing modes, the relationship between time intervals and switch costs, and the neurophysiological mechanisms underlying switching (Kiesel et al., 2010; Koch, Gade, Schuch, & Philipp, 2010; Koch, Poljac, Muller, & Kiesel, 2018; Sun Tianyi, Xiao Xin, & Guo Chunyan, 2007).

Executive function effectively predicts individual academic achievement, socioeconomic status, and physical health (Karbach & Unger, 2014). Consequently, many scholars have investigated how cognitive training might enhance executive functions (Talanow & Ettinger, 2018). Relevant research has encompassed healthy populations across various age groups (Guye & Bastian, 2017; Wang, Luo, Shi, Yu, & Wang, 2018; Wang & Ku, 2018; Zhao Xin & Zhou Renlai, 2014) as well as special populations (Chacko et al., 2014; Pan Dongni & Li Xuebing, 2017). As one of the most commonly used cognitive abilities in daily life (Sun Tianyi et al., 2007; Zhao et al., 2018), shifting ability is crucial for multitasking operations, particularly in complex scenarios—for instance, when an employee stops work to answer a ringing phone, when a driver alternates attention between forward and side road conditions, or when a pilot monitors flight status while communicating with air traffic control. Therefore, the trainability of shifting ability has attracted scholarly attention. Karbach and Kray (2009) demonstrated that task-switching training can improve not only shifting ability but also inhibition, working memory, and fluid intelligence, linking task-switching training to executive function plasticity. Since then, increasing research has explored how task-switching training might enhance executive functions (Gaál & Czigler, 2018; Koch et al., 2018; Sabah, Dolk, Meiran, & Dreisbach, 2018; Zhao, Wang, & Maes, 2018). Task-switching training has now become an established method for improving executive functions (Pereg, Shahar, & Meiran, 2013). This paper reviews research on task-switching training across four dimensions: training paradigms, training effects, influencing factors, and mechanisms underlying the plasticity of shifting ability.

Task-switching paradigms include alternating-runs, task-cueing, intermittent-instruction, and voluntary task-switching paradigms (Kiesel et al., 2010). The intermittent-instruction paradigm presents instructions or cues between two or more trials indicating which task to perform next, while the voluntary task-switching paradigm requires participants to voluntarily select task rules and respond to target stimuli (Arrington & Logan, 2004; Jiang Hao, 2018). In task-switching training research, investigators have primarily employed alternating-runs or cueing paradigms; thus, this review focuses on these two training approaches.

2.1 Alternating-Runs Paradigm

Rogers and Monsell (1995) proposed the alternating-runs paradigm (AR-TS), in which different tasks follow a fixed sequence (e.g., AABBAABB···), with task rules A and B alternating every two trials. Participants must remember both task rules and the task sequence during execution. Many researchers have used this paradigm for cognitive training. For example, Karbach and Kray (2009) required participants to switch between tasks A and B in a fixed sequence to investigate whether cognitive training could improve shifting ability and produce transfer effects. Kray, Karbach, Haenig, and Freitag (2011) examined whether alternating-runs training could enhance executive control in children with ADHD. Zinke, Einert, Pfennig, and Kliegel (2012) employed the alternating-runs paradigm to investigate executive control plasticity in adolescents. Pereg et al. (2013) used alternating-runs training to examine the role of updating components within this paradigm.

2.2 Cueing Paradigm

The task-cueing paradigm (CUE-TS) represents another common task-switching approach (Meiran, 1996). In this paradigm, task sequences are randomly presented, and cues (e.g., colors or words) appear during each trial to clarify the upcoming task type. Cues may appear simultaneously with or before the stimulus. Many researchers have used the cueing paradigm to train shifting ability, typically with simultaneous cue-stimulus presentation. For instance, Tayeb and Lavidor (2016) required participants to judge digit magnitude (greater or less than 5) against a blue background and parity (odd or even) against a gray background, investigating whether tDCS stimulation of the dorsolateral prefrontal cortex could improve switching performance. Gaál and Czigler (2018) asked participants to judge whether letters were vowels or consonants under yellow or orange cues, and whether numbers were odd or even under green or blue cues, to examine training effects in the cueing paradigm.

2.3 Differences Between Task-Switching Types

Task-switching paradigms can be categorized as predictable or unpredictable. The alternating-runs paradigm, with its fixed task sequence, is considered predictable, whereas the cueing paradigm (with simultaneous cue and stimulus presentation) is unpredictable (Deng Yuqin, Wang Yan, Ding Xiaoqian, & Tang Yiyuan, 2015). These types differ in cognitive processing modes. Task switching involves both endogenous preparation and exogenous adjustment (Guo Chunyan & Sun Tianyi, 2007). Under predictable conditions, individuals must reconfigure task settings, a process comprising two phases (Kiesel et al., 2010; Rogers & Monsell, 1995). The first phase occurs before new stimulus onset, when individuals inhibit the previous task set and activate the current one—this constitutes endogenous preparation. The second phase occurs upon stimulus presentation, when the new stimulus triggers a change in response rules, switching to and executing the current task' s response rules—this is exogenous adjustment. Thus, predictable switching involves both processes. Under unpredictable conditions, the unknown task sequence prevents advance preparation; rule changes and response execution can only occur when the new stimulus appears. Consequently, unpredictable switching relies primarily on exogenous adjustment (Sun Tianyi, Xu Yuanli, & Guo Chunyan, 2011).

Research suggests that different cognitive processing modes may involve distinct brain regions (Sohn, Ursu, Anderson, Stenger, & Carter, 2000). Accordingly, different switching tasks activate different brain areas. Dreher, Koechlin, Ali, and Grafman (2002) used fMRI to investigate neural mechanisms of different switching types, finding that predictable sequence tasks activated the right hippocampus, medial prefrontal cortex, and posterior cingulate cortex; unpredictable sequence tasks activated bilateral medial parietal cortex; and random sequence tasks with fixed stimulus timing activated the right cerebellum. Additionally, left frontal cortex showed greater activation when both task order and timing were predictable, whereas lateral prefrontal cortex was more active when both were unpredictable. Sun Tianyi et al. (2011) examined ERP evidence for predictable versus unpredictable switching, finding that under predictable conditions, switching was sequentially managed by temporal and parietal regions—endogenous preparation originated in the left temporal area, while exogenous adjustment originated in the right parietal area. Under unpredictable conditions, switching simultaneously activated left and right frontal regions, suggesting that the neural substrates of exogenous adjustment differ between predictable and unpredictable conditions. Kim, Johnson, Cilles, and Gold (2011) conducted a meta-analysis of brain imaging studies on different switching types, revealing that stimulus-based switching activated premotor cortex and dorsal anterior cingulate; response-based switching primarily activated left dorsolateral prefrontal cortex and rostral dorsal anterior cingulate; and anterior prefrontal cortex participated in cognitive set switching. Kim, Cilles, Johnson, and Gold (2015) used activation likelihood estimation across 36 task-switching studies with 562 activation coordinates, finding that perceptual switching activated dorsal premotor cortex; contextual switching activated frontopolar cortex, including lateral and medial prefrontal cortex (BA10); and both response-based and contextual switching activated dorsolateral prefrontal cortex. These results confirm that task switching involves coordinated processing across different brain regions, with varying involvement depending on switching type.

From a training perspective, predictable and unpredictable switching tasks may produce different training effects. For example, Minear and Shah (2008) randomly assigned 93 participants to predictable training, unpredictable training, or control groups, finding that the predictable training group showed significantly greater reduction in switch costs than the unpredictable group. Both training groups exhibited significant near-transfer effects, but the predictable group showed reduced switch costs on similar tasks, while the unpredictable group showed reduced mixing costs on similar tasks. However, some studies have found no differences in training effects between task types. Sabah et al. (2018) found that different task types did not mediate effects on switch cost reduction or transfer. Additionally, Pereg et al. (2013) found that training on predictable switching (alternating-runs) did not transfer to unpredictable switching tasks, suggesting fundamental differences in cognitive structure and processing between predictable and unpredictable switching.

2.4 tDCS and Switching Training

Most previous task-switching training studies have employed pre-test—training—post-test designs focusing on cognitive and behavioral training (Gaál & Czigler, 2018; Karbach & Kray, 2009; Kray & Feher, 2017). Recently, transcranial direct current stimulation (tDCS) has been applied in cognitive plasticity research (Strobach & Antonenko, 2016). tDCS is a non-invasive technique that uses constant, low-intensity direct current (1-2 mA) to modulate cortical neuronal activity, increasing or decreasing brain excitability through polarity manipulation. Studies show that short-term tDCS can affect shifting ability (Nejati, Salehinejad, Nitsche, Najian & Javadi, 2017; Leite, Carvalho, Fregni, Boggio & Goncalves, 2013). Nejati et al. (2017) applied 1 mA tDCS to the dorsolateral prefrontal cortex and orbitofrontal cortex of children with ADHD for 15 minutes, finding that anodal stimulation of the left dorsolateral prefrontal cortex combined with cathodal stimulation of the right orbitofrontal cortex significantly improved WCST performance. Leite et al. (2013) stimulated bilateral dorsolateral prefrontal cortex in 16 participants during letter/digit naming and vowel-consonant/odd-even switching tasks, finding that stimulation location affected task-switching ability. In letter/digit naming, left anodal/right cathodal stimulation improved switching performance while left cathodal/right anodal stimulation improved accuracy. In vowel-consonant/odd-even tasks, left anodal/right cathodal stimulation improved accuracy but reduced switching performance. These results demonstrate a causal relationship between dorsolateral prefrontal cortex and switching processing, and provide some evidence for lateralization effects.

Some researchers have used long-term tDCS to enhance shifting ability. Huo et al. (2018) stimulated the left dorsolateral prefrontal cortex of healthy older adults daily for 30 minutes over 10 days, testing updating, inhibition, and switching before, after, and three months post-stimulation. Long-term tDCS did not improve executive functions, suggesting that tDCS alone cannot enhance cognition and that combining brain stimulation with behavioral training may be necessary. Tayeb and Lavidor (2016) assigned participants to left anodal/right cathodal (LA-RC), left cathodal/right anodal (LC-RA), or sham stimulation groups, requiring them to judge digit magnitude against blue cues and parity against gray cues during stimulation. After one week of training, real stimulation groups showed significantly improved switching ability compared to sham, with the LA-RC group showing particularly reduced switch costs. These findings demonstrate that combined brain stimulation and behavioral training can effectively improve shifting ability and provide further evidence for lateralization effects in the dorsolateral prefrontal cortex.

3.1 Training Effect Evaluation

Evaluation of task-switching training effects includes assessment of the training itself and its near-transfer and far-transfer effects. Researchers typically measure shifting ability and near-transfer using alternating-runs (Kray & Feher, 2017) or cueing tasks (Pereg et al., 2013; Zinke et al., 2012) that differ from the training content. Far-transfer effects are assessed through inhibition, updating, working memory, and fluid intelligence measures. Common assessments include Stroop (Karbach & Kray, 2009), Flanker (Zinke et al., 2012), and go/no-go tasks (Brocki & Tillman, 2014) for inhibition; n-back tasks (Kray & Feher, 2017) for updating; reading span, counting span, digit ordering, and digit backward tasks for working memory; and matrix reasoning (Kray et al., 2011; Sabah et al., 2018) and Raven' s Progressive Matrices (Kray & Feher, 2017) for fluid intelligence.

3.2 Transfer Effects

Most studies indicate that task-switching training reduces individual switch costs (Baniqued et al., 2015; Strobach, Liepelt, Schubert, & Kiesel, 2012; Tayeb & Lavidor, 2016). Researchers have also found improved performance on untrained switching tasks (near-transfer effects) (Minear & Shah, 2008; Karbach & Kray, 2009; Buitenweg, Murre, & Ridderinkhof, 2012; Kray & Feher, 2017; Gaál & Czigler, 2018; Zhao et al., 2018), and potential enhancements in inhibition, updating, working memory capacity, and fluid intelligence (far-transfer effects). Some studies have reported broad far-transfer effects (Anguera et al., 2013; Karbach & Kray, 2009; Kray et al., 2011). For instance, Karbach and Kray (2009) found significant far-transfer to Stroop performance, verbal and spatial working memory, and fluid reasoning. Kray et al. (2011) obtained similar results in a clinical population, showing that task-switching training in children with ADHD improved inhibition and verbal working memory. However, other studies have found limited transfer effects (Zinke et al., 2012; Pereg et al., 2013; Kray & Feher, 2017; Zhao et al., 2018). Zinke et al. (2012) found that training reduced mixing costs on structurally similar untrained switching tasks but showed limited far-transfer to choice reaction time and updating tasks, with minimal effects on inhibitory control. Pereg et al. (2013) observed near-transfer only to structurally identical alternating-runs tasks, with no far-transfer to inhibition or choice reaction time tasks. Zhao et al. (2018) found that cue-stimulus intervals of 300ms and 600ms significantly reduced switch costs and produced near-transfer, but no far-transfer effects on interference control, response inhibition, working memory, or IQ.

3.3 Maintenance Effects

Maintenance effects represent a crucial criterion for cognitive training effectiveness. Brehmer, Westerberg, and Bäckman (2012) conducted a five-week multitasking working memory training with 55 young adults (20–30 years) and 45 older adults (50–70 years), finding significant transfer effects maintained three months post-training. Tennstedt and Unverzagt (2013) trained 2,802 older adults (65+ years) for 5–6 weeks in memory, reasoning, and speed tasks, with effects lasting 1–2 years and five- and ten-year follow-ups showing better daily functioning in trained groups. However, these studies involved multiple or complex training tasks with only general shifting components. Therefore, some researchers have specifically examined maintenance effects of task-switching training (Gaál & Czigler, 2018; Kray & Feher, 2017). Gaál and Czigler (2018) used an adaptive cueing paradigm with 39 young women (18–25 years) and 40 older women (60–75 years) for eight hours of training, finding significant near-transfer and partial far-transfer (improvements in switching variants and executive aspects of alerting and orienting networks) maintained one year later. Kray and Feher (2017) assigned 81 young and 82 older adults to cued-univalent, cued-ambivalent, uncued-univalent, or uncued-ambivalent groups for four 30-40 minute training sessions, finding significant near-transfer and limited far-transfer across ages, but only ambivalent-stimulus older adults maintained effects at six months. Overall, research on maintenance effects remains limited, and future studies should prioritize this important aspect.

4 Factors Influencing Transfer and Maintenance Effects

In task-switching training, variations in task settings (paradigm, duration) and assessment methods may produce different transfer and maintenance effects (Zhao et al., 2018). Additionally, age, involvement of other executive components, task variability, and strategy use may influence training outcomes.

4.1 Age

Multiple studies show that children and older adults exhibit more pronounced training effects than young adults (Karbach & Kray, 2009; Karbach & Unger, 2014; Kray & Feher, 2017; Gaál & Czigler, 2018). However, children show less transfer when training content varies, possibly because variable content increases cognitive load beyond children' s processing capacity (Karbach & Kray, 2009; Kray, Gaspard, Karbach, & Blaye, 2013). Additionally, children's baseline executive function levels and caregivers' executive function may affect outcomes (Blair, 2016). Kray and Feher (2017) found older adults showed greater improvements than young adults when switching to new untrained tasks. Gaál and Czigler (2018) found older adults showed greater performance improvements on non-informative cue switching and color/shape switching tasks after informative cue training. According to the compensation account hypothesis (Karbach & Unger, 2014), high-performing individuals benefit less from intervention because they are already near optimal levels, suggesting baseline cognitive level should negatively correlate with training gains. Young adults' higher baseline levels produce less obvious benefits compared to cognitively declining older adults, making older adults prime candidates for cognitive intervention.

4.2 Involvement of Other Executive Function Components

Unlike other cognitive training that yields limited transfer, task-switching training produces relatively broad transfer effects (Melby-Lervåg & Hulme, 2013; Shipstead, Redick, & Engle, 2012) because switching itself requires multiple executive control abilities (Kiesel et al., 2010; Karbach & Unger, 2014; Gaál & Czigler, 2018), including attention maintenance, task set reconfiguration, updating of task goals or stimulus-response mappings, selective processing of task rules, and inhibition (Yeung, Nystrom, Aronson, & Cohen, 2006). Therefore, training material selection differentially engages other components, potentially affecting transfer effects. Kray and Feher (2017) manipulated inhibition demands (through stimulus ambivalence) and working memory demands (through cue presence) in switching training, finding these components unrelated to shifting improvement. However, older adults in high-inhibition-demand training showed more pronounced near-transfer effects maintained over six months, suggesting that control processes required to resolve interference between competing tasks are key to transfer in older adults (Anguera et al., 2013). Zinke et al. (2012) found limited far-transfer to choice reaction time and updating tasks, implying updating may be closely related to training effects. Pereg et al. (2013) used alternating-runs training and found near-transfer only to structurally identical tasks, with no far-transfer to updating tasks, suggesting that alternating-runs training involves working memory updating but at low levels. In other words, components with high involvement (e.g., inhibition) may substantially affect training effects, while those with low involvement (e.g., updating) may not. From the perspective of executive functions as both unified and separable (Miyake & Friedman, 2012), task-switching training engages multiple components, and training multiple executive functions may better transfer to other tasks.

4.3 Task Variability

From an evolutionary perspective, learning in variable environments is more effective because variability promotes flexibility, facilitates rule learning, and enables transfer of skills to new contexts through prefrontal cortex mediation (Cole, Etzel, Zacks, Schneider, & Braver, 2011). Thus, variability may be one factor enabling broad transfer effects. Karbach and Kray (2009) found that variable training content produced less transfer in children but broader transfer in adults. Sabah et al. (2018) used short-term task-switching training to examine effects of content and sequence variability, finding that fixed-content tasks produced faster learning gains, but variable-content training yielded significantly lower switch costs on untrained tasks, indicating greater training effectiveness. These results suggest task content variability is a means to enhance positive transfer and avoid negative transfer.

4.4 Strategy

Some researchers have examined relationships between verbal self-instructions (VSI) and task-switching training. Karbach, Mang, and Kray (2010) investigated VSI effects on transfer in older adults, finding no substantial role during training but significant switch cost reductions at post-test. Kray et al. (2013) examined VSI in children (8–13 years), similarly finding that VSI only improved near-transfer after training. These studies suggest limited transfer of strategy training, with better auxiliary effects on well-trained shifting abilities. Zinke et al. (2012) examined whether vigorous exercise before training could enhance effects, but found no enhancement. Additionally, during training, individuals may adopt inappropriate strategies to increase response speed, such as orienting only to part of stimulus combinations—focusing only on letters (or numbers) to make correct judgments (Gaál & Czigler, 2018).

5 Mechanisms of Shifting Plasticity

The three core functions of working memory' s central executive system are inhibition, updating, and shifting (Miyake & Friedman, 2012). Previous work has summarized mechanisms underlying inhibition and updating plasticity (Zhao Xin, Chen Ling, & Zhang Peng, 2015; Zhao Xin, Xu Yiwenjie, & Huo Xiaoning, 2016; Liu Chunlei & Zhou Renlai, 2012). This section analyzes mechanisms of shifting plasticity from perspectives of cognitive processing, brain activity, and automatic control.

Task-switching training may improve shifting ability by enhancing conscious cognitive control. From a cognitive processing perspective, training may improve conflict resolution between task sets, thereby improving performance. Minear and Shah (2008) found reduced mixing costs after training, suggesting that a single switch activates both task sets, creating intense competition that training may resolve through enhanced attentional control. From a brain activity perspective, training may increase engagement of the frontoparietal network associated with task switching, particularly prefrontal regions involved in conscious cognitive control (Zhao Xin et al., 2015). For example, Gaál and Czigler (2018) found that just eight hours of training could alter P3b and N2 components. Olfers and Band (2018) found increased N2 amplitude after cognitive flexibility training. These results indicate training affects conscious cognitive control. Tayeb and Lavidor (2016) found that activating prefrontal cortex during training significantly improved shifting ability, confirming the positive role of cognitive control-related brain regions. Zhao Xin et al. (2015) noted that inhibition training can improve effects through top-down conscious inhibitory control, while Zhao Xin et al. (2016) suggested updating training can improve mental function by altering brain activation patterns and structure. Thus, plasticity across all three core executive functions is intimately related to brain activity, particularly frontal cortex function.

Second, task-switching training may improve shifting ability by establishing bottom-up automatic control. Studies show improved switching performance after unpredictable task-switching training (Minear & Shah, 2008; Kray & Feher, 2017; Sabah et al., 2018; Gaál & Czigler, 2018). As unpredictable switching is externally triggered and relies primarily on exogenous adjustment, these results suggest that abilities related to automatic control—such as changing previous response rules, switching to current task rules, and executing responses when facing new stimuli—may be enhanced.

Overall, research on mechanisms underlying task-switching training plasticity remains limited, with many questions unresolved. For example, which brain regions are altered by training and how? When do these changes occur during training? Additionally, since switch costs may arise from task-set inertia, might training improve shifting ability by reducing inertia duration? These questions require deeper investigation.

6 Summary and Outlook

Task-switching training is considered an effective method for improving executive control, though its efficacy has been questioned. Numerous studies demonstrate that training can effectively reduce switch costs and improve performance on structurally similar, untrained switching tasks. However, far-transfer effects remain controversial, with some studies reporting broad far-transfer (Karbach & Kray, 2009), others limited far-transfer (Pereg et al., 2013), and still others no far-transfer effects (Zhao et al., 2018). These discrepancies may result from differences in task settings (paradigm, content, duration) and assessment methods across studies (Shipstead et al., 2012). While Sabah et al. (2018) examined relationships between different paradigms and training effects, how specific training parameters affect outcomes remains poorly understood. Future research should systematically investigate these factors and standardize methodologies, training procedures, and assessment protocols.

Second, transfer and maintenance effects represent the ultimate goals of training. While many studies focus on transfer effects, research on maintenance effects remains scarce (Gaál & Czigler, 2018; Kray & Feher, 2017). Future studies should prioritize investigating maintenance effects and identify effective methods for enhancing both transfer and maintenance, such as increasing task content variability (Sabah et al., 2018), appropriate strategy application (Karbach et al., 2010), or incorporating neurofeedback-based learning methods (Enriquez-Geppert, Huster, Figge, & Herrmann, 2014). Additionally, combining electrical stimulation with behavioral training to reduce training time while improving effects warrants consideration (Tayeb & Lavidor, 2016). Current research combining tDCS with task-switching training remains limited (Strobach & Antonenko, 2017), leaving many gaps to explore: (1) Stimulation sites—which region(s) most effectively improve shifting ability? How can tDCS be better integrated with behavioral training? Do different training paradigms show differential effects? (2) Training effects—can long-term combined tDCS and behavioral training shorten duration while improving transfer and maintenance? (3) Effects across age groups—is tDCS more effective in older adults? (4) Parameter settings—do identical parameters differentially affect individuals of different ages and genders? Do online and offline tDCS produce different effects? These questions require deeper investigation.

Third, shifting processing involves multiple executive components, including attention maintenance, task set reconfiguration, updating of task goals or mappings, and selective processing and inhibition of task rules (Yeung et al., 2006). From a process perspective, switching training inevitably trains other components, making it more than pure shifting ability training. What are the mechanisms? Are observed transfer effects truly due to improved shifting ability? Does shifting ability play a dominant role? These questions need deeper exploration (Gaál & Czigler, 2018). Notably, high-inhibition-demand switching training does improve transfer and maintenance effects (Kray & Feher, 2017), suggesting that training involving multiple executive functions may better enhance behavioral and neural plasticity (Shipstead et al., 2012). Future research should adopt a comprehensive perspective on both unified and separable executive function structures (Miyake & Friedman, 2012) to more holistically understand task-switching training.

Fourth, special populations (ADHD, schizophrenia, depression, anxiety, addiction, autism) often exhibit various cognitive deficits (Pan Dongni & Li Xuebing, 2017), and working memory training can significantly alleviate symptoms. While working memory training research in special populations is extensive (Chacko et al., 2014; Pan Dongni & Li Xuebing, 2017; Nejati et al., 2017), switching training research remains limited. For example, Kray et al. (2011) showed that brief task-switching training effectively reduced switch costs and enhanced inhibitory control and verbal working memory in ADHD. Future research should further investigate mechanisms and maintenance effects of task-switching training in ADHD and other special populations.

In summary, shifting ability is an essential cognitive capacity in daily life and work. Task-switching training can effectively improve individual shifting ability with relatively broad transfer effects. Scholars should therefore prioritize research on task-switching training to better apply findings to education, personnel selection, training, and other domains.

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