A Selective Review of the Effect of Self-Regulation Strategies on Response Inhibition in Children with ADHD

Shuan-Ju Rita Hung[1*], Caterina Gawrilow[2]

[1]School of Occupational Therapy, National Taiwan University, Taipei, Taiwan
[2]Departmant of Psychology, Eberhard Karls University of Tuebingen, Tuebingen, Germany

Abstract

Attention deficit hyperactivity disorder (ADHD) is a common clinical disorder observed in children. The prevalence rate in school-age children is approximately 5-10% and inattention, hyperactivity, and impulsivity are core symptoms of ADHD. An underlying deficit in inhibitory control has been proposed to account for dysfunctional behaviors associated with this disorder. Furthermore, recent research has shown that the self-regulation strategy of implementation intentions is effective for improving inhibitory control in children with ADHD. This article, therefore, reviews research related to response inhibition in ADHD including behavioral and electrophysiological studies exploring the effect of self-regulation strategies on response inhibition of children with ADHD in experimental settings or in schools. This review is expected not only to provide clinical psychologists or teachers with an effective behavioral strategy for the treatment of children with ADHD from the perspective of behavioral treatment but also to provide future research with several possible factors that may influence the application of implementation intentions.

Keywords*:* attention deficit hyperactivity disorder; implementation intentions; response inhibition; self-regulation

*Corresponding author: Shuan-Ju Rita Hung
School of Occupational Therapy, National Taiwan University
No.17, Xuzhou Rd., Zhongzheng Dist., Taipei 100, Taiwan
E-mail: shuanjuhung@gmail.com

華醫學報　第 45 期
2016 年 12 月
頁數 110-131

自我調控策略對注意力不足過動症兒童反應抑制的影響之選擇性回顧

洪川茹[1*]、Caterina Gawrilow[2]

[1]國立臺灣大學職能治療學系

[2]德國杜賓根大學心理學系

摘要

注意力不足過動症(簡稱過動症)為一常見於孩童的臨床疾患。學齡兒童的盛行率約 5-10%。患有過動症的孩童(簡稱過動兒)的核心症狀為注意力不足、過動和衝動。之前研究指出，抑制功能的缺損可能導致與此疾患相關的功能失調。近來，相關研究顯示，運用執行意向此自我調控策略可以有效地改善過動兒的行為抑制能力。因此，本論文選擇性地回顧和過動症反應抑制相關的研究以及探討自我調控策略在實驗室或學校等不同情境下對過動兒反應抑制之影響的行為及電生理研究。藉由本論文的回顧，除了盼望能從行為治療的觀點提供臨床領域的專業人員或教師在過動兒的治療上一個有效的行為策略，也能提供未來研究數個會影響執行意向運用的因子。

關鍵字: 注意力不足過動症、執行意向、反應抑制、自我調控

[*]通訊作者：洪川茹
國立臺灣大學職能治療學系
100 臺北市中山區徐州路 17 號
E-mail: shuanjuhung@gmail.com

Introduction

Attention deficit hyperactivity disorder (ADHD) is a childhood-onset disorder characterized by developmentally inappropriate behaviors such as inattention, hyperactivity, and impulsivity (American Psychiatric Association [APA], 2013) with an estimated prevalence rate of 5–10% among school-age children worldwide (Faraone, Sergeant, Gillberg, & Biederman, 2003) and 7.5% in Taiwan (Gau, Chong, Chen, & Cheng, 2005). According to the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM*-5; APA, 2013), three presentations are outlined in ADHD: the predominantly inattentive presentation, the predominantly hyperactive-impulsive presentation, and the combined presentation. Children diagnosed with ADHD are frequently found to have difficulties sustaining their attention or regulating their behaviors in everyday life (Nigg, 2001; Reid, Trout, & Schartz, 2005). They, for instance, cannot wait for their turn patiently when playing with others, tend to interrupt others when they are not supposed to, or seem not to listen when spoken to (APA, 2013). Impacts of ADHD cardinal symptoms may persist into adolescence and adulthood (Barkley, 2004, 2010).

Methylphenidate (MPH), a central nervous system (CNS) stimulant, has been widely and increasingly used in the treatment of ADHD (e.g., Broyd et al., 2005; Paul-Jordanov, Bechtold, & Gawrilow, 2010). For example, in the U.S., the rate of 18-year-old and younger individuals using stimulants rose from 0.6% in 1987 to 4.8% in 2002 (Zuvekas, Vitiello, & Norquist, 2006). Approximately 48.6 million daily doses of MPH in Germany were prescribed in 1990, whereas this number increased to 1036 million daily doses in 2000 (Schubert, Selke, Osswald-Huang, Schroeder, & Nink, 2002). In Taiwan, MPH is the first-line medication to treat ADHD. Its immediate-release formulation (i.e., IR MPH) has been used for decades, and after October 2003 (Gau, Shen, Soong, & Gau, 2006), osmotic-release oral system-MPH (OROS-MPH) is accepted as an alternative for ADHD treatment. These trends show that an increasing number of children are exposed to psychotropic drugs.

A body of empirical studies has documented that MPH has the short-term or long-term efficacy to improve most clinical symptoms in children with ADHD (e.g., Abikoff et al., 2004; Van der Oord, Prins, Oosterlaan, & Emmelkamp, 2008), which is based on subjective ratings by teachers, parents, and psychiatrists (Abikoff et al., 2004; Van der Oord et al., 2008). However, despite its desirable effects on ADHD symptoms, at least two concerns have arisen regarding the use of MPH. First, MPH is questioned for its prescription among children who may not meet ADHD criteria or no medical treatment is received in those who meet clinical ADHD criteria (Angold, Erkanli, Egger, & Costello, 2000). Second, possible side effects accompanying MPH such as decreased appetite are concerned by parents (Charach, Ickowicz & Schachar, 2004).Therefore, in the sections that follow, we bring clinicians attention to a self-regulation strategy without side effects for the management of ADHD by first selectively reviewing behavioral, electrophysiological and neuroimaging studies related to response inhibition (Barkley, 1997), which is proposed to explain dysfunctional behaviors associated with ADHD, and by second reviewing several empirical studies concerning the effectiveness of forming self-regulation strategies on response inhibition in ADHD.

Deficient Response Inhibition in ADHD

Numerous theories have emerged to account for the inappropriate behaviors observed in ADHD, for instance, Douglas's (1972) sustained attention theory, Sonuga-Barke's (2002) theory of delay aversion, and Barkley's (1997) model of behavioral inhibition. Among these, deficient inhibitory control is suggested to primarily explain dysfunctional behaviors associated with this disorder (Barkley, 1997). Barkley (1997) established the neuropsychological model of executive functions by integrating the concepts of executive functions, inhibition, and self-regulation in order to account for clinical symptoms of children with ADHD (specifically, those with the combined presentation or predominantly hyperactive-impulsive presentation; APA, 2013). According to this model (Barkley, 1997), ADHD primarily arises from a deficit in behavioral inhibition, which refers to three abilities: (a) inhibition of prepotent responses to events (e.g., to press a response key on the keyboard every time when letters are presented but not to press the response key when the letter is X), (b) ceasing of ongoing responses, and (c) the protection of responses during the delay from being interrupted by irrelevant events (interference control). Deficient behavioral inhibition leads to secondary impairments in four executive functions subserved by the prefrontal lobe, including working memory, self-regulation of affect/motivation/arousal, internalization of speech, and reconstitution. These four executive functions are dependent upon behavioral inhibition in order to be executed efficiently. Both primary and secondary deficits have direct or indirect impacts on the development of motor control. Abnormal executive functioning and motor control then develop to dysfunctional behaviors associated with ADHD.

For the issue of interest and the purpose of brevity, this article is narrowly focused on one process, which is inhibiting prepotent responses to events. In this section, we review studies on inhibition measured by the Go/NoGo or stop tasks but not by Stroop, Simon, or Flanker task as inhibition measured by these two groups are considered to tap into different cognitive constructs of inhibition (Hart, Radua, Nakao, Mataix-Cols, & Rubia, 2013), which are motor response inhibition (i.e., measured by the Go/NoGo or stop task) and interference inhibition (i.e., measured by Stroop, Simon, or Flanker task), respectively.

Behavioral Correlates of Response Inhibition

Impaired inhibitory control causes individuals with ADHD to perform more poorly than controls on tasks that require inhibition, for instance, the Stop Signal Task (SST; Pliszka, Borcherding, Spratley, Leon, & Irick, 1997; Pliszka, Liotti, & Woldorff, 2000), Go/NoGo task (Paul-Jordanov et al., 2010), and Continuous Performance Task (CPT, a version of the Go/NoGo task; Fallgatter et al., 2004; Valko et al., 2009).

The SST is a reliable measure of response inhibition across the lifespan (Williams, Ponesse, Schachar, Logan, & Tannock, 1999). It has been extensively used with ADHD populations (e.g., Pliszka et al., 2000). In a typical SST, there is a certain proportion of the Go stimuli (e.g., 25% of the total trials) followed by stop signals with randomized intervals (Logan, Cowan, & Davis, 1984; Pliszka et al., 1997). Participants are instructed to respond to Go stimuli by pressing corresponding buttons but withholding their already-initiated responses when stop signals are presented. According to the Horse-Race Model (Logan et al., 1984), the probability of successful inhibitions is dependent on a race between the mean reaction time to the Go stimulus (MRT; the Go process) and the Stop Signal Reaction Time (SSRT; the Stop process), which is assumed to be an index reflecting an internal attempt to inhibit the responses to stop signals. The SSRT is estimated by subtracting the delay between the Go stimulus and the stop signal (stop signal delay; SSD) from the MRT (i.e., SSRT = MRT – SSD). When the Go process finishes earlier than the Stop process (i.e., MRT < SSRT + SSD), the response is executed, resulting in a failed inhibition. In contrast, the response is successfully inhibited when the Stop process finishes before the Go process (i.e., MRT > SSRT + SSD; Alderson, Rapport, & Kofler, 2007).

Previous meta-analytic reviews (Alderson et al., 2007; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005) showed that children with ADHD had slower and more variable mean reaction times to Go stimuli in comparison to healthy controls. According to Alderson et al. (2007), effect size estimates were 0.45 for MRT and 0.72

for standard deviation RT (SDRT). Similarly, the SSRT was found to be significantly longer for the ADHD group than for the control group (mean effect size = 0.61; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). A meta-analysis of 29 studies of SSTs (Lijffijt et al., 2005) revealed that the indices of deficient inhibitory control such as the prolongation of SSRT existed significantly in the ADHD group relative to controls robustly across the lifespan, while on measures of inattention such as longer RTs and variable SDRT, a pronounced difference between groups was observed in the child population (see also Alderson et al., 2007), but not seen in the adult population. These substantial findings point to abnormalities in response inhibition among children with ADHD.

Additionally, inhibition has been assessed with the Go/NoGo task (e.g., Broyd et al., 2005; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009), which is a task requiring a response to a type of stimulus (the Go stimulus) but the withdrawal of a prepared but not yet initiated response to another type of stimulus (the NoGo stimulus). Compared to healthy controls, children with ADHD are observed to display slower and more variable mean RTs (Epstein et al., 2011; Uebel et al., 2010) and to exhibit more omission (i.e., people do not respond to Go stimuli to which they are required to respond) and commission errors (i.e., false alarm: an error occurring when people respond to NoGo stimuli to which they are not supposed to respond) (Broyd et al., 2005; Paul-Jordanov et al., 2010).

Electrophysiological Correlates of Response Inhibition

A vast number of studies have been conducted to obtain electrophysiological data while participants with and/or without ADHD are performing inhibition related tasks (applying visual/auditory stop tasks in particular). These studies can enhance our understanding on the pathophysiology of ADHD and the neural mechanisms underlying inhibitory control in ADHD (e.g., Dimoska, Johnstone, Barry, & Clarke, 2003; Johnstone et al., 2007; Liotti et al., 2007; Senderecka, Grabowska, Szewczyk, Gerc, & Chmylak, 2012).

In event-related potential (ERP) research, continuous electroencephalogram (EEG) data are collected while participants are performing cognitive tasks, in which different types of stimuli/trials are repeatedly presented. Recorded EEG data are then averaged across many trials, causing the cancel-out of the noise, which may result from random brain activity, physiological signals such as electrooculography (EOG) and electrocardiography (EKG) as well as interferences from the external environment (e.g., electronic noise). After that, a waveform is produced representing brain activity in response to a type of stimulus in the task (e.g., Broyd et al., 2005; Paul-Jordanov et al., 2010).

Stimulus-Related Event-Related Potentials. Typically, two stimulus-locked ERP components, the N2 and P3, are elicited when inhibition tasks are administered, both of which are stable and heritable electrophysiological markers involved in the inhibitory process (Dimoska et al., 2003; Falkenstein, Hoormann, & Hohnsbein, 1999; Pliszka et al., 2000).

The N2 component. The N2, which is associated with conflict monitoring, is a negative going shift with a peak at approximately 200 ms after stimulus onset. Functional responses of the N2 are mostly interpreted as the initiation of inhibitory processing (Pliszka et al., 2007; Pliszka et al., 2000) while one study (Dimoska et al., 2003) suggests that the N2 may be an indicator of the activation level of the inhibitory process. In accordance with the former view (i.e., the N2 represents the initiation of inhibition control), amplitudes of the NoGo N2 (i.e., the NoGo stimuli-evoked N2) have been found to be larger over frontal-central brain regions than those of the Go N2 (i.e., the Go stimuli-evoked N2), showing inhibitory processing is manipulated to withhold an ongoing but inappropriate response on NoGo trials (e.g., Broyd et al., 2005; Falkenstein et al., 1999; Pliszka et al., 2007). With respect to the NoGo N2, Falkenstein et al. (1999) found in a Go/NoGo task that, relative to healthy controls, children with ADHD displayed a significant correlation between reduced N2 amplitudes for NoGo stimuli and higher commission errors, indicating the weakness in successfully inhibiting responses to NoGo stimuli in ADHD. Additionally, in the SST, Pliszka et al. (2007) demonstrated that children with ADHD exhibited a strongly diminished NoGo N2 in the right frontal lobe, a brain region found to be impaired in the inhibitory process (Rubia et al., 1999), which is in line with the observation that inhibition is executed with a right-hemisphere dominance (Garavan, Ross, & Stein, 1999).

The P3 component. Following the N2, the P3 deflects positively peaking at around 300 ms after stimulus onset. This component has been closely linked to selective attention and allocation of efforts (Picton, 1992). In Go/NoGo studies, greater amplitudes and longer latencies are observed on NoGo trials than Go trials, indicating resources are more demanding in processing NoGo trials (Picton, 1992; Pliszka et al., 2007). As the NoGo P3 (i.e., the NoGo stimuli-evoked P3) was found diminished in ADHD, P3 amplitude differences between NoGo and Go trials were significantly smaller in participants with ADHD relative to normally developing children (Paul-Jordanov et al., 2010), reflecting poor attention and impaired response control in ADHD. The NoGo P3 has a more frontal-central/anterior topographical distribution than does the Go P3 (i.e., the Go stimuli-evoked N2) (Fallgatter et al., 2004; Picton, 1992). Distinct scalp distributions suggest that different neural cortical generators underlie the Go and NoGo P3, respectively (Tekok-Kilic, Shucard, & Shucard, 2001). While the Go P3 is recorded maximally at parietal electrode sites (Fallgatter et al., 2004), the topographical distribution of the NoGo P3 is accounted for by dipoles located in the anterior cingulate cortex (ACC) (Paul et al., 2007), a central brain area consistently reported to be dysfunctional in the ADHD group from electrophysiological and neuroimaging studies (Bush et al., 1999; Fallgatter et al., 2004).

Failed Response Inhibition-Related Event-Related Potentials. Two error-related components have received increasing attention and been reported in several inhibition-related studies using the Go/NoGo task (Groom et al., 2010; O'Connell et al., 2009; Wiersema, van der Meere, & Roeyers, 2009) or the SST (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005; Senderecka et al., 2012; Shen, Tsai, & Duann, 2011). After the onset of incorrect button presses, the error-related negativity (ERN), a negative-going component with a frontal-central scalp distribution, is evoked at approximately 100 ms, while the error positivity (Pe) peaks at 300 ms over the central-parietal scalp (Senderecka et al., 2012). Both components, which appear to be generated in the ACC, represent different aspects associated with error processing (Garavan, Ross, Murphy, Roche, & Stein, 2002). More specifically, the ERN may be elicited unconsciously and reflect the detection of an error resulting from a conflict between the intended and actual responses; the Pe occurs only when the participant is aware of an erroneous response (Shen et al., 2011; Wiersema et al., 2009). Deficits in error processing have been shown in ADHD children (Senderecka et al., 2012; Shen et al., 2011), adolescents (Groom et al., 2010), and adults (O'Connell et al., 2009; Wiersema et al., 2009), which may partially be associated with poor performance on inhibition tasks. Inconsistent findings on the ERN amplitude are reported in a series of studies. For example, studies using the SST either in visual (Liotti et al., 2005) or auditory modality (Senderecka et al., 2012) demonstrated that the ERN was markedly diminished in the ADHD group relative to healthy children, while some studies showed that larger ERNs were observed in the ADHD group (e.g., Burgio-Murphy et al., 2007) or no significant difference on the ERN was noted between groups in child (Wiersema, van der Meere, & Roeyers, 2005) and adult populations (Wiersema et al., 2009) in studies with the Go/NoGo task. By contrast, the Pe is consistently found smaller in the ADHD group than controls across developmental age (Groom et al., 2010; O'Connell et al., 2009; Senderecka et al., 2012; Wiersema et al., 2005). Therefore, these findings imply that rather than error detection, abnormal neural activity in the late stage of error processing (i.e., conscious evaluation of an error), which is indexed by reduced Pe, appears to serve as a lifelong trait marker in ADHD (Wiersema et al., 2009).

Evidence from Neuroimaging Studies on Response Inhibition

Frontal lobe dysfunction has been an active focus of ADHD research because of the observation that experimental animals or human patients with frontal lesions sometimes produce ADHD-like symptoms of hyperactivity or impulsivity alone or in combination (Fuster, 1993). The right inferior prefrontal cortex serves as the crucial brain region for response inhibition, while the mesial frontal cortex, including the ACC and bilateral inferior parietal lobes, is responsible for error detection or error monitoring (Rodrigo et al., 2014). Abnormal brain activity in these regions has been reported in individuals with ADHD across the lifespan (e.g., Cubillo et al., 2010; Smith, Taylor, Brammer, Toone, & Rubia, 2006), and certain brain dysfunction (i.e., the right inferior prefrontal cortex) is reportedly disorder-specific to ADHD (Rubia et al., 2010). However, findings from neuroimaging or event-related potential studies are mixed. In a functional magnetic resonance imaging (fMRI) study with the stop task, Pliszka et al. (2006) found that children with ADHD were more likely than healthy controls to show decreased activation in the ACC and left ventrolateral prefrontal cortex on unsuccessful inhibitions, but increased activation in the right inferior performance cortex on successful inhibitions. The finding of enhanced right inferior prefrontal cortex activation is in line with reports of increased activation of the right ventrolateral prefrontal cortex in adolescents with childhood ADHD during the Go/NoGo task (Schulz et al., 2004) but inconsistent with a previous study (Rubia, Smith, Brammer, Toone, & Taylor, 2005) that reported reduced activation in the right inferior prefrontal cortex in medication-naïve adolescents with ADHD performing the stop task. These discrepant results could be explained by different experimental designs or techniques in the studies (Pliszka et al., 2006). Recently, a meta-analysis of fMRI studies (Hart et al., 2013) showed that individuals with ADHD, compared to controls, exhibited significantly reduced activation in the right inferior frontal cortex (IFG) and insula, the right supplemental motor area (SMA) and ACC, the right thalamus, left caudate, and the right occipital lobe.

Moreover, studies found that frontal-striatal and parietal dysfunctions during motor inhibition, which were observed in children (Rubia et al., 2010), adolescents (A. Smith et al., 2006), and adults (Cubillo et al., 2010) with ADHD, were unrelated to long-term stimulant medication exposure (Pliszka et al., 2006; Smith et al., 2006). These dysfunction similarities between age groups may therefore suggest a continuation of frontostriatal inhibitory network deficits from childhood to young adulthood in ADHD (Cubillo et al., 2010). Furthermore, Cubillo et al. (2010) observed reduced functional interconnectivity between critical brain areas involving inhibition (i.e., between the right inferior prefrontal cortex and other dysfunctional regions such as the left inferior prefrontal cortex, striatum, parietal lobe, and anterior and posterior cingulate cortex), indicating that the dysfunctions in ADHD may affect not only individual brain regions but also the inter-regional connectivity between these affected regions. These findings together with evidence from another study (Wolf et al., 2009) extend the functional deficit findings on motor inhibitory control to the neural network level in ADHD.

In sum, evidence from behavioral, electrophysiological, and imaging studies supports that response inhibition is impaired in children with ADHD to some extent.

The Effect of Self-Regulation Strategies on Response Inhibition

An implementation intention (Gollwitzer, 1993, 1999), which is viewed as a self-regulation strategy, emphasizes an anticipated critical situation (i.e., the if-component) and a goal-directed response (i.e., the then-component). It is important to recognize that implementation intentions differ from goal intentions. Goal intentions merely specify an anticipated outcome and have the format of "I intend to achieve Z." When people form an implementation intention, a mental link is created between the two components (If situation X arises, then I will initiate goal-directed response Y!). As forming an if-then plan implies the selection of an anticipated situation, the mental representation of this situation becomes highly activated, and therefore more easily accessible. Additionally, this critical cue automatically triggers the intended (and pre-planned) response and/or behavior: it is enacted immediately, efficiently, and without conscious intent (e.g., Bayer, Achtziger, Gollwitzer, & Moskowitz, 2009). Both mechanisms, the heightened accessibility of the cue and the automatic activation of the intended behavior, produce a perceptual and behavioral readiness that accounts for if-then plan effects on goal attainment (e.g., Webb & Sheeran, 2008). In this way, implementation intentions help people initiate their action more automatically, thereby enhancing the self-regulation of goal striving and the attainment of self-set or assigned task goals effectively. If-then plans have been proven to have benefits above mere goal intentions: A meta-analysis by Gollwitzer and Sheeran (2006) revealed an effect size of *d* = 0.65, which is a medium-to-large effect size (Cohen, 1992) and represents that the additional facilitation size of this effect is remarkable because goal intentions commonly have a facilitating effect on behavior enactment by themselves (Webb & Sheeran, 2006).

A study conducted by Gawrilow and Gollwitzer (2008) showed that children with ADHD benefited from forming if-then plans on a modified Go/NoGo task. This task required participants to classify stimuli that were presented on a computer screen by pressing a prespecified key on the computer keyboard and to inhibit this classification in response to a NoGo signal. Children with ADHD were randomly assigned to one of two groups: Children in the goal intention group formed a goal to inhibit a classification response for marked stimuli, whereas children in the implementation intention group, in addition to forming this goal intention, formed an if-then plan. In the first experiment, Gawrilow and Gollwitzer (2008) compared the performance of children with and without ADHD: Children without ADHD performed on a high level no matter whether they had formed a goal intention or an implementation intention. Children with ADHD, however, reached this high performance level only when they had furnished the goal intention with an if-then plan; children with ADHD in the goal intention condition showed a significantly lower performance level.

Paul et al. (2007) collected electrophysiological data when children with and without ADHD were administered with the same modified Go/NoGo task under two different task instruction conditions, which were the baseline condition without a self-regulation strategy and the planning condition with a self-regulation strategy. The children with ADHD went through both two conditions, which is the only difference from the previous study (Gawrilow & Gollwitzer, 2008), in which children with ADHD were randomly assigned to either condition. The Go/NoGo task consisted of 300 stimuli (50% colored drawings of transportation vehicles and 50% colored drawings of animals). Children were asked to respond to animals and vehicles by pressing one of two colored buttons. The correspondence of stimulus type and response-button was reversed after the first half of the experiment to prevent the task becoming too easy. In 33% of the trials, a stop sign, which was a white sprawled-out hand on a circular purple background, was presented before the stimulus. This is the difference from the task used by Gawrilow and Gollwitzer (2008), in which a tone was used as the stop signal. The stop sign indicated that no response was to be given on the following trial. The trials following stop signs were treated as NoGo trials; all other trials were Go trials. In the baseline condition, children received a neutral instruction containing information regarding how to perform the task (e.g., pressing different buttons corresponding to animals or vehicles and not pressing any buttons at times the hand was shown). In the planning condition, children were given an instruction furnished with an if-then plan (i.e., if I see a hand, then I will not press a button). The study showed that more inhibition errors were found in children with ADHD than controls in the baseline condition. No group difference was significantly revealed in the planning condition. Response errors to Go stimuli did not differ between ADHD and control children in the baseline or planning condition. Slower reaction times were significantly found in the ADHD group relative to the control group across both conditions. Moreover, children with ADHD exhibited greater NoGo P3 and NoGo-Go (NoGo minus Go) P3 with the assistance of the self-regulation strategy of if-then plans in comparison to their electrophysiological performance in the baseline condition. This indicates that the better response control was achieved, which was supported by the high correlation between the successful inhibition and the NoGo-Go P3 amplitude (Paul et al., 2007). As the P3 is an ERP component related to selective attention (Picton, 1992) and the NoGo P3 is usually reduced in children with ADHD (e.g., Fallgatter et al., 2004), the self-regulation strategy of if-then plans is apparently effective for enhancing inhibitory control in children with ADHD (Paul-Jordanov et al., 2010).

More recently, the application of if-then plans is extended to various settings such as school settings and findings are promising. Guderjahn, Gold, Stadler, and Gawrilow (2013) found that children with ADHD from grades five to ten in a secondary school exhibited improved self-regulatory competencies with the assistance of if-then plans (i.e., the use of goal intention furnished with if-then plans) compared with their performance in the baseline (i.e., the use of goal intention) in their everyday school life.

Based on the aforementioned studies, the self-regulation strategies of implementation intentions are shown to enhance response inhibition in children with ADHD.

Conclusion

Evidence from behavioral, event-related potential, or neuroimaging studies supports the proposal that individuals with ADHD are impaired in inhibitory control to some extent. A series of empirical studies of behavioral intervention have revealed that the self-regulation strategy of implementation intentions (i.e., if-then plans) may be a behavioral strategy/intervention for ADHD that has an effective impact regarding the support of inhibition (Gawrilow & Gollwitzer, 2008; Guderjahn et al., 2013; Paul-Jordanov et al., 2010; Paul et al., 2007). Although previous studies provide clinical psychologists or teachers an effective behavioral strategy for the management of ADHD, several unclear points need to be investigated regarding the effect of forming if-then plans on response inhibition in ADHD.

First, as a number of factors such as comorbid disorders, intelligence, and the severity of ADHD may moderate the association between ADHD and executive functioning and thus affect children's behavioral performance on inhibition tasks (Willcutt et al., 2005), it is worthwhile to explore if the effect of forming if-then plans on response inhibition could vary by the occurrence of comorbid disorders (e.g., conduct disorder [CD] and oppositional defiant disorder [ODD]), child's intelligence, or the severity of ADHD. Second, extant studies are primarily focused on child populations and the samples (e.g., Paul-Jordanov et al., 2010; Paul et al., 2007) are mostly composed of male participants, which may hamper the generalization of previous findings to other age (e.g., adolescent or adult populations) or gender groups. Additionally, as indicated by Oettingen, Sevincer, and Gollwitzer (2008), the context of socio-culture may have a potential impact on the effect of forming if-then plans. As most extant studies exploring the effect of forming if-then plans on ADHD are conducted in one country (i.e., Germany), it will be compelling for future studies to investigate whether if-then plans can serve as an effective behavioral strategy for children with ADHD in different cultural contexts (e.g., Taiwan or China).

To sum up, if-then plans have been shown to be an effective self-regulation strategy regarding the support of response inhibition in children with ADHD. Several unknown issues, however, need to be explored more fully in order to extend its application and increase its feasibility in different sociocultural contexts.

References

Abikoff, H., Hechtman, L., Klein, R. G., Weiss, G., Fleiss, K., Etcovitch, J. O. Y., . . . Pollack, S. (2004). Symptomatic improvement in children with ADHD treated with long-term methylphenidate and multimodal psychosocial treatment. *Journal of the American Academy of Child and Adolescent Psychiatry, 43*(7), 802-811. doi: 10.1097/01.chi.0000128791.10014.ac

Alderson, R. M., Rapport, M. D., & Kofler, M. J. (2007). Attention-deficit/hyperactivity disorder and behavioral inhibition: A meta-analytic review of the stop-signal paradigm. *Journal of Abnormal Child Psychology, 35*(5), 745-758. doi: 10.1007/s10802-007-9131-6

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Angold, A., Erkanli, A., Egger, H. L., & Costello, E. J. (2000). Stimulant treatment for children: a community perspective. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*(8), 975-984. doi: 10.1097/00004583-200008000-00009

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychological Bulletin, 121*(1), 65-94. doi: 10.1037/0033-2909.121.1.65

Barkley, R. A. (2004). Adolescents with attention-deficit/hyperactivity disorder: an overview of empirically based treatments. *Journal of Psychiatric Practice, 10*(1), 39-56. doi: 10.1097/00131746-200401000-00005

Barkley, R. A. (2010). Differential diagnosis of adults with ADHD: the role of executive function and self-regulation. *The Journal of Clinical Psychiatry, 71*(7), e17. doi: 10.4088/JCP.9066tx1c

Bayer, U. C., Achtziger, A., Gollwitzer, P. M., & Moskowitz, G. B. (2009). Responding to subliminal cues: Do if-then plans facilitate action preparation and initiation without conscious intent? *Social Cognition, 27*(2), 183-201. doi: 10.1521/soco.2009.27.2.183

Broyd, S. J., Johnstone, S. J., Barry, R. J., Clarke, A. R., McCarthy, R., Selikowitz, M., & Lawrence, C. A. (2005). The effect of methylphenidate on response inhibition and the event-related potential of children with attention deficit/hyperactivity disorder. *International Journal of Psychophysiology, 58*(1), 47-58. doi: 10.1016/j.ijpsycho.2005.03.008

Burgio-Murphy, A., Klorman, R., Shaywitz, S. E., Fletcher, J. M., Marchione, K. E., Holahan, J., . . . Shaywitz, B. A. (2007). Error-related event-related potentials in children with attention-deficit hyperactivity disorder, oppositional defiant disorder, reading disorder, and math disorder. *Biological Psychology, 75*(1), 75-86. doi: 10.1016/j.biopsycho.2006.12.003

Bush, G., Frazier, J. A., Rauch, S. L., Seidman, L. J., Whalen, P. J., Jenike, M. A., . . . Biederman, J. (1999). Anterior cingulate cortex dysfunction in attention-deficit/hyperactivity disorder revealed by fMRI and the Counting Stroop. *Biological Psychiatry, 45*(12), 1542-1552. doi: 10.1016/S0006-3223(99)00083-9

Charach, A., Ickowicz, A., & Schachar, R. (2004). Stimulant treatment over 5 years: adherence, effectiveness, and adverse effects. *Journal of the American Academy of Child and Adolescent Psychiatry, 43*(5), 559-567. doi: 00004583-200405000-00009

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155-159. doi: 10.1037/0033-2909.112.1.155

Cubillo, A., Halari, R., Ecker, C., Giampietro, V., Taylor, E., & Rubia, K. (2010). Reduced activation and inter-regional functional connectivity of fronto-striatal networks in adults with childhood attention-deficit hyperactivity disorder (ADHD) and persisting symptoms during tasks of motor inhibition and cognitive switching. *Journal of Psychiatric Research, 44*(10), 629-639. doi: 10.1016/j.jpsychires.2009.11.016

Dimoska, A., Johnstone, S. J., Barry, R. J., & Clarke, A. R. (2003). Inhibitory motor control in children with attention-deficit/hyperactivity disorder: event-related potentials in the stop-signal paradigm. *Biological Psychiatry, 54*(12), 1345-1354. doi: 10.1016/S0006-3223(03)00703-0

Douglas, V. I. (1972). Stop, look and listen: The problem of sustained attention and impulse control in hyperactive and normal children. *Canadian Journal of Behavioural Science, 4*(4), 259-282. doi: 10.1037/h0082313

Epstein, J. N., Langberg, J. M., Rosen, P. J., Graham, A., Narad, M. E., Antonini, T. N., . . . Altaye, M. (2011). Evidence for higher reaction time variability for children with ADHD on a range of cognitive tasks including reward and event rate manipulations. *Neuropsychology, 25*(4), 427-441. doi: 10.1037/a0022155

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica, 101*(2-3), 267-291. doi: 10.1016/S0001-6918(99)00008-6

Fallgatter, A. J., Ehlis, A. C., Seifert, J., Strik, W. K., Scheuerpflug, P., Zillessen, K. E., . . . Warnke, A. (2004). Altered response control and anterior cingulate function in attention-deficit/hyperactivity disorder boys. *Clinical Neurophysiology, 115*(4), 973-981. doi: 10.1016/j.clinph.2003.11.036

Faraone, S. V., Sergeant, J., Gillberg, C., & Biederman, J. (2003). The worldwide prevalence of ADHD: is it an American condition? *World Psychiatry, 2*(2), 104-113.

Fuster, J. M. (1993). Frontal lobes. *Current Opinion in Neurobiology, 3*(2), 160-165. doi: 10.1016/0959-4388(93)90204-C

Garavan, H., Ross, T. J., Murphy, K., Roche, R. A., & Stein, E. A. (2002). Dissociable executive functions in the dynamic control of behavior: inhibition, error detection, and correction. *Neuroimage, 17*(4), 1820-1829. doi: 10.1006/nimg.2002.1326

Garavan, H., Ross, T. J., & Stein, E. A. (1999). Right hemispheric dominance of inhibitory control: an event-related functional MRI study. *Proceedings of the National Academy of Sciences of the United States of America, 96*(14), 8301-8306. doi: 10.1073/pnas.96.14.8301

Gau, S. S., Chong, M. Y., Chen, T. H., & Cheng, A. T. (2005). A 3-year panel study of mental disorders among adolescents in Taiwan. *The American Journal of Psychiatry, 162*(7), 1344-1350. doi: 10.1176/appi.ajp.162.7.1344

Gau, S. S., Shen, H. Y., Soong, W. T., & Gau, C. S. (2006). An open-label, randomized, active-controlled equivalent trial of osmotic release oral system methylphenidate in children with attention-deficit/hyperactivity disorder in

Taiwan. *Journal of Child and Adolescent Psychopharmacology, 16*(4), 441-455. doi: 10.1089/cap.2006.16.441

Gawrilow, C., & Gollwitzer, P. (2008). Implementation intentions facilitate response inhibition in children with ADHD. *Cognitive Therapy and Research, 32*(2), 261-280. doi: 10.1007/s10608-007-9150-1

Gollwitzer, P. M. (1993). Goal achievement: The role of intentions. *European Review of Social Psychology, 4*(1), 141-185. doi: 10.1080/14792779343000059

Gollwitzer, P. M. (1999). Implementation intentions: Strong effects of simple plans. *American Psychologist, 54*(7), 493-503. doi: 10.1037/0003-066X.54.7.493

Gollwitzer, P. M., & Sheeran, P. (2006). Implementation intentions and goal achievement: A meta-analysis of effects and processes. In P. Z. Mark (Ed.), *Advances in experimental social psychology* (Vol. 38, pp. 69-119): Academic Press.

Groom, M. J., Cahill, J. D., Bates, A. T., Jackson, G. M., Calton, T. G., Liddle, P. F., & Hollis, C. (2010). Electrophysiological indices of abnormal error-processing in adolescents with attention deficit hyperactivity disorder (ADHD). *Journal of Child Psychology and Psychiatry, 51*(1), 66-76. doi: 10.1111/j.1469-7610.2009.02128.x

Guderjahn, L., Gold, A., Stadler, G., & Gawrilow, C. (2013). Self-regulation strategies support children with ADHD to overcome symptom-related behavior in the classroom. *Attention Deficit and Hyperactivity Disorders, 5*(4), 397-407. doi: 10.1007/s12402-013-0117-7

Hart, H., Radua, J., Nakao, T., Mataix-Cols, D., & Rubia, K. (2013). Meta-analysis of functional magnetic resonance imaging studies of inhibition and attention in attention-deficit/hyperactivity disorder: Exploring task-specific, stimulant medication, and age effects. *JAMA Psychiatry, 70*(2), 185-198. doi: 10.1001/jamapsychiatry.2013.277

Johnstone, S. J., Barry, R. J., Markovska, V., Dimoska, A., & Clarke, A. R. (2009). Response inhibition and interference control in children with AD/HD: a visual ERP investigation. *International Journal of Psychophysiology, 72*(2), 145-153. doi: 10.1016/j.ijpsycho.2008.11.007

Johnstone, S. J., Dimoska, A., Smith, J. L., Barry, R. J., Pleffer, C. B., Chiswick, D., & Clarke, A. R. (2007). The development of stop-signal and Go/Nogo response inhibition in children aged 7-12 years: performance and event-related potential indices. *International Journal of Psychophysiology, 63*(1), 25-38. doi: 10.1016/j.ijpsycho.2006.07.001

Lijffijt, M., Kenemans, J. L., Verbaten, M. N., & van Engeland, H. (2005). A meta-analytic review of stopping performance in attention-deficit/hyperactivity disorder: deficient inhibitory motor control? *Journal of Abnormal Psychology, 114*(2), 216-222. doi: 10.1037/0021-843X.114.2.216

Liotti, M., Pliszka, S. R., Perez, R., 3rd, Luus, B., Glahn, D., & Semrud-Clikeman, M. (2007). Electrophysiological correlates of response inhibition in children and adolescents with ADHD: influence of gender, age, and previous treatment history. *Psychophysiology, 44*(6), 936-948. doi: 10.1111/j.1469-8986.2007.00568.x

Liotti, M., Pliszka, S. R., Perez, R., Kothmann, D., & Woldorff, M. G. (2005). Abnormal brain activity related to performance monitoring and error detection in children with ADHD. *Cortex, 41*(3), 377-388. doi: 10.1016/S0010-9452(08)70274-0

Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: a model and a method. *Journal of Experimental Psychology: Human Perception and Performance, 10*(2), 276-291. doi: 10.1037/0096-1523.10.2.276

Nigg, J. T. (2001). Is ADHD a disinhibitory disorder? *Psychological Bulletin, 127*(5), 571-598. doi: 10.1037/0033-2909.127.5.571

O'Connell, R. G., Bellgrove, M. A., Dockree, P. M., Lau, A., Hester, R., Garavan, H., . . . Robertson, I. H. (2009). The neural correlates of deficient error awareness in attention-deficit hyperactivity disorder (ADHD). *Neuropsychologia, 47*(4), 1149-1159. doi: 10.1016/j.neuropsychologia.2009.01.011

Oettingen, G., Sevincer, A. T., & Gollwitzer, P. M. (2008). Goal pursuit in the context of culture. In R. Sorrentino & S. Yamaguchi (Eds.), *The handbook of* *motivation and cognition across cultures* (pp. 191-211). San Diego: Elsevier/Academic Press.

Paul-Jordanov, I., Bechtold, M., & Gawrilow, C. (2010). Methylphenidate and if-then plans are comparable in modulating the P300 and increasing response inhibition in children with ADHD. *Attention Deficit and Hyperactivity Disorders, 2*(3), 115-126. doi: 10.1007/s12402-010-0028-9

Paul, I., Gawrilow, C., Zech, F., Gollwitzer, P., Rockstroh, B., Odenthal, G., . . . Wienbruch, C. (2007). If-then planning modulates the P300 in children with attention deficit hyperactivity disorder. *Neuroreport, 18*(7), 653-657. doi: 10.1097/WNR.0b013e3280bef966

Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology, 9*, 456-479. doi: 10.1097/00004691-199210000-00002

Pliszka, S. R., Borcherding, S. H., Spratley, K., Leon, S., & Irick, S. (1997). Measuring inhibitory control in children. *Journal of Developmental and Behavioral Pediatrics, 18*(4), 254-259. doi: 10.1097/00004703-199708000-00005

Pliszka, S. R., Glahn, D., Semrud-Clikeman, M., Franklin, C., Perez Iii, R., Xiong, J., & Liotti, M. (2006). Neuroimaging of inhibitory control areas in children with attention deficit hyperactivity disorder who were treatment naive or in long-term treatment. *The American Journal of Psychiatry, 163*(6), 1052-1060. doi: 10.1176/appi.ajp.163.6.1052

Pliszka, S. R., Liotti, M., Bailey, B. Y., Perez, R., 3rd, Glahn, D., & Semrud-Clikeman, M. (2007). Electrophysiological effects of stimulant treatment on inhibitory control in children with attention-deficit/hyperactivity disorder. *Journal of Child and Adolescent Psychopharmacology, 17*(3), 356-366. doi: 10.1089/cap.2006.0081

Pliszka, S. R., Liotti, M., & Woldorff, M. G. (2000). Inhibitory control in children with attention-deficit/hyperactivity disorder: event-related potentials identify the processing component and timing of an impaired right-frontal response-inhibition mechanism. *Biological Psychiatry, 48*(3), 238-246. doi: 10.1016/S0006-3223(00)00890-8

Reid, R., Trout, A. L., & Schartz, M. (2005). Self-regulation interventions for children with attention deficit/hyperactivity disorder. *Exceptional Children, 71*, 361-377.

Rodrigo, A. H., Domenico, S. I. D., Ayaz, H., Gulrajani, S., Lam, J., & Ruocco, A. C. (2014). Differentiating functions of the lateral and medial prefrontal cortex in motor response inhibition. *Neuroimage, 85, Part 1*(0), 423-431. doi: 10.1016/j.neuroimage.2013.01.059

Rubia, K., Cubillo, A., Smith, A. B., Woolley, J., Heyman, I., & Brammer, M. J. (2010). Disorder-specific dysfunction in right inferior prefrontal cortex during two inhibition tasks in boys with attention-deficit hyperactivity disorder compared to boys with obsessive–compulsive disorder. *Human Brain Mapping, 31*(2), 287-299. doi: 10.1002/hbm.20864

Rubia, K., Overmeyer, S., Taylor, E., Brammer, M., Williams, S. C., Simmons, A., & Bullmore, E. T. (1999). Hypofrontality in attention deficit hyperactivity disorder during higher-order motor control: a study with functional MRI. *The American Journal of Psychiatry, 156*(6), 891-896.

Rubia, K., Smith, A. B., Brammer, M. J., Toone, B., & Taylor, E. (2005). Abnormal brain activation during inhibition and error detection in medication-naive adolescents with ADHD. *The American Journal of Psychiatry, 162*(6), 1067-1075. doi: 10.1176/appi.ajp.162.6.1067

Schubert, I., Selke, G. I., Osswald-Huang, P. H., Schroeder, H., & Nink, K. (2002). *Methylphenidat-Verordnungsanalyse auf der Basis von GKV-Daten.* Bonn: Wissenschaftliches Institut der AOK.

Schulz, K. P., Fan, J., Tang, C. Y., Newcorn, J. H., Buchsbaum, M. S., Cheung, A. M., & Halperin, J. M. (2004). Response inhibition in adolescents diagnosed with attention deficit hyperactivity disorder during childhood: an event-related FMRI study. *The American Journal of Psychiatry, 161*(9), 1650-1657. doi: 10.1176/appi.ajp.161.9.1650

Senderecka, M., Grabowska, A., Szewczyk, J., Gerc, K., & Chmylak, R. (2012). Response inhibition of children with ADHD in the stop-signal task: an event-related potential study. *International Journal of Psychophysiology, 85*(1), 93-105. doi: 10.1016/j.ijpsycho.2011.05.007

Sheeran, P., Webb, T. L., & Gollwitzer, P. M. (2006). Implementation intentions: Strategic automatisation of goal striving. In D. T. M. de Ridder & J. B. F. de Wit (Eds.), *Self-regulation in health behavior* (pp. 121-145). London: John Wiley & Sons Ltd.

Shen, I. H., Tsai, S. Y., & Duann, J. R. (2011). Inhibition control and error processing in children with attention deficit/hyperactivity disorder: an event-related potentials study. *International Journal of Psychophysiology, 81*(1), 1-11. doi: 10.1016/j.ijpsycho.2011.03.015

Smith, A., Taylor, E., Brammer, M., Toone, B., & Rubia, K. (2006). Task-specific hypoactivation in prefrontal and temporoparietal brain regions during motor inhibition and task switching in medication-naive children and adolescents with attention deficit hyperactivity disorder. *The American Journal of Psychiatry, 163*(6), 1044-1051. doi: 10.1176/appi.ajp.163.6.1044

Sonuga-Barke, E. J. (2002). Psychological heterogeneity in AD/HD-a dual pathway model of behaviour and cognition. *Behavioural Brain Research, 130*(1-2), 29-36. doi: 10.1016/S0166-4328(01)00432-6

Tekok-Kilic, A., Shucard, J. L., & Shucard, D. W. (2001). Stimulus modality and Go/NoGo effects on P3 during parallel visual and auditory continuous performance tasks. *Psychophysiology, 38*(3), 578-589. doi: 10.1017/S0048577201991279

Uebel, H., Albrecht, B., Asherson, P., Börger, N. A., Butler, L., Chen, W., . . . Banaschewski, T. (2010). Performance variability, impulsivity errors and the impact of incentives as gender-independent endophenotypes for ADHD. *Journal of Child Psychology and Psychiatry, 51*(2), 210-218. doi: 10.1111/j.1469-7610.2009.02139.x

Valko, L., Doehnert, M., Müller, U. C., Schneider, G., Albrecht, B., Drechsler, R., . . . Brandeis, D. (2009). Differences in neurophysiological markers of inhibitory and temporal processing deficits in children and adults with ADHD. *Journal of Psychophysiology, 23*(4), 235-246. doi: 10.1027/0269-8803.23.4.235

Van der Oord, S., Prins, P. J. M., Oosterlaan, J., & Emmelkamp, P. M. G. (2008). Efficacy of methylphenidate, psychosocial treatments and their combination in school-aged children with ADHD: A meta-analysis. *Clinical Psychology Review, 28*(5), 783-800. doi: 10.1016/j.cpr.2007.10.007

Webb, T. L., & Sheeran, P. (2006). Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. *Psychological Bulletin, 132*(2), 249-268. doi: 10.1037/0033-2909.132.2.249

Webb, T. L., & Sheeran, P. (2008). Mechanisms of implementation intention effects: the role of goal intentions, self-efficacy, and accessibility of plan components. *The British Journal of Social Psychology, 47*(Pt 3), 373-395. doi: 10.1348/014466607X267010

Wiersema, J. R., van der Meere, J. J., & Roeyers, H. (2005). ERP correlates of impaired error monitoring in children with ADHD. *Journal of Neural Transmission, 112*(10), 1417-1430. doi: 10.1007/s00702-005-0276-6

Wiersema, J. R., van der Meere, J. J., & Roeyers, H. (2009). ERP correlates of error monitoring in adult ADHD. *Journal of Neural Transmission, 116*(3), 371-379. doi: 10.1007/s00702-008-0165-x

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57*(11), 1336-1346. doi: 10.1016/j.biopsych.2005.02.006

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology, 35*(1), 205-213. doi: 10.1037/0012-1649.35.1.205

Wolf, R. C., Plichta, M. M., Sambataro, F., Fallgatter, A. J., Jacob, C., Lesch, K.-P., . . . Vasic, N. (2009). Regional brain activation changes and abnormal functional connectivity of the ventrolateral prefrontal cortex during working memory processing in adults with attention-deficit/hyperactivity disorder. *Human Brain Mapping, 30*(7), 2252-2266. doi: 10.1002/hbm.20665

Zuvekas, S. H., Vitiello, B., & Norquist, G. S. (2006). Recent trends in stimulant medication use among U.S. children. *The American Journal of Psychiatry, 163*(4), 579-585. doi: 10.1176/appi.ajp.163.4.579