ADHD

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ADHD: State Regulation and Motivation

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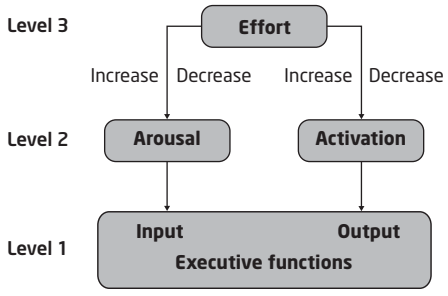
Decades ago, research indicated that poor motivation is involved in attention-deficit/hyperactivity disorder (ADHD; DSM-IV criteria) [1]. Two current cognitive models of ADHD address the concept of motivation in different ways. The response inhibition model considers impaired response inhibition to be the cardinal feature in ADHD that provides the key to understanding a range of apparently unrelated problems, such as poor motivation [2]. In contrast, the state regulation model (**Figure 1**) assumes that ADHD is associated with a motivation deficit, with consequences for cognitive and social functioning [3,4]. The contrast between the two models has been placed firmly on the scientific agenda. At face value, the rule of thumb in the debate seems to be simple: ADHD is considered to be a motivation deficit if research shows motivating factors to overcome inhibition problems, otherwise ADHD is a pure response inhibition deficit.

However, in reality, the interplay between cognition (including response inhibition) and motivation is far from simple and explicit predictions to test the models are, although necessary, difficult to formulate [5]. This is partly due to the fact that the motivation/affective part of cognition has generally been studied in isolation from the cognitive part (including response inhibition) [4]. In addition, many definitions of motivation are available, based on personality models, cognitive models, and physiological models; the subjective experience of motivation is one of "trying hard" [6]. Needless to say, it is unsatisfactory to challenge the response inhibition hypothesis when children with ADHD overcome their poor response inhibition in a motivating condition by saying that they "tried harder". A more adequate explanation is needed. The state regulation model might offer some guidelines for obtaining a strong hypothetical deductive approach in order to base taxonomies on empirical evidence in the near future.

The state regulation model was originally developed in the field of ergonomics. Experts have convincingly demonstrated that incentives, noise, and variations of the presentation rate of Go/No-Go stimuli may influence the psychophysiological state in those who are tested: they may improve or decline the quality of executive functions [7–9]. To prevent such unwanted interference, energy mobilization is needed to change the actual (non-optimal) state into the required (target) state. This top-

Figure 1. The state regulation model.



In this model, task efficiency is considered to be a product of elementary cognitive stages (level 1) and their energy distribution (level 2 and 3). The elementary stages at level 1 are stimulus encoding, memory search, binary decision, and motor preparation. These stages may be seen as structural processes (processes that mediate between stimulus and response). They are assumed to function serially and discretely, meaning that contingent stages operate in strict succession, with each stage finishing before the next can begin. The stages are involved in executive functioning and their availability is related to the arousal and activation levels of the subject. The effort system (level 3) is under control of an evaluation mechanism, which scans the momentary state of the arousal and activation levels. A suboptimal state of arousal and/or activation is compensated through the effort mechanism by either activating or inhibiting the arousal and/or activation pool/resources. Thus, unlike the traditional activation theory, in which the energetical processes are essentially stimulus-driven, the energetic resources may be controlled through strategic resource-management decisions, wherein motivation is not only a driving or energizing force but also a key factor involved in the initiation, maintenance, and regulation of action.

down skill is called state control and requires strategic resource management decisions. If there is a discrepancy between the actual and the required state, the subject may decide to change the criteria for optimal reaction time (RT) performance, as a result accepting a decline in performance, or to mobilize extra energy to protect performance. The latter decision is called "motivation" and confers costs to physiological subsystems, primarily the limbic system in a circuit involving the cingulate cortex, hippocampus, septal nuclei, and anterior hypothalamus [9]. This motivation system (or effort system) controls two basic mechanisms: arousal (defined as a bottom-up, time-locked, phasic, physiological response to input ["what is it" reaction]) and activation (defined as a bottom-up, tonic, long-lasting, voluntary readiness for action ["what is to be done" reaction]). The core brain system associated with arousal extends from the spinal cord through the brainstem reticular formation including the hypothalamus. The amygdala and related frontal cortical structures are involved in the control of the core brain arousal system. Serotonin and norepinephrine are the dominant neurotransmitters. Structures related to the activation system are the dorsal thalamus and the basal ganglia, in particular, the corpus striatum of the forebrain, with dopamine as the most important neurotransmitter [9].

Recent ADHD studies have investigated the effects of incentives, noise, and the presentation rate of Go/No-Go stimuli on response inhibition. In the present review, the outcomes of these studies are discussed in terms of the state regulation model.

Incentive studies

According to the state regulation model, incentives have a direct effect on effort allocation (motivation) [9]. A review by Luman, Oosterlaan, and Sergeant reported that ADHD studies have produced equivocal results; some studies found that an apparent response inhibition deficit in ADHD disappeared or declined following the instruction of incentives, whereas other studies reported that the deficit remained despite incentives [10]. According to the review, one reason for the inconsistency is that results are sensitive to task parameters such as immediate or delayed reward. However, an important issue that is not addressed in ADHD incentive studies is that effort allocation only takes place when the basic states of arousal and/or activation deviate from the optimal state. For instance, incentives have virtually no effect after normal sleep, but they have a pronounced one after sleep deprivation in adults [9]. Thus, the outcomes of ADHD incentive studies are difficult to explain in terms of state regulation when the associated tasks are not apt to put participants in a non-optimal state, as could be the case with the Stop task, which has often been used in incentive studies. The Stop task has a short duration, with many stimulus events containing auditory stop signals that – according to the state regulation model – may lift arousal [9].

Another more general issue of concern is that incentives are signals, and an increase

in the signal rate increases motor activation [9]. Thus, a performance difference between groups could be the result of impaired effort, impaired arousal, impaired activation, or combinations of these factors. To avoid such problems, incentive paradigms need baseline conditions with neutral signals presented at the same time as incentive signals.

Noise studies

According to the state regulation model, noise may activate the arousal system. This might be beneficial if one is underaroused, but harmful when one is in a normal or an overaroused state. Overarousal leads to reduced attention and an emphasis on speed rather than accuracy [9]. As reviewed by Sikstrom and Soderlund, ADHD studies showed that white noise exerted a positive effect on cognitive performance in children with ADHD but impaired performance in the control groups; this is explained by underarousal associated with ADHD [11].

Studies varying the presentation rate of stimuli

According to the state regulation model, the presentation rate of stimuli affects motor activation [9]. RT performance in children with ADHD normalizes or comes close to the performance of a control group under conditions with a fast presentation rate of stimuli and is reduced under conditions with a slow presentation rate of stimuli [4]. Studies using three presentation rates produced an inverted U-shape curve, suggesting that children with ADHD are easily overactivated and underactivated. For example, optimal performance on the Matching Familiar Figure Test has been found in trials with a presentation rate of 10 s [12] and studies have reported optimal performance on Go/No-Go trials with a presentation rate of 4 s [4] in children with ADHD. Thus, characteristics of the curve depend on the type of task. The age of the child is also important. A developmental study that was focused on healthy children showed poor impulse control in children aged 7 or 8 years compared with children aged 9–12 years. This was particularly the case in conditions with fast and slow presentation rates of stimuli [13].

So far, few RT studies conflict with the state regulation theory. For example, a study by Raymaekers et al. reported the same effects of presentation rate on performance in children with and without ADHD [14]. This conflicting finding with the state regulation theory could be due to the fact that the investigator was sitting behind the child during testing; it is well recognized that the feeling of being monitored has a motivating effect and improves RT performance in children with ADHD, especially in conditions with a slow presentation rate [4]. In addition, two-thirds of the children with ADHD who participated in the Raymaekers et al. study fulfilled criteria for the DSM-IV inattentive subtype. Although controversial, it has been suggested that this is a distinct diagnostic disorder and not actually a subtype of ADHD [15]. In another study with conflicting results with the state regulation theory [16], it remained unclear whether the children with ADHD also fulfilled criteria for oppositional defiant disorder (ODD; DSM-IV criteria). There is some evidence to suggest that children with ADHD and ODD are more easily overactivated compared with children with ADHD alone [17]. In any case, given the inconsistencies in findings, it seems appropriate to conduct meta-analyses of studies that vary the presentation rate of stimuli.

Top-down versus bottom-up

The RT profile produced by stimuli presentation rate manipulation reflects the interaction between motor activation and its control by effort. Thus, it remains to be seen whether ADHD is associated with a bottom-up deficit in motor activation *per se*, which is difficult to control for by the top-down effort mechanism, or whether the motor activation mechanism is intact but is not adequately controlled by the effort mechanism. This issue is of importance given the suggestion that ADHD is due to bottom-up, non-cortical deficits that manifest early in development, whereas the maturation of the prefrontal cortex more closely parallels recovery from ADHD [18].

One possibility to disentangle bottom-up motor activation from top-down effort regulation is to investigate the separate and combined effects of incentives and the stimuli presentation rate on RT performance. The findings have been equivocal. In one study, the combination had a greater impact on RT performance in children with ADHD compared with the control group [19]. In another study, incentives, not presentation rates, were crucial in children with ADHD, indicating an effort deficit and not a motor activation deficit [20]. In addition, other research has found that the isolated and combined effects of reward and the presentation rate were the same for children with signs of ADHD and a control group [21]. The drawback of the latter study is that it remains unclear whether the participating children with signs of ADHD fulfilled DSM criteria for ADHD.

Psychophysiological studies and stimuli presentation rates

Candidate markers of psychophysiological strain to maintain performance at an optimal level include the 0.10 Hz heart rate variability component [22] and the parietal P300 amplitude [23], among others. ADHD research using such psychophysiological indices supports the idea that ADHD is associated with an effort deficit, not with a motor activation deficit, under conditions with slow presentation rates of stimuli [17,24–27]. Additional support for the hypothesis that children with ADHD differ from controls in effort allocation, not motor activation, is provided by data showing no difference between children with and without ADHD in terms of their heart rate deceleration prior to Go/No-Go signals under conditions with slow presentation rates, indexing motor activation [24]. A somewhat different finding has recently been published. In a study using three stimuli presentation rates, children with ADHD showed poorer response inhibition during the fast condition, accompanied by (among other factors) atypical orienting and motor preparation, as indexed by the late contingent negative variation [28].

Dopamine and stimuli presentation rates

Relationships between dopamine, incentives, and effort exist; however, they are far from clear. Researchers in the field of neuroscience are challenging the numerous problems concerning effort-related processes and brain dopamine systems, particularly in the nucleus accumbens. The dopamine hypothesis, suggesting reduced dopamine levels in ADHD, has a long history, and theoretical connections between dopamine and the state regulation theory have recently been made [29]. The response impairments found for both slow and fast stimuli presentation rates have been explained by too low and too high levels of dopamine, respectively. In one study, optimal performance under a condition with an intermediate presentation rate was associated with a well-adjusted level of dopamine [11]. In other words, children with ADHD may have an "appetite" for dopamine and "adore" a fast presentation rate of stimuli [30].

The combined effect of methylphenidate (MPH) and the presentation rate on RT performance has been studied recently [31]. The authors reasoned that if MPH and a fast presentation rate are acting by the same mechanism (i.e. the dopamine level [32]), then the combined effect of the two stimulants may produce an overactive response state, shown by a fast, inaccurate response style. The results of the study indicated that a fast presentation rate and MPH individually improved performance (including response inhibition), but the combination produced fast but inaccurate responses, reflecting overactivation. Thus, the combination of the two stimulants (MPH and a fast presentation rate) had placed the participant's scores of performance at the left side of the inverted U-curve. MPH alone normalized the performance of the children during the slow condition, suggesting that the compound is effective when children are in an underactivated state.

Metabolic energy and stimuli presentation rate

Increased neuronal activity raises the demand for metabolic energy and leads

to an increase in regional cerebral blood flow. Glucose is the brain's main source of energy; therefore, measuring brain glucose metabolism by means of functional magnetic resonance imaging (fMRI) may provide further insight into effort allocation to protect a decline in performance efficiency [33]. So far, the findings from only one stimulus presentation rate study using fMRI are available in the field of ADHD [34]. The results from this study indicated that adults with childhood ADHD use a different performance strategy during Go/No-Go conditions with fast and slow presentation rates compared with controls. In the ADHD group, accurate response inhibitions, especially during the slow condition, were associated with widespread frontostriatal activity, including the cingulate and the thalamus. In contrast, in the controls, activity within these same areas was associated with correct Go trials. The observed thalamic activity during No-Go trials in the slow condition in the ADHD group deserves further exploration, as it may be related to the presumed poor effort allocation theory to remain in an optimal motor state. There is ample evidence showing that the thalamus, through effortful control, is involved in preserving cognitive task performance by modulating activation in proportion to task demands [35,36].

Body activity and stimuli presentation rate

Low stimulation, which is the case in conditions with slow presentation rates, is in fact very strenuous for everybody, including healthy adults. This has been attributed to the effort exerted to compensate for low stimulation. Adults tend to avoid this resource-consuming top-down compensation by creating or selecting environmental conditions that provide bottom-up stimulation [37]. A recent study indicated that self-chosen stimulation in adults optimizes cortical excitability indexed by the characteristics of the contingent negative variation and minimizes compensatory effort [38]. Increased body and eye movements of children with ADHD seen especially during a slow condition could be explained in terms of stimulation seeking to avoid top-down effort allocation [4].

Boredom, stress, and negative affect

Boredom, stress, and negative affect can be seen as clinical correlates of the assumed state regulation deficit and an integration of these concepts will improve understanding of ADHD [39]. It is well recognized that boredom proneness is a strong predictor of high ADHD scores in adults [40]. Boredom-prone individuals perform below average on tasks that require vigilance [41] and have reduced ability to complete tasks [42], and scores on scales intended to measure boredom have been positively correlated with lapses in attention [43]. Thus, on the basis of adult studies using self-reports in tandem with cognitive measures, it seems that effort allocation and boredom are negatively correlated: when boredom increases, effort allocation decreases. So far, the results of only one ADHD study are available on this subject [44]. In this study, RTs and facial expressions were studied in tandem during the fast and slow Go/No-Go conditions. The findings suggest that stress in healthy control children is caused by effort allocation (motivated behavior: try to avoid a decline in performance), whereas stress in children with ADHD is caused by boredom. The findings need to be replicated and studies should focus on stress-related issues, such as negative affect.

The subjective perception of the passage of time is a critical component of the experience of boredom [45], and is the key concept of another important motivation theory in the field, namely delay aversion [46]. A head-to-head study has been recently formulated to test the state regulation theory versus the delay aversion theory [47]. The study is attempting to resolve the issue of whether ADHD is associated with a failure to mobilize extra energy to keep performance at an optimal level or whether the disorder is associated with a deficit response style.

Conclusions and future research

Evidence is accumulating that the cognitive performance (including response inhibition) of children with ADHD is connected with poor state regulation. The contribution of familial factors concerning state regulation is approximately 60–70% [48,49]. In addition, links with other possible causes of ADHD such as very low birth weight [50] and antenatal maternal anxiety levels [51] have been made. Nevertheless, the definition of motivation used in the state regulation theory (i.e. top-down energy allocation to prevent a decline in test performance) is not perfect. It should be noted that rather than a top-down or bottom-up deficit, it is plausible that both could be present. Moreover, each mechanism is unclear as to what extent ADHD is associated with an arousal deficit (noise studies) and/or an activation deficit (presentation rate studies). However, we must not reject the entire concept: children with ADHD try hard in certain conditions and as a result may overcome their poor impulse control. Investigation of this phenomenon may lead to a better underpinning of neural circuits involved in ADHD.

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