ARTICLE

Giftedness and the brain

Christian Hoppe and **Jelena Stojanovic** look towards the neural mechanics behind talent

In the study of neural activity underlying task performance, neuroscientists have discovered that different neural states arise in low and high performers on the same cognitive tasks. What then sets the high performer apart?

This article discusses the various neural mechanisms advanced to account for differences between gifted and non-gifted performers. Is there a gender association? Do 'talents' have access to more neural resources? Or do they just use their resources more efficiently? And what is the role of practice and motivation in achieving expertise?

question

How is the triad of talent – higher capability, less effort in standard tasks, and high motivation – represented on the brain level?

resources

Howe, M.J.A., Davidson, J.W. & Sloboda, J.A. (1998). Innate talents: Reality or myth? *Behavioral and Brain Sciences, 21,* 399-442.
Pfeiffer, S.I. (Ed.) (2008). *The handbook of giftedness in children: Psychoeducational theory, research and best practices.* Berlin: Springer.
Centre for Gifted Education Policy: www.apa.org/ed/cgep.html

Giftedness or genius in children and adolescents is an intriguing phenomenon seeking scientific explanation. What makes a child stand out from their peers as talented? What pushes their performance into the uppermost part of the normal 'bell curve' distribution of different levels of performance, whether it is music, maths, sport or some other domain? Or consider general intelligence: reaching the 97th percentile (IQ > 130) is as unlikely as mental retardation (IQ < 70). Although an empirical definition and 'diagnosis' of talent does not necessarily imply or refer to later academic or professional achievement, the question of what drives such ability is still of interest on a personal and professional level. What can modern methods tell us?

Cognitive neuroscience and performance

While other scientific approaches seek psychological (e.g. working memory capacity), psychosocial (e.g. parents' income), biological (e.g. gender), or genetic (e.g. specific polymorphisms) explanations of giftedness, neuroscientists look for structural and functional brain-related factors covarying with performance. Classical neuropsychology explored (and continues to explore) the cerebral causes of the loss of function in neurological patients; modern brain research seeks to understand the intact cognitive function. Non-invasive methods (e.g. EEG, MRI) allow the observation of brain structures and processes in healthy people as they perform cognitive tasks.

However, there is a potential problem here. If the task is too hard or too easy for the person, how do we know they actually perform the cognitive process under examination while their brains are scanned? In the majority of current neuroimaging studies, the inevitable variations in individual performance are widely ignored. All subjects work on the same task, irrespective of their variant performance levels.

Cause or effect?

However, recent studies show that identical cognitive tasks do not induce identical neuronal states in high and low performers. For example, Rypma et al. (2006) considered the variation of performance on an easy cognitive task (symbol–digit comparison task, from the Wechsler intelligence scales) in a normal sample of subjects. They split the sample, on the basis of median response times. While the fast-reacting subjects showed posterior (i.e. parietal) brain activation during the task, the slower-reacting subjects showed anterior (i.e. frontal) activation during the identical task; this finding is termed the 'anterior–posterior pattern'.

This study raises doubts that cognitive states can be defined by tasks without reference to the individual performance levels. Interindividual variation of performance levels cannot be ignored when neuroscientists search for correlates of talent: it actually represents the research objective. Nevertheless, most of the presently available neurocognitive research on talent adheres to the principle (or

references

Alexander, J.E., O'Boyle, M.W. & Benbow, C.P. (1996). Developmentally advanced EEG alpha power in gifted male and female adolescents. *International Journal of Psychophysiology, 23*, 25–31.
Benbow, C.P. (1988). Sex differences in mathematical reasoning ability in intellectually talented preadolescents, their nature, effects, and possible causes. *Behavioral Brain Science, 11*, 169–232.
Duckworth, A.L. & Seligman, M.E. (2005). Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychological Science, 16*, 939–944.
Elbert, T., Pantev, C., Wienbruch, C. et al. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270*, 305–307.
Ericsson, K.A. & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist, 49*, 725–747.
Geschwind, N. & Galaburda, A.M. (1985a). Cerebral lateralization. Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of Neurology, 42*, 428–459.
Geschwind, N. & Galaburda, A.M. (1985b). Cerebral lateralization. Biological mechanisms, associations, and pathology: II. A hypothesis and a program for research. *Archives of Neurology, 42*, 521–552.
Geschwind, N. & Galaburda, A.M. (1985c). Cerebral lateralization. Biological mechanisms, associations, and pathology: III. A hypothesis and a program for research. *Archives of Neurology, 42*, 634–654.

perhaps illusion?) that a task can produce a consistent neurocognitive state, regardless of differences in performance.

The 'neural resource' account

Neuroscientists assume that cognitive functions are realised by neuronal activity. Consequently, complex skills should require additional neuronal resources.

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 favoured 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).
- 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). Grey matter density in Broca's area was positively correlated with years of musical practice, indicating that the increase may have been an effect rather than a cause.
- In violin playing, the left-hand fingers create musical notes by stopping the strings on the fingerboard. 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 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

Grabner, R.H., Neubauer, A.C. & Stern, E. (2006). Superior performance and neural efficiency: The impact of intelligence and expertise. *Brain Research Bulletin, 69*, 422–439.

Haier, R.J., Siegel, B.V. Jr, MacLachlan, A. et al. (1992). Regional glucose metabolic changes after learning a complex visuospatial/motor task: A positron emission tomographic study. Brain Research, 570, 134–143.

Hyde, J., Lindberg, S.M., Linn, M.C. et al. (2008). Gender similarities characterize math performance. *Science, 321*, 494–495.

Jaušovec, N. (1996). Differences in EEG alpha activity related to giftedness. *Intelligence, 23*, 159–173.

Larson, G.E., Haier, R.J., LaCasse, L. & Hazen, K. (1995). Evaluation of a 'mental effort' hypothesis for correlations between cortical metabolism and intelligence. *Intelligence, 21*, 267–278.

Lee, K.H., Choi, Y.Y., Gray, J.R. et al. (2006). Neural correlates of superior intelligence: Stronger recruitment of posterior parietal cortex. *NeuroImage, 29*, 578–586.

Miller, E. (1994). Intelligence and brain myelination: A hypothesis. *Personality and Individual Differences, 17*, 803–832.

Neubauer, A.C., Grabner, R.H., Fink, A. & Neuper, C. (2005). Intelligence and neural efficiency: Further evidence of the influence of task content and sex on the brain–IQ relationship. *Brain Research Cognitive Brain Research, 25*, 217–225.

O'Boyle, M.W., Cunnington, R., Silk, T.J. et al. (2005). Mathematically gifted male adolescents activate a unique brain network during mental

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 saltatory 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 resources). The correlation between developmental dynamics and intelligence primarily appeared in the prefrontal cortex.

Several neuroimaging studies on talent (or high performance levels) reveal an anterior–posterior pattern of activation 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., 1995), 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 fronto-parietal 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

Professional mastership requires at least 10,000 hours training

rotation. *Cognitive Brain Research, 25*, 583–587.

Pantev, C., Ross, B., Fujioka, T. et al. (2003). Music and learning-induced cortical plasticity. *Annals of the New York Academy of Science, 999*, 438–450.

Rypma, B., Berger, J.S., Prabhakaran, V. et al. (2006). Neural correlates of cognitive efficiency. *NeuroImage, 33*, 969–979.

Schlaug, G., Jäncke, L., Huang, Y. & Steinmetz, H. (1995). In vivo evidence of structural brain asymmetry in musicians. *Science, 267*, 699–701.

Shaw, P., Greenstein, D., Lerch, J. et al. (2006). Intellectual ability and cortical development in children and adolescents. *Nature, 440*, 676–679.

Sluming, V., Barrick, T., Howard, M. et al. (2002). Voxel-based morphometry reveals increased gray matter density in Broca's area in male symphony orchestra musicians. *NeuroImage, 17*, 1613–1622.

Sluming, V., Brooks, J., Howard, M. et al. (2007). Broca's area supports enhanced visuospatial cognition in orchestral musicians. *Journal of Neuroscience, 27*, 3799–3806.

Snyder, A.W., Bahramali, H., Hawker, T. & Mitchell, D.J. (2006). Savant-like numerosity skills revealed in normal people by magnetic pulses. *Perception, 35*, 837–845.

Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459–482.

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.

Christian Hoppe
is in the Department of Epileptology, University of Bonn Medical Centre, Bonn
christian.hoppe@ukb.uni-bonn.de

Jelena Stojanovic
is in the Department of Epileptology, University of Bonn Medical Centre, Bonn