Giftedness and the brain


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In violin playing, the left-hand fingers create musical notes by stopping the strings on the fingernail. This requires perfect motor control of each finger, whereas the right hand just holds the bow. Elbert et al. (1995) showed that the regional volume of the primary motor areas were larger for the fingers of the left hand in violinists compared to the same areas for the right hand; the effect was smallest for the thumbs. However, the effect emerged only when the person had started playing the violin before the age of seven. This indicates that neuroplasticity works more effectively during childhood and could explain why learning may become more difficult thereafter.

Musicians showed higher grey matter (i.e. neuronal cell somata) density in the left inferior frontal lobe, or Broca's area (Sluming et al., 2007). This area is crucial for language production but is also involved in sight-reading of musical notes in professional musicians, as shown by the same group (Sluming et al., 2002).

The Geschwind–Galaburda model (Geschwind & Galaburda, 1985a-c) represents the classical 'neuronal resource' account of giftedness. It was based on the empirical observation that giftedness was associated to some degree with the male gender, atypical handedness, less expressed functional asymmetry of the hemispheres as measured by visual-hemifield stimulation and dichotic listening tests, and higher prevalence of allergies and myopia. From this pattern, the authors concluded that the right hemisphere was more active in talents (i.e. that talented people show less left-hemispheric dominance and more pronounced interhemispheric exchange). Geschwind and Galaburda speculated that in talents fetal exposure to higher levels of the male sex hormone testosterone might have favored the relative growth of the right hemisphere and the corpus callosum.

Parts of the model were confirmed in several studies. For example, using fMRI, O'Boyle et al. (2005) reported increased right hemisphere contributions to maths-related tasks in mathematical talents. Alexander et al. (1996) revealed increased activity of the right hemisphere in talents during rest by EEG analysis.

However, recent research has challenged the evidence for the almost classical dogma of a higher proportion of male talents. While Benbow (1988) had reported a gender ratio of 15:1 for male mathematical talents, Hyde et al. (2008) recently showed that no gender effects on maths skills could be revealed in any grade and on any level of performance (provided that the maths test was mandatory for all pupils, both girls and boys).

Research with musical experts provides evidence for the 'neuronal resource' account of exceptional skills; however, it also underlines the general role of years of practice. Since psychophysiological research is correlational and quasi-experimental, it remains unclear whether neurophysiological correlates of musical expertise are a cause or an effect of such training. Evidence is mixed, for example:

In a magnetoencephalography (MEG) study, the neural response (so called mismatch negativity) to occasional changes in melodic contour or interval was 25 per cent higher in musicians than in non-musicians when they were listening to notes from musical scales, whereas no remarkable group differences occurred during pure 'nonmusical' note stimulation (Pantev et al., 2003).

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Musicians with perfect pitch – the ability to name a note and to evaluate whether it is tuned precisely without reference to adjacent notes – have a more expressed left–right asymmetry in the volume of the planum temporale (superior temporal lobe) than musicians without perfect pitch but with the same amount of practice (Schlaug et al., 1995). A relatively
larger left planum temporale might represent a morphological disposition for a specific music-related, potentially inborn, skill that appears to be independent of formal training. Although this finding seems to reveal a congenital difference, and thus a neurophysiological correlate of musical talent, it cannot be excluded that early experience and implicit practice contributed to the morphological differences.

The 'neural efficiency' account

While the 'neural resource' account aims to point out the high capability of talents, the 'neural efficiency' account addresses differences between the talents and nontalents while working on identical tasks. Obviously, a skilled cognitive system is more efficient – it achieves goals with fewer resources (time, subjective effort) than an unskilled system. But how does cognitive efficiency translate to the neuronal level?

Neurocognitive efficiency has primarily been probed by task-related EEG recordings and advanced methods of EEG data analysis. For example, Jaušovec (1996) reported that talented individuals showed increased alpha-EEG power, indicating less cognitive effort than in a normal cohort while working on an identical task. (Interestingly, the study also showed that the talented individuals showed more mental activity when not working on a task.) Further evidence for increased neural efficiency in talents was provided by several studies from Neubauer (e.g. Neubauer et al., 2005; Grabner et al., 2006). In these studies less mental effort in talents was indicated by less event-related desynchronisation of the alpha-EEG in talents as compared to nontalents during identical tasks.

Another explanation for higher neurocognitive efficiency in talents is offered by Miller (1994), who suggested that efficiency might depend on stronger 'myelination', the electrically insulating sheath that allows action potentials to 'leap' along the axon by salutary transmission.

Convergence of both models

In terms of general intelligence Shaw et al. (2006) revealed that the developmental dynamics, but not specific developmental stages, differ between high-IQ talents and nontalents. The study provided evidence for both accounts of talent: the cortex of highly intelligent children is thinner before the age of eight years (indicating neural efficiency) but then grows faster and is finally thicker than that of their average-intelligent peers in adolescence (indicating neural differences between high and low performers (e.g. Rypma et al., 2006; see above). Frontal activation is related to a more controlled (i.e. more effortful and energy-consuming) cognitive activity (i.e. working memory), which mainly occurs at the system’s capability limits. Posterior activation is related to a more automatic perceptual processing below the capability limits.

It’s here that we run into that issue again: that differences in brain activation are often related to task difficulty (Haier et al., 1992; Larson et al., 1993), which partly depends on subjective capability. When working on easy tasks, talented participants show less metabolic activation than nontalented participants, providing the evidence for the ‘neural efficiency’ account. However, applying a more difficult task revealed more activation in talented individuals, supporting the ‘neuronal resource’ account. In Lee et al.’s (2006) study, increasing task difficulty yielded stronger activation in posterior parts of the frontoparietal brain network in highly intelligent teenagers than in age-matched peers of average intelligence.

Conversely, our own (as yet unpublished) studies on mental arithmetic and mental 3D-rotation in adolescents revealed higher frontal activation in mathematically nontalented participants than in their talented counterparts. It’s a mixed picture!

Taken together, the neuroimaging


findings suggest that talented people are more efficient in their particular domain because they can recruit more neuronal resources for automatic processing prior to frontal activation. Alternatively, their working memory (or frontal brain system) might be more efficient as well (cf. Shaw et al., 2006). Frontal activation as revealed in neuroimaging studies may be regarded as a general indicator of reaching individual capability limits. In this way, it could allow us to make a distinction between high and low performers.

Talent and motivation

Comprehensive explanations of giftedness need to explain not only higher performance, but also the high motivation to practise. It is now generally accepted that professional mastership requires dedicated high-quality training of at least 10,000 hours (i.e. nearly two hours per day of practice from the age of 3 to 17 years; Ericsson & Charness, 1994). Notably, it has been shown that for high academic achievement, it is not necessary to have an IQ much above the average. Duckworth and Seligman (2005) reported that the individual differences in achievement among the students with the same IQs were explained by motivation, self-discipline and practice.

The neuroscientific findings on talent remind us of the classical law of Yerkes and Dodson (1908) that states that optimal performance is achieved at (individual) medium levels of arousal. Our speculation is that the onset of frontal activation, as revealed by neuroimaging studies, may serve as an indicator of the critical transition from optimal medium arousal to stress, (i.e. mental overload). An implication of this assumption is the notion that frontal activation does not specifically contribute to solving a task, but instead indicates unspecific and potentially disturbing neurocognitive activity at capacity limits (cf. Snyder et al., 2006).

So what are the lessons of this for the real world? Talented and nontalented individuals are often exposed to the same tasks irrespective of their different capability (e.g. in school classes). Perhaps in such tasks the former achieve good results with very little or medium effort, which reinforces positive attitudes and practising. In contrast, the latter experience stress, or even fail, despite making a strong effort, which reinforces negative attitudes. A possible lesson from psychological and neuroscientific talent research might be the idea that higher motivation – and, consequently, more practice and higher achievement – result from an individualised task selection, ensuring success at an individual’s medium levels of arousal and effort, prior to the onset of frontal activation.