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Developing self-regulation in early childhood ☆

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ABSTRACT

Studies using fMRI at rest and during task performance have revealed a set of brain areas and their connections that can be linked to the ability of children to regulate their thoughts, actions and emotions. Higher self-regulation has also been related favorable outcomes in adulthood. These findings have set the occasion for methods of improving self-regulation via training. A tool kit of such methods is now available. It remains to be seen if educators will use these new findings and tools to forge practical methods for improving the lives of the world's children.

1. Introduction

Imaging the human brain using methods like functional magnetic resonance imaging (fMRI) has revealed brain networks common to people when they perform tasks like reading, computing or playing video games [19]. Some of these networks are linked to more specific sensory and motor aspects of learning; others are more general, playing a role in a wide variety of tasks. One of the most important of these sets of networks is involved in attention. At least three brain networks have been identified, whose functions include maintaining the alert state, orienting to sensory stimuli or resolving conflict among competing responses.

All three of these networks are involved in school study. Being able to carry out successful learning in school depends upon the efficiency of the *alerting network*. The *orienting network* exerts most of the regulatory control in infancy and early childhood [23,27] and plays a role in the classroom by reducing distraction and amplifying input relevant to the subject being studied. The *executive network* is important for self-regulation in middle childhood and beyond and its efficiency correlates with school performance [3]. The executive network is involved in resolving conflict and also serves as a means of self-regulation through control of brain networks involved in emotion, cognition and behavior [1,20].

While everyone has these attentional networks people differ in their efficiency. The *Attention Network Test* (*ANT*) was devised as a means to measure these differences [9]. The task requires the person to press one key if the central arrow points to the left and another if it points to the right. Conflict is introduced by having surrounding flankers either point in the same (congruent) or opposite (incongruent) condition. Cues presented prior to the target provide information on either where or when the target will occur. Subtractions are used to provide three numbers that represent the skill of each individual in the alerting, orienting and executive networks.

Most MRI studies involve imaging the brain during task performance, but it has recently become common to study the brains of children and adults during the resting state (rsMRI [22]). One of the brain networks active during rest is the executive network involved in resolving conflict and self-regulation [7,8]. Resting state methods can be applied at any age because they do not require a task. Studies have examined how brain networks change with age [8,10]. Resting state studies have found that during infancy and early childhood most brain networks involve short connections between adjacent areas, but the long connections that underlie self-regulation develop slowly over childhood [8]. The brain network related to orienting to sensory events seems to provide the primary source of regulation prior to 2–3 years of age [21,24].

2. Training brain networks

Just as task related and resting state MRI are two fundamentally different methods of conducting MRI experiments to image

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the brain network involved in self-regulation, there are also two very different methods for achieving improvements in self-regulation. We call one of these methods network training and the other brain state training. In network training, specific tasks are used to exercise the brain network to be trained. Such training is assumed to increase efficiency in two ways. Repeated use of the network (1) tunes the neurons in each node to fit more completely with the mental operation being performed and (2) strengthens the connection between nodes. Conflict tasks, working memory tasks, and executive function tasks have all been used to improve self-regulation by network training. Meditation and aerobic exercise are two examples of efforts to improve attention through the training of a specific brain state In order to clarify the similarities and differences between the two types of brain training, the next two sections of our paper consider their use in more detail.

2.1. Network training

To examine the role of training on attention networks, we adapted a method that had been used by NASA to train monkeys for space travel [26] to the training of attention in children age 4–7 years. The 5-day training intervention used computerized exercises. We randomly assigned children to either an experimental group trained in executive attention or a control group that viewed child-appropriate videos for the same amount of time the intervention group was trained. Children in the experimental group first learned to use a joy stick to move a cat displayed on the monitor to the grass and avoid the mud. As the child progressed the task became more difficult because the grass shrank and mud increased. We built on the joy stick skills to involve prediction, working memory and conflict resolution. To study conflict we used a numerical task that asked the child to select the larger of two arrays of items, and conflict was introduced by showing a large array of small digits versus a small array of larger digits. Before and after training the children performed the children's version of the Attention Network Test [9] that includes a conflict condition produced by the direction in which fish swim, while their brain responses were measured by scalp electrodes.

The effect of training was tested at ages that were within the period of major improvement of executive attention, between ages 4 and 7 years. After training, EEG data showed clear evidence of improvement in network efficiency in resolving conflict as the result of training (see Fig. 1). The N2 component of the scalp

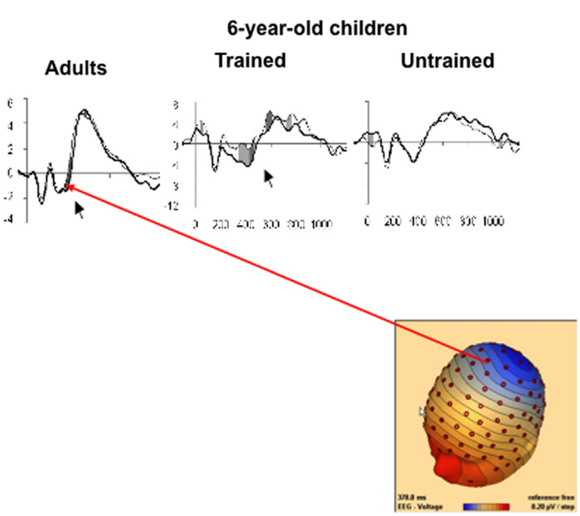

Fig. 1. Event related potentials for congruent and incongruent trials during the Attention Network Test for adults and trained and untrained children. Dark areas between the solid (incongruent) and dotted (congruent) lines show significant differences between incongruent and congruent trials.

recorded averaged electrical potential (shown by the arrow in Fig. 1) has been found to arise in the anterior cingulate and is related to the resolution of conflict [4,32]. The N2 differences between congruent and incongruent trials of the ANT in trained 6-year-olds resembled differences found in adults. These data suggest that training altered the network for the resolution of conflict in the direction of being more like what is found in adults.

The trained group also showed a greater improvement in intelligence compared to controls, as measured by the K Bit test (a child friendly test of IQ; [13]). The improvement was in overall IQ and in a matrix portion similar to the adult Ravens test. The IQ result suggested that training effects had generalized to a measure of cognitive processing far removed from the training exercises.

A replication and extension of this study was carried out for 5 year olds in a Spanish preschool [25]. Several additional exercises were added and 10 days of training were provided for both experimental and control groups. A follow-up session for all children was also given 2 months after the training. Unlike the control group, trained children showed improvement in intelligence scores, as measured by the matrices scale of the K-BIT intelligence test, following training. In addition, the trained group held sustained improvement over the 2 months without further training, while the control group did not show improvement from pre- to post-test. Similar changes in the N2 component of the EEG related to executive attention were found for the training as had been observed in the previous study. The training of attention also produced beneficial effects on performance of tasks involving affective regulation, such as the ability to delay reward.

A number of studies with varying methods have been shown to improve attention in preschool children [6]. Practice may be part of classroom activities [5,27] or individual computer training [14,26,25], and may involve attention or working memory tasks. Usually the tasks increase in difficulty over time, pushing the trainee to continually improve performance. Some of the training methods involve a classroom curriculum that may be easier to implement than individual exercises. For example, a year long test of Tools of the Mind, a curriculum designed to improve executive function, has shown large changes in tasks that measure the ability to resolve conflict [6]. Working memory training involves executive attention as one component and thus overlaps heavily with attention training. Studies have shown that working memory training leads to improvements in the performance of children with attention deficit disorder [15]. This form of training has also been found to improve IQ in undergraduates [12].

Programs that teach specific skills to preschool children often do not maintain their advantage when experimental and control children are examined many years later [11]. However, a few skills continue to show an advantage even after a number of years of schooling. Those skills showing an advantage seem to involve the ability to employ aspects of self-control [16,17]. Self-control or regulation as assessed by parental report of effortful control is influenced by the executive attention network, and is correlated with the ability to resolve conflict [23]. The training of self-regulation may underlie the finding that, although the advantages in test performance may not be maintained for trained children, other aspects of behavior that may be important for success in life after school continue to favor trained children many years later [2,16,17].

2.2. Training brain states

The approaches discussed above seek to obtain improvement in networks by exercising them. A rather different approach to training may be to develop a brain state that is conducive to self-control. One example of brain state training is a method called Integrative Body-Mind Training (IBMT), a form of meditation

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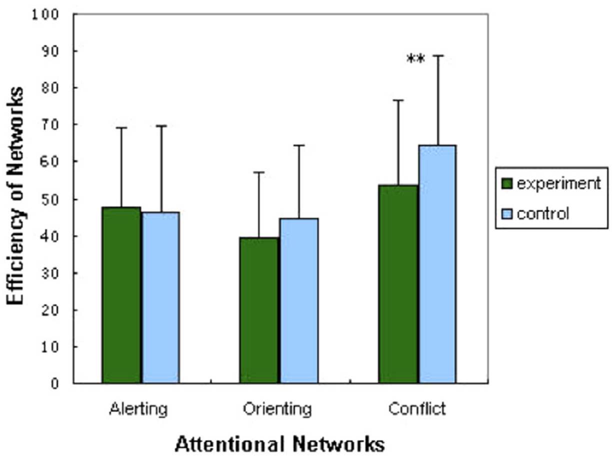

Fig. 2. Performance on ANT after 5 days of IBMT (experiment) or Relaxation Training (control). *Y* axis shows difference in reaction time for alert, orient and executive networks. For the conflict (executive network) scores the lower score reflects faster ability to resolve conflict and thus greater efficiency.

adapted from traditional Chinese Medicine [28]. It includes elements of body relaxation, imagery, and achievement of a non-judgmental mental state. IBMT uses a trainer to ensure that naïve learners achieve the state without strong effort to control thoughts.

The IBMT method leads to very rapid change in brain state, including both the central and autonomic nevous system. The rapid effectiveness of IBMT allows studies involving random assignment of persons to experimental and control groups. In our studies, the control group was given a form of relaxation training very popular in the west as a part of cognitive behavioral therapy. In relaxation training individuals are instructed to relax different muscle groups in turn. They tend to concentrate attention on the instructed muscle group as they relax it.

In one study only 5 days of practice with 30 min per session were used. The IBMT and Relaxation Training control groups were given a battery of tests a week before training and immediately after the final training session. The Attention Network Test (ANT, see Fig. 2), the Profile of Mood States, and a stress challenge of a mental arithmetic task followed by measures of cortisol and secretory immunoglobulin A (sig A) were given before and after training. All of these are standard assays scored objectively by people blind to the experimental condition.

The expectation was that IBMT training would improve functioning of the executive attention network by changing the brain state. The experimental group showed significantly greater improvement than the control group in the executive attention network, in mood scales related to self-control, and on cortisol and immunoreactivity measures of stress to a mental arithmetic challenge [28]. The improvements appear to involve a change of state, in that there is increased brain activity in areas related to the parasympathetic portion of the autonomic nervous system producing a quiet alert state conducive to focused attention. Also indicative of a change of brain state is that IBMT alters the resting state (default state) fMRI.

Further research revealed the mechanisms underlying this change of state [29]. This study used 1 week of training and pre- and post-training assays of neuroimaging were used to assay brain changes due to training. The IBMT group improved functional activity and connectivity between the ACC and striatum. Moreover, parasympathetic function had changed more in the IBMT group than in the controls. Further studies using diffusion tensor imaging revealed that several white matter tracts that connected the ACC to other areas had improved their efficiency [30]. These tracts include the anterior corona radiata which had previously been shown to be specifically related to the executive attention network [18]. These findings indicate that connectivity related to self-regulation can be altered in adults by meditation training. It has potential implications for all aspects of self-regulation, for example, in educational applications in pre-school. Recently studies have applied IBMT to children of 4 years of age [31].

3. Does training last?

As mentioned earlier, studies conducted on the role of pre-school training such as Headstart have often concluded that effects on schooling can be found at first, but over a few years they are reduced or eliminated [11]. However, these studies generally examined the school subjects taught during elementary school and this specific training may have reduced whatever general effects might have been expected from the preschool work. Studies of more general effects of training have shown improved life outcomes [16].

There is ample evidence that self-regulation matters in school and life. For example, one study of middle school children showed that a parent report measure of self-regulation correlated (3) with grades more strongly than other general measures such as IQ. In a large study of 1000 children followed for 30 years self-regulation as children was positively related to income, health, and reduced criminality in adulthood [17]. Although this was not a training study, those children who, for whatever reason, spontaneously improved during development showed enhanced outcomes over those who did not show improvement. This, as well as more direct training studies [16] suggests that interventions leading to higher self-regulation during childhood may well last until adulthood

4. Future research

Brain networks underlie aspects of attention and self-regulation. In recent years two fundamentally different approaches have been reported to improve attention and self-regulation. One practices the attention network through the execution of specific tasks. A second involves the use of meditation as a means of developing a brain state that serves to improve self-regulation and to reduce stress. There is evidence that early self-regulation is related to more favorable life outcomes.

This new knowledge can be used to improve the lives of children. To do this, we need to investigate how to combine methods of improving self-regulation that fit well with the educational system. Methods involving training of specific attention networks and those that involve changing brain states may involve different rates of learning and may work on different aspects of network improvement. Moreover, individual differences in temperament [23] could make one method more useful than the other for particular children. Thus imaging the brain may give us clues as to how best to develop a combination of training methods. Studies of self-regulation may also lead to more refined ways to improve this function. This line of research could provide unusual opportunities for educators, psychologists, and neuroscientists to work together toward the common goal of improving children's lives.

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