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Educating executive attention

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Researchers in the newly emerging field of developmental cognitive neuroscience seek to understand how postnatal brain development relates to changes in perceptual, cognitive, and social abilities in infants and children (1). One of the areas of cognitive development that has benefited most from a developmental cognitive neuroscience approach is attention. The ability to attend to individual objects, people, and spatial locations within our complex and varied sensory environment is fundamental to human cognition. One important aspect of attention, so-called executive attention, refers to our ability to regulate our responses, particularly in conflict situations where several responses are possible. This aspect of attention is thought to develop until early adulthood but seems to undergo a particularly rapid development between 2 and 7 years of age (2, 3), and problems with this function as well as other executive functions may underlie some of the difficulties observed in children with Attention-Deficit/Hyperactivity Disorder (ADHD) (4).

In this issue of PNAS, Rueda *et al.* (5) present a study that elucidates several aspects of executive attention in young children. In their work, they have gathered measures of brain activity, cognition, and behavior in children aged 4 and 6 years. These measures include behavioral assessments of executive attention and intelligence, genotyping of a dopamine-related gene (DAT1), recording electrical activity at the scalp generated by neuronal function (ERPs), and parental questionnaires relating to the child's temperament. For each age group, half of the participants received a specific educational intervention designed to enhance executive attention. This training program, adapted to be child-friendly from a method originally used to prepare macaque monkeys for space travel, was given for 5 days over a 2- to 3-week period.

Rueda *et al.* (5) build on previous work showing that executive attention has a specific developmental course and strong genetic associations. For example, it has been shown that the executive attention network (6, 7) has a relatively large genetic component compared to more basic aspects of attention such as alerting and orienting (8). In addition, several studies have demonstrated that younger children, especially children below 4 years of age, have great difficulty performing tasks that involve solving some form of stimulus conflict and thereby engaging the executive attention network (2, 3, 5, 9–11). However, in a recent study, Rueda *et al.* (3) found that performance on the executive component of the Attention Network Test (ANT, a test battery measuring three core attentional functions) does not improve significantly beyond age 7, indicating that children this age perform close to adult levels. On this basis, Rueda *et al.* (5) reason that because children between 4 and 6 years of age are still developing this ability, they constitute the ideal group for studying training effects on executive attention. Furthermore, because of the strong genetic influence on executive attention in adults, possible interaction effects between genotype and training can potentially be established in a combined developmental and training study.

Executive attention refers to our ability to regulate our responses, particularly in conflict situations.

The work of Rueda *et al.* (5) significantly advances our understanding of the development of executive attention in two ways. Firstly, for the first time in young children they show an association between a cognitive function (executive attention), a measure of brain function (event-related potentials recorded from the scalp), and genotype (DAT1). This breakthrough potentially opens a new vista for experiments in developmental cognitive neuroscience in which genetics, brain function, and behavior can be related through the study of individual differences. Secondly, the paper advances the field because it demonstrates that executive attention skills can be trained, or development accelerated, in young children. This finding could potentially lead to better intervention strategies for children with attentional and other behavioral problems.

In their interpretation of the results, the authors propose that improvements in performance induced by training are similar or identical to improvements caused by the passage of developmental time, i.e., maturation. Thus, they argue that the immature system can be trained to function in a more mature way (albeit that in their study the effects of training were smaller than the effects of maturation). They also argue that the effect of attention training extends to more general skills such as those measured by intelligence tests.

The behavioral data from the 6-year-old children strongly support their conclusions. In this experiment, the trained group did better than the untrained group on both the ANT and K-BIT (a test of general intelligence). The 6-year-olds improved more on the ANT measure than on the K-BIT. The behavioral data were supported by event-related potential (ERP) findings. These data showed a strong effect of "conflict" recorded over parietal channels for the trained group, whereas the untrained group tended to show an effect over frontal channels. These ERP findings fit well with the authors' claim that the trained 6-year-olds showed a more adult-like neural response than the untrained group did. The ERP result might also indicate that the trained 6-year-olds engage a more automatic posterior cortical system, whereas the untrained 6-year-olds have to recruit frontal cortical networks to exert executive control. This in itself is an interesting finding.

The data from 4-year-old children appear less clear-cut. Although the trained group did show significant improvement in their general intelligence measures, effects of training were not as strong on measures of executive attention. It is possible that other neural mechanisms are at play in the 4-year-old group, perhaps expressing the great difficulty with which this group performs executive attention tasks in the

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See companion article on page 14931.

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first place. A similar interpretation is discussed in another study by Rueda and colleagues (11) that compared adult and 4-year-old children's ERPs during ANT performance. Further studies will no doubt be required to establish the extent to which training affects executive attention measures in 4-year-old children.

An alternative interpretation of the data is that training effects lead to more mature or adult-like performance in various ways, but that such training depends on the age of the child. For example, the 6-year-old children may show a large training effect on the executive attention measure because they are approaching adult levels in the first place. The effect would thus constitute an acceleration at the end of the normal developmental course of this attentional function. Conversely, the 4-year-old children may not benefit so much in terms of executive attention performance because this function is still quite immature in children this age. However, as can be seen in tables 2 and 3 in Rueda *et al.* (5), the 4-year-olds actually showed a larger increase in intelligence measures than the 6-year-olds indicating that they may benefit from training in a more general way. We have illustrated these differential age and training effects in Fig. 1.

The genetic and temperament data presented in Rueda *et al.* (5) are interesting and consistent with the authors' hypothesis. As in previous studies (8, 12), the authors are able to show strong genetic contributions to individual differences in executive functioning even in a relatively small sample of children. As Diamond *et al.* (12) point out, gene association studies that are focused on well studied candidate genes do not require the usual large sample sizes used in genetic studies.

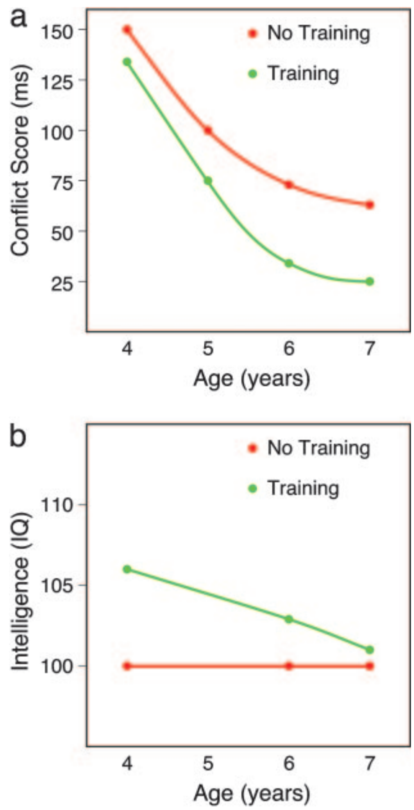

Fig. 1. Differential training effects across age. (*a*) The effect of training vs. no training (baseline) on executive attention performance. (*b*) The effect of training vs. no training on intelligence performance. Data points at ages 4 and 6 are based on data from Rueda *et al.* (5). The data point at age 7 for the average conflict score of the untrained group is based on data from Rueda *et al.* (3). All other data points are hypothesized because no data are available for these ages at present. Note that the IQ measure has been adjusted to a mean of 100 because this is likely to be the population mean of standardized test scores at all ages.

Nevertheless, a replication in a larger sample of children would allow an analysis of possible differential effects of training on children with different genotypes.

At a more general level, the study raises the question of the relationship between executive function and intelligence. As discussed above, the results seem to indicate that the training advanced children in different ways depending on their age. Whether this finding means that executive attention is a separate function that develops independently from intelligence, or whether executive attention is an integral part of intelligence that shows different training effects at different ages, cannot be addressed by the current study. In future studies, it will be interesting to investigate this question further. In addition, it would be relevant to follow up a group of children to establish whether the training effects persist over time or whether the effects of training are only short-term.

In conclusion, the study reported by Rueda *et al.* (5) shows that both genotype and training influence performance on specific attentional tasks and tests of general intelligence in 4- and 6-year-old children. However, more work will be required to unravel the complex interactions between age, genotype, and training efficacy. The training program devised in the study has considerable potential for practical application to both typical and atypical populations, especially children affected by ADHD. (The authors offer their program on the web at www.teach-the-brain.org/learn/attention.) However, it is clear from the results of the study that any training program should take into account factors such as the individual child's genotype and age. Such age and genotype targeted training programs offer great promise for the future.

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