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Review Article

Developing Attention: Behavioral and Brain Mechanisms

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Brain networks underlying attention are present even during infancy and are critical for the developing ability of children to control their emotions and thoughts. For adults, individual differences in the efficiency of attentional networks have been related to neuromodulators and to genetic variations. We have examined the development of attentional networks and child temperament in a longitudinal study from infancy (7 months) to middle childhood (7 years). Early temperamental differences among infants, including smiling and laughter and vocal reactivity, are related to self-regulation abilities at 7 years. However, genetic variations related to adult executive attention, while present in childhood, are poor predictors of later control, in part because individual genetic variation may have many small effects and in part because their influence occurs in interaction with caregiver behavior and other environmental influences. While brain areas involved in attention are present during infancy, their connectivity changes and leads to improvement in control of behavior. It is also possible to influence control mechanisms through training later in life. The relation between maturation and learning may allow advances in our understanding of human brain development.

1. Introduction

Few life changes are as dramatic as the development that occurs between infancy and elementary school, with locomotion, language, and voluntary control as the most obvious behavior changes. We also know that the brain changes in size, connectivity, and synaptic density during this period. What is least explored is exactly how these brain changes support behavioral change. Our research traces the development of attention networks that support the mechanisms of self-regulation, allowing children to control their emotions and behavior. In this paper, we first outline the connection between attention and self-regulation. In the next section, we examine measurement of individual differences in attention in adults. The heart of the paper summarizes the relation of early temperament (7 months) to later temperament and attention (age: 7 years). We show how changes in mechanisms of control over this period relate to genes and to the environment provided by the caregiver. Finally, we examine training studies that influence some of the same brain connections that change during development.

During infancy, the caregiver provides much of the child's regulation. Soothing by holding and rocking or by orienting of attention is a common practice for control of distress. Holding supports the child's focus on the external physical environment, and the social world of interaction with the caregiver provides a means of raising and lowering sensory stimulation [1]. This process allows the caregiver to accommodate the child to controls appropriate for a given culture and environment. External controls on arousal, distress, and sensory input eventually become internalized as toddlers come to control their own emotional and cognitive levels through self-regulation. Success in the development of self-regulation has many advantages for the child's future.

2. Attention and Self-Regulation

Starting at about the age of 3 years, parents can answer questions about their children's ability to control their own emotions and behavior. For example, caregivers answer questions such as when playing alone, how often is your child distracted? How often does your child look immediately when you point? The answers are aggregated to form scales measuring attention focusing, inhibitory control, low intensity pleasure, and perceptual sensitivity. These are summarized in a higher order scale called effortful control (EC) [1]. Effortful control has been studied in relation to many important achievements of childhood. For example, empathy is strongly related to EC, with children high in EC showing greater empathy [1].

Imaging the human brain has revealed brain networks related to specific aspects of attention, including obtaining and maintaining the alert state, orienting to sensory stimuli, and resolving conflict among competing responses [2, 3].

The alerting network is modulated by the brain's norepinephrine system and involves major nodes in frontal and parietal cortex. The alert state is critical to high level performance. Phasic changes in alertness can be produced by the presentation of a signal warning of an impending target. This leads to a rapid change from a resting state to one of increased receptivity to the target. The orienting network interacts with sensory systems to improve the priority of information relevant to task performance. The orienting network exerts much of the control over other brain networks during infancy and early childhood [4, 5].

The executive network is involved in resolving competing actions in tasks where there is conflict. The executive network includes the anterior cingulate cortex, anterior insula, areas of the midprefrontal cortex, and the underlying striatum [2, 3]. Regulation occurs by enhancing activity in networks related to our goals and inhibiting activity in conflicting networks. These controls operate through long connections between the nodes of the executive network and cognitive and emotional areas of the frontal and posterior brain. In this way, the executive network is important for voluntary control and self-regulation [6, 7]. As mentioned previously, effortful control is a higher order temperamental factor assessing self-regulation that is obtained from parent report questionnaires [1]. In childhood, performance on conflict related cognitive tasks is positively related to measures of children's effortful control [1]. During childhood and in adulthood, effortful control and self-regulation are correlated with school performance and with indices of life success, including health, income, and successful human relationships [8, 9]. In Figure 1 we illustrate our hypothesis about the relative influence of the attention networks on self control in early development.

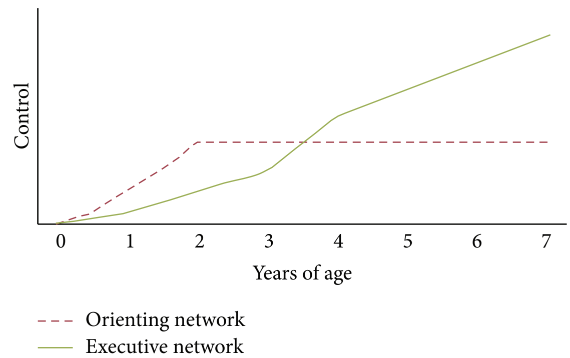

Figure 1: Hypothesized relation between brain attention networks and dominance of control between birth and adulthood.

3. Measuring Individual Differences in Executive Attention

There are individual differences in the efficiency of each of the three attentional networks. The attention network test (ANT) was devised as a means of measuring these differences [10]. The task requires the person to press one key if a central arrow points to the left and another if it points to the right. Conflict is introduced by having surrounding flanker arrows point in either the same (congruent) or the opposite (incongruent) direction. Cues presented prior to the target provide information on where or when the target will occur. Three scores are computed that are related to the performance of each individual in alerting, orienting, and executive control. In our work, we have used the ANT to examine the efficiency of brain networks underlying attention [10]. A children's version of this test is very similar to the adult test but replaces the arrows with animal figures [11].

Studies have shown moderate reliability of conflict scores and lower reliability for the orienting and alerting scores [12], but recent revisions of the ANT provide better measures of orienting and alerting that may improve these results [13]. The attentional networks involve different cortical brain areas [14], and scores on the ANT are related to distinct white matter pathways [15] as well as structural differences in cortical thickness [16]. Thus, the attentional networks show independent anatomy and connectivity. However, the ANT and its various revisions show significant interaction among networks [13, 17]. The networks communicate and work together in many situations, even though their anatomy is mostly distinct. The dorsal part of the anterior cingulate cortex (ACC) is involved in the regulation of conflict in cognitive tasks, while the more ventral part of the cingulate is involved in regulation of emotion [6, 18]. One way to examine regulation is to image the structural connections of different parts of the cingulate using diffusion tensor imaging (DTI). This form of imaging traces diffusion of water molecules in long myelinated fibers and provides a means of examining the physical connections present in the brain. DTI studies have shown that the dorsal (cognitive) part of the ACC is connected primarily to parietal and frontal lobes, while the ventral (emotional) part of the ACC has strong connections to subcortical limbic areas [19].

The executive attention network also includes the underlying striatum and adjacent areas of the midprefrontal cortex. There is evidence that the anterior insula is involved particularly in switching between tasks [20], while adjacent midprefrontal cortex is important during complex decision making [21]. Comparative anatomical studies point to important differences in the evolution of cingulate connectivity between nonhuman primates and humans. Anatomical studies show the great expansion of white matter, which has increased more in recent evolution than has the neocortex itself [22]. One type of projection cell called the von Economo neuron is found only in the anterior cingulate and a related area of the anterior insula, two brain areas that are active together even when the person is resting and not performing a task [23, 24]. It is thought that von Economo neurons are important in communication between the cingulate and other brain areas. This neuron is not present at all in monkeys and there are many more such neurons present in adult humans than in great apes. Moreover, there is some evidence that the frequency of the neuron increases in development between infancy and later childhood [23].

4. Principles of Development of Self-Regulation

4.1. Control Systems. Some individuals have stronger activations and connectivity in brain areas related to self-regulation than others and are thus better able to exercise the various functions of self-regulation. Moreover, childhood assessments of self-regulation as measured by the ability to delay rewards [25] and by observer reports of the child's self-control predict performance as adults [9]. How do these individual differences arise?

To investigate this question, we have run a longitudinal study of the development of attentional networks starting in infancy (7 months), and now the children are 7 years of age. In our longitudinal study, we have found evidence of both behavioral and neural mechanisms of self-regulation. The earliest form of regulation appeared to come from the orienting rather than the executive network (see Figure 1). This conclusion was based on several findings. First, parent reports of their child's orienting to the environment were correlated with reports of their positive and negative affect [5, 26]. Moreover, direct tests were done on the role of orienting to novel objects in soothing. Distressed infants, while orienting was maintained showed a reduction in overt signs of distress, but the distress returned when orienting was broken [27].

Second, in our longitudinal study, we observed that children of 7 months showed evidence of behavior related to self-regulation. When confronted with novel objects, some infants oriented for a long period before reaching towards them. This tendency for a cautious reach was positively correlated with the number of anticipations infants made in orienting to a repetitive sequence of visual events [26]. This striking observation showed that infants fast in orienting to repetitive visual sequences, often in anticipation of the object, exercised stronger controls over whether and when they reached for an object by moving toward it slowly. At the time, we did not know if rapid orienting to repetitive locations was controlled by the executive or the orienting network, but because ours was a longitudinal study, we later found that anticipations at 7 months were more closely related to orienting at 4 years than to the executive network [4]. We have confirmed this idea in our examination of the children at 7 years. The time that infants examined a novel toy before starting to reach for it, their overall latency to reach, and the total time they examined the toy were all significantly correlated with the orienting network at the age of 7.

Lewkowicz and Hansen-Tift [29] provided dramatic evidence that orienting can demonstrate a high level of discrimination in attending environmental events. Infants prior to 6 months and after one year oriented primarily to the eyes of pictures of faces, just as adults do, but between 6 and 12 months when language learning was prominent they were more likely to orient to the mouth. This shows direction of attention by orienting, but it does not let us know whether this control also involves the executive network.

Resting state brain imaging data have also indicated that the orienting system shows greater connectivity during infancy than do brain areas associated with the executive network [30]. In the first week of life, resting state data show an important hub in infants in the ACC/SMA area. Although this hub shows the largest number of connections in infancy, [31]; it is much less strongly activated than hubs found in adults. Fransson et al. also report a hub area in the left parietal lobe during infancy. Menon [32] indicates a substantial increase in connectivity between core areas of what he calls the salience network, but we term the executive network (ACC and insula) between childhood (7–9 years) and adulthood (20 years). He finds no significant developmental change in connections between lateral parietal and frontal areas (orienting network). This imaging data provides further support for the slow development of control from the ACC and the early dominance of the orienting network (see Figure 1). In addition, most hubs for information processing in the infant brain are closely related to sensory and motor brain areas [31, 32] that would be targets of the orienting network. While there is evidence that some of these resting state studies may be confounded by greater movement that can occur in younger subjects [33], in our view it seems unlikely that this artifact will change the conclusions discussed above. However, the problems that occur with any one imaging method support the approach of relating different imaging methods [34] and establishing their connections to behavior as we have sought to do in this paper.

We think the relatively slow development of long-term connections to distant brain areas allows the executive network to provide more control at later ages. Indeed direct evidence on this point came from a study of 7-month-old infants viewing visual displays [35]. They oriented longer when the display was in error [36] and this behavior was associated with a set of scalp electrodes at the frontal midline which localized to the anterior cingulate, an important node of the executive network. However, the lack of connections of the cingulate to remote areas was shown in an inability to use error to control behavior. The most frequent adult response to a self-made error is to slow down during the next trial [37]. We traced the evidence for this kind of control and found that it emerged around three years of age and was not found at the age of 2 [38].

The growing behavioral influence of executive control is shown in an MRI study of the resolution of conflict in the flanker task [39] by 725 children from 4 to 21 years [40]. From 4 to 8 years, ability to resolve conflict was positively related to the size of the anterior cingulate. Beyond the age of 8, the connectivity of the anterior cingulate was correlated with the speed of response. The brain and behavior correlation in early childhood was similar to our finding that flanker task performance showed a specific improvement in children of 6–8 years, but reaction time in the task continued to improve until adulthood [11]. A different study [41] used emotional responses to a fear face during a rewarded go/no-go task to explore the role of brain connectivity in regulation of the amygdala from the ventral anterior cingulate. They found a significant correlation between age and the efficiency of connectivity between the ventral ACC and amygdala during the presentation of fear faces.

The major change in connectivity took place between ages 5 and 7. These studies show substantial overlap in age between development of purely cognitive and emotional self-regulation. We do not believe that the flanker task and emotional go/no-go tasks index the full development of control mechanisms, since more complex tasks may show longer periods of development, but these studies do provide strong confirmation of growing executive system control during early childhood and the close correspondence of brain connectivity to behavioral performance.

In summary, we have discovered a transition between the brain networks responsible for control at 7 months and those at 4 years and later. At 7 months, control involves the orienting network, but by 4 years the executive network dominates. Behaviorally, the orienting network involves sensory stimulation and we believe this is a major reason why infants show control by external stimulation provided by caregivers and sensory events. We also do not believe that control through orienting ends with the preschool transition. We view adults as having dual control. Looking away from disturbing or highly arousing events is clearly a major coping strategy in adults. However, the growing influence of executive control allows the person's internally controlled goals to become generally dominant.

4.2. Control of Emotion and Cognition. The structural connectivity of the anterior cingulate reflects its control functions [6, 18]. The ventral portion of the ACC and adjacent orbital frontal cortex connects mainly to limbic regions and its function is thought to be related to control of emotions [6, 42]. The more dorsal part of the cingulate connects more strongly to cortical areas in the frontal and parietal lobes. This is reflected in evidence of increased connectivity between the dorsal ACC and auditory areas when attending to speech, while a switch to visual input is reflected in increased connectivity between the ACC and occipital lobe [43]. The developmental data cited in the last section [40, 41] support separate functions for the ventral and dorsal ACC and show they both develop strongly between 5 and 8 years of age.

We want to understand the origins of cognitive and emotional controls in the developing infant and child. As mentioned previously, one important function of the anterior cingulate is to play a role in the detection of error [44]. Error detection found at 7 months may reflect either the cognitive or emotional aspects related to the violation of expectation. However, studies using high density scalp EEG at 4–6 years suggest that the resolution of conflict at 4 years involves primarily ventral areas of the cingulate [45, 46]; later more dorsal areas become involved. In addition, studies of resting state MRI in infancy suggest a node in the midprefrontal cortex adjacent to emotional parts of the ACC [30]. This evidence fits with the idea that emotional control develops more quickly than cognitive control during early life, although there is strong overlap in their later development. While the data are not completely clear on this point, it is of obvious importance to parents in fostering the development of these controls.

Table 1: Correlations between temperament measures at 7 months and ANT scores at 7 years.

IBQ	ANT at age 7					
	Alerting		Orienting		Conflict	
	r	P	r	P	r	P
Perceptual sensitivity	.56*	.02	.18	.51	−.07	.79
Duration of orienting	.55*	.03	.01	.96	.03	.91
Approach	.29	.27	.76*	.001	−.28	.29
Soothability	.13	.63	.56*	.024	−.24	.37
Smiling and laughter	.17	.53	.06	.84	−.60*	.015
Vocal reactivity	.24	.37	.20	.47	−.64*	.007
Cuddliness	−.04	.88	.08	.77	−.64*	.008
Positive Affect (higher order)	.43	.10	.38	.15	−.58*	.019

* denotes $P < .05$.

5. Early Temperament Predicts Later Control

By temperament, we mean constitutionally based individual differences in reactivity and self-regulation [47]. At 7 months, we used a parent report scale, the Infant Behavior Questionnaire (IBQ), which heavily weighs reactive responses of the infant, although it does provide a measure of orienting that involves an early control network.

5.1. Predicting Attention Networks. We found surprisingly high and significant correlations between temperament measures at 7 months and performance on the attention network test at 7 years. Our surprise reflects the fact that these correlations are found over an extended time course during which there is considerable neural maturation and they also involve parent report during infancy and behavior in a cognitive reaction time task (ANT) during childhood. These correlations must be regarded as tentative, however, since they involve only sixteen of the seventy infants who remained in the study when the ANT was measured at 7 years of age. The small remaining sample is partly self-selected (some loss resulting from moving away may have been involuntary) from the larger number of infants involved at 7 months.

Separate aspects of temperament were related to each of the attention networks. For a correlation matrix, see Table 1, and in what follows we report significant correlations. Infants' perceptual sensitivity to the environment (.56) and duration of orienting (.55) were correlated with ANT scores of the alerting network at the age of 7 years. While we did not predict that parent ratings of orienting would be related to the alerting network rather than the orienting network, this may reflect dependence of orienting on alertness during infancy when sleep occupies so much of the day.

Infant approach behavior (.76) and soothability (.56) as rated by parents were correlated with ANT scores for the orienting network at the age of 7. As we have seen previously, orienting as reported by parents and measured in the laboratory can be used to control emotional reactivity in infancy, and this aspect seems to predict the skill of taking in sensory information later in life. Soothability as reported by the parent may reflect both the child's propensity and the parent's skill. This could mean that the parents' ability to provide emotional soothing to the child is an important determinant of cognition via the orienting network.

The scales of infant smiling and laughter (−.60), vocal reactivity (−.64), and cuddliness (−.64) were negatively correlated with the ability to resolve conflict and, in addition, the higher order factor of positive affect that contains these scales was also negatively correlated with ANT conflict at 7 years. Multiple regression indicates that these factors could account for about 50 percent of the variance in the difference between reaction time in incongruent and congruent flankers.

In addition, negative affect measured in infancy is correlated with the total errors found in the ANT at the age of 7. It is interesting that positive affect was related to the speed of the children's response, which may largely reflect the efficiency of white matter connections [40], while negative affect predicted the errors that arise due to competition from the incompatible flankers.

Many older ideas of temperament are based on stability between childhood and adults traits. However, Rothbart and Derryberry [47] suggested that we should expect temperament to change as new neural systems come on line. They recognize that there is stability, but change is be expected as neural systems and connections are established. A number of the temperament correlations between infancy and childhood in the previous literature support the ability to predict control in children from infant emotion. Putnam et al. [48] found that positive emotion in infancy is related to later parent reports of their child's effortful control and that infant surgency (smiling and laughter and approach) predicted high effortful control in toddlers. Komsi et al. [49] also found that infant smiling and laughter predicted effortful control in children when they were 5 years old. In addition, the overall orienting measure in infancy predicted 7-year-old soothability, effortful control, and interest. Thus, both ANT cognitive tests and parent reported effortful control support the relation of early reactive emotion in infancy to control systems of childhood.

The correlations found between parent reported temperament at 7 months and ANT performance at 7 years were as high or higher than those found between temperament at the two ages. It is possible these high correlations are due to the unique nature of the 16 families who persisted from 7 months to 7 years. Comparison of those infants who remained in the study until the age of 7 with those who dropped out did not reveal any striking differences, although there was some evidence that the parents continuing with the study were more committed to timely submission of questionnaires than those who dropped out. Moreover, we found neither significant demographic nor behavioral differences between the 16 persistent families and those who were involved at 7 years but not at 7 months.

However, the 16 children who had participated at 7 months were faster in ANT performance than the new recruits. Since faster speed of responding is frequently related to better overall performance, this finding suggests that the 16 children who persisted from time 1 were relatively high performing children. This effect was probably not due to practice, since a direct comparison of performance on the ANT at the age of 7 of children who had also taken the test at the age of 6 and those who had not practiced it previously showed no differences in speed. The speed differences may have reflected recruitment of lower SES families at the age of 7 years than we had previously recruited or other unknown characteristics of the persistent families. A more interesting possibility is that early positive emotional reactivity reflects a particularly predictive feature of child behavior. One possible mechanism for the strong influence of early positive emotion on later control is that more reactive children in infancy come to control their positive emotions more strongly and that this transfers to cognitive control as measured by the ANT.

Table 2: Relating attention networks to dominant modulators and relevant genes.

Network	Modulator	Genes
Alerting	Norepinephrine	ADRA2A
		NET
Orienting	Acetylcholine	CHRNA4 APOE
Executive	Dopamine	DRD4, DAT1, and COMT
		MAOA, DBH
	Serotonin	TPH2, 5HTT

This table is adapted from Green et al., 2008 [28].

5.2. Role of Genetic Variation. We have pursued two strategies to help understand how genes are related to the individual efficiency of attention networks. One approach involves adults and uses the association of attentional networks with particular neuromodulators. These associations have led to identification of candidate genes that relate to each network. The results were summarized by Green et al. [28] and are shown in Table 2. A number of other results have qualified the view of Green et al. somewhat. It seems clear that serotonin as well as dopamine can influence the executive attention network [50] and that there are interactions between dopaminergic and cholinergic genes at the molecular level that modify the degree of independence between them [51]. Nonetheless, the scheme in Table 2 provides a degree of organization and prediction that is often lacking in studies of genetic influences on cognition and behavior.

In our longitudinal study, we examined genetic variation in twelve genes that had been related to attention in adult studies (see Table 2 and [52]). The children had been evaluated when they were 7 months old, and genotyping took place when they returned to the laboratory at 18–20 months. We also genotyped all of the children at 7 years. We compared the results at two ages to be sure of high replication of our classifications. We found supportive evidence for some of the genes discussed in Table 2. The COMT gene was related to number of anticipatory looks at 7 and 18 months [53]. The DRD4 7 repeat allele was not related to our attention measures in infancy or among toddlers but did relate to effortful control at the age of 4 [54]; [55]. This discontinuity likely reflected the change in networks of control from orienting to executive control that we found between 2 and 4 years of age.

In addition, parenting quality at 18–20 months was examined through observation of caregiver-child interactions in which the children played with toys in the presence of one of their caregivers. Raters reviewed videotapes of the caregiver-child interaction and rated the parent on five dimensions of parenting quality according to a schedule developed by NICHD [56]: support, autonomy, stimulation, lack of hostility, and confidence in the child. According to their scores, parents were divided at the median into two groups: one showing a higher quality of parenting and the other a lower quality.

We reported previously [57] that variations in COMT, SNAP25, CHRNA4, and DRD4 were related to elements of emotion during infancy (age of 7 months) and during the toddler period (18–20 months). COMT was related to positive affect including smiling and laughter and high intensity pleasure at 7 months. SNAP 25 was related to negative affect, mainly distress at 7 and 18 months. CHRNA 4 was related to effortful control at 18 months and DRD4 was related to sensation seeking at 18 months.

However, unlike the temperament measure of emotion to which the genetic variations were often related, there was little evidence that the genetic variations by themselves predicted behavior at 7 years on the ANT. A recent meta-analysis of studies of twins indicates that genetic factors that influence cognition at one point are largely different from those at later times (see, [58], p. 19). Our studies suggest that shifts in control networks and gene X environment interactions may be among the reasons for this lack of prediction in early life.

6. Simulating Development through Training

Development in the title of this paper refers both to changes in attention through the natural maturation of the brain and to our efforts to develop attention through training. Below we discuss similarities between the development of white matter pathways between infancy and childhood with the influence of meditation training on adult white matter. It is our hope that efforts to train attention may help us to better understand the process of infant and child development. As we have seen, parenting influences this development, and we hope to better inform parents about what can be done to improve this process.

The developmental process through which attention networks and self-regulation mature is very complex. There are many changes in brain structure and function that may be related to the multiple changes in voluntary behavior in early development. As discussed previously, an increasingly popular way of tracing brain changes is to use resting state MRI to characterize how the brain changes in development [30, 59]. In our recent work, we have tried to relate behavior changes to changes in functional connectivity [4].

The changes in connectivity during development reported in resting state MRI studies involve functional connectivity based upon correlations between BOLD activity in separated brain areas. There is also evidence of actual physical changes in the white matter thought to underlie these correlations [34]. Our recent training work with adults using diffusion tensor imaging (DTI) has uncovered white matter changes that have some similarities to those found in development. Changes in connectivity surrounding the ACC have been shown to be critical to improved reaction time in the flanker task during development [40]. Training adults might thus allow us to uncover how connections developing during childhood support the changes in self- control between infancy and adulthood.

During development, there is a large change in the physical connections between brain areas. The density of axons in pathways connecting brain areas increases, followed by an increase in the myelin sheath that surrounds the axons and provides insulation. Together, these changes result in more efficient connections [60]. Fractional anisotropy (FA) is the main index for measuring the integrity of white matter fibers when using DTI.

In our work, we studied FA in college students before and after a form of mindfulness meditation called integrated body mind training (IBMT) in comparison to a control group given the same amount of relaxation training. We found clear improvement in the executive attention network after only five days of training [61]. After two to four weeks of training, we found significantly greater change in FA following meditation training than following the relaxation training control. This change was found in all white matter tracts surrounding the ACC, but not in other brain areas [62]. This was particularly striking because one of these pathways, the anterior corona radiata, has previously been reported to be correlated with individual differences in the ability to resolve conflict using the ANT [15].

These alterations in FA could originate from several factors, such as changes in myelination, axon density, axonal membrane integrity, axon diameter, intravoxel coherence of fiber orientation, and others. Several DTI studies have examined axial diffusivity (AD) and radial diffusivity (RD), the most important indices associated with FA, to understand the mechanisms of FA change [63, 64]. Changes in AD are associated with axon morphological changes, with lower AD value indicating higher axonal density. In contrast, RD relates to the myelin insulation surrounding the axons. Decreases in RD imply increased myelination, while increases represent demyelination.

In our study [65], we investigated AD and RD where FA indicated that integrity of white matter fibers was enhanced in the IBMT group more than control group. We found that after two weeks of training, there were changes in axonal density but not in myelination. In some areas, these changes in axonal density were correlated with improved mood and affect as measured by self-report. After 4 weeks of training, we found evidence of myelination changes. Our studies also found that reaction time in the attention network test and specifically the executive network was improved more by IBMT training than by the control. Since the developmental changes in childhood first involve changes in axonal density and only later myelination, our training may provide changes that are somewhat similar to those found in development. If so, it might be possible to use training to study how physical changes in connectivity alter aspects of control, including reaction time, control of affect, stress reduction, and other changes found with training.

7. Future Directions

The work described here has barely begun to open up a window on the dramatic changes in control between infancy and childhood. Some changes in the size and connectivity of brain areas related to cognitive and emotional control have been documented by resting state and task related MRI methods. More work needs to be done in these areas.

Moreover, we are at the very beginning of understanding the joint role of caregivers and genetic endowment in creating the brain networks of control. We have clear evidence that parents can rate in infancy critical aspects of their child's emotions and behavior that seem to exert influence on the development of control and in some cases we know that specific genes are important, but confirmation and extension of these ideas are critical to understand what environments and experiences will foster self-regulation. Research is starting to provide ideas as to the epigenetic basis of environmental influence [66, 67], and these need to be expanded and applied to the development of self-regulation.

It is important that specific interventions can influence connectivity even into adulthood. More studies are needed to connect brain changes fostered by learning with specific behavioral gains and then to determine if there are more than superficial similarities between adult development through specific interventions and the changes that take place in early child development. We think the small scale and tentative steps outlined in this report point the way to the types of studies that can lead to improved understanding of how specific brain changes support the child's developing abilities for self-regulation.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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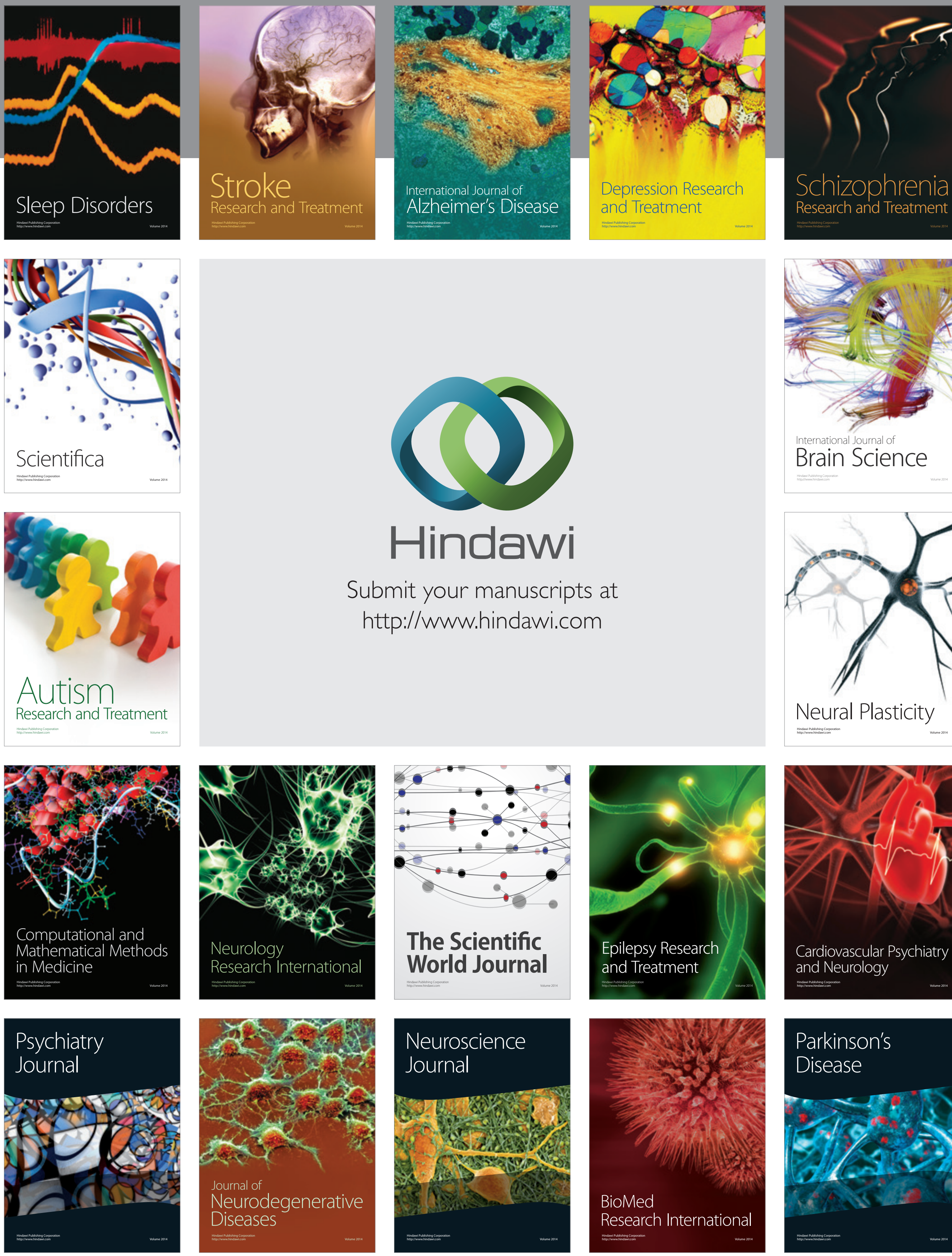

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