Chapter 10
Individual Differences in Cognition from a Neurophysiological Perspective: The Commentaries

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1. Does the concept of general arousal have a central place in modern neuroscience theory?

Todd Braver and Tal Yarkoni

We think this is an open empirical question. A good analogy is the concept of general intelligence, which has been the focus of many recent neuroscience studies. It is ultimately an empirical question as to whether intelligence is best described as a single monolithic construct or in terms of narrower lower-order abilities (e.g., visuospatial ability, verbal intelligence, etc.). Some studies have found important brain structural and functional correlates of general intelligence, when treated as a monolithic construct (e.g., Thompson). However, other work has led potential to refinement or revision of the construct (e.g., placing focus on lower-level processes, such as interference control). The concept of arousal has received less attention in cognitive neuroscience research, but the situation may nevertheless be similar. Is there a monolithic arousal system in the brain? Perhaps not, just as few people would argue that there is a single "intelligence system"; on the other hand, we suspect that when arousal is operationalized in relatively general ways – e.g., in terms of individuals' propensity to respond to emotional stimuli, their basal activity level, etc. – there will be identifiable neural correlates. Moreover, it may turn out that the construct of general arousal has little utility when compared to narrower conceptions of arousal, much as some would argue that notions of general intelligence are ill-founded. In this regard, the recent work on the locus coeruleus/norepinephrine (LC–NE) system is instructive (Aston-Jones & Cohen, 2005). Although the LC–NE system has long been linked to arousal, current theorizing suggests a more nuanced functional account that can still explain relevant arousal phenomena (i.e., the Yerkes-Dodson U-shaped relationship to performance), but also provides a narrower and more constrained interpretation of relevant functional mechanisms (e.g., attentional effects of tonic vs. phasic LC–NE activity). Thus, like much of cognitive neuroscience research, it is important not only to search for neural correlates of classic psychological constructs, but also to utilize new data to revise, refine and reshape such constructs.

Aleksandra Gruszka, Adam Hampshire and Adrian M. Owen

At the moment, the answer to this question is "No". Currently, the concept of "general arousal" – as a subject of an ongoing psychological debate whether it is a valid construct at all – does not play an important role in neuroscience, unless more specific uses of the term arousal (i.e., as

A. Gruszka et al. (eds.), *Handbook of Individual Differences in Cognition: Attention, Memory, and Executive Control*, The Springer Series on Human Exceptionality, DOI 10.1007/978-1-4419-1210-7_10,

wakefulness in a context of a role of noradrenergic locus coeruleus in circadian regulation of arousal or as vigilance in a context of attentional performance) are considered. In a way, the status of “general arousal” is similar to the status of “attentional resources”. Both these terms are very broad and ill-defined and have been extensively criticized. At the same time, both constructs are surprisingly vivacious as they are often used to account for a wide variety of behavioral observations in the absence of more suitable hypothetical constructs. Perhaps a less obvious yet exciting possibility would be to use behavior–brain based associations to gain empirical constraints that help to parse “general arousal” into more valid psychological constructs to account for individual differences in a set of dispositions described jointly as “general arousal”. This promise, however, is still an open question.

Norbert Jaušovec and Ksenija Jaušovec

No, but this is just an opinion, and I have no arguments to support or refute the answer. It is mainly based on my recall of articles I read when preparing my research.

Almira Kustubayeva

Since G. Moruzzi and H.W. Magoun discovered the “arousal reaction”, the concept of general arousal has influenced understanding of neurophysiological mechanisms of behavior. Arousal has been represented in different theories such as extraversion theory, optimal arousal theory of motivation, cognitive arousal theory of emotion, etc. A vast number of neurophysiological studies have provided mixed evidence, sometimes supporting and sometimes contradicting the various theories. To what extent the arousal concept has a central place in modern neuroscience is an arguable question. Modern neuroscience has been basically oriented to assume localization of cognitive functions in specific brain areas ever since Broca and others found relationships between specific brain areas and cognitive functions such as speech, movement, and other functions. So far, we have a large number of neuroimaging studies that have shown activation of different brain networks under different cognitive tasks performed in experimentally controlled conditions. Nevertheless, generalization vs. localization remains a main issue in cognitive neuroscience. All higher cortical functions such as working memory, learning, and problem solving are involved in multiple areas of brain activity. Luria’s hierarchical systems approach has been valuable for exploring basic principles of cognitive function (Kustubayeva, this volume). The first bloc, which includes the brainstem, reticular formation, mediobasal cortex and limbic system, regulates nonspecific activation and modulates appropriate tonus of normal work conditions for higher cortical areas. In my opinion, the operation of this bloc supports the significance and topicality of arousal theory. Hierarchical models of cognition have inspired the modern neuroscience of complex brain mechanisms. Basar’s theory of whole-brain-work explains oscillatory dynamics of the brain during cognitive function, which supports an idea about “constant reciprocal activation within the subprocesses of attention, perception, learning, and remembering” (APLR alliance; Basar, 2006). Friston’s “Free energy theory” (Friston & Stephan, 2007) concerns brain functions as a part of an entire system.

In terms of physiological understanding, arousal is related to the regulation of function, and regulation of balance of excitatory and inhibitory processes. In particular, Pavlov’s idea of higher nervous system properties comes from the study of digestive regulation. Inhibitory processes shape excitation of specific brain areas during regulation of the nervous system. Indeed, the concept of inhibitory control is one of the central ones in understanding mechanisms of executive control, and development of self-regulation (Fernandez-Duque, Baird, & Posner, 2000).

2. What advances in methods may be critical for future individual differences research?

Todd S. Braver and Tal Yarkoni

As we note in our chapter, the current Achilles heel of individual differences research, at least in the cognitive neuroscience literature, is insufficient power due to the use of small sample sizes. For researchers who rely primarily on psychophysiological techniques that are (relatively) cost-effective, there is a simple solution that requires no methodological advances: collect more data! But fMRI and PET scanners have considerable maintenance and operating costs, and it is unlikely that the cost of using these techniques will fall dramatically any time soon. As such, we would suggest that a stronger push is needed toward the development of novel multivariate statistical techniques that may indirectly compensate for insufficient power, e.g., by increasing measurement reliability, decreasing the number of statistical comparisons conducted, and so on. Ultimately, of course, we want what everyone else wants: a neuroimaging technique that has the spatial resolution of fMRI, the temporal resolution of EEG, and the cost of a behavioral study.

Aleksandra Gruszka, Adam Hampshire and Adrian M. Owen

The chapter by Yarkoni and Braver makes an excellent contribution to the answer to this question and, indeed, it is difficult to add up at the moment. In the ideal world, psychologists would wish to have a kind of litmus paper that would serve as an indicator of various perfectly theoretically valid constructs (e.g., a level of extraversion, neuroticism or intelligence) with least possible effort from our participants. In a more realistic fashion, we would all wish to replace our imperfect questionnaires with a set of theoretically driven, perfectly validated tasks critical for neurotics, extraverts and so on, that would be decomposed into cognitive components perfectly localized to discrete brain regions and thus suitable for neuroimaging. The outcomes of studies utilizing such perfectly validated paradigms then could be linked to molecular and behavior genetics. Such genomic imaging strategy will eventually bridge the gaps between psychological theory, biological mechanism and genome and help us progress from the question of *how* people differ from each other to *why* they differ from each other in the first place. Although methodological and practical difficulties are substantial, some preliminary findings suggest proof-of concept. So in the future, we will see what advances in methods will be critical for future individual differences research. Perhaps the more intriguing answer which needs to be foreseen now is, however, what we will do with such detailed knowledge.

Norbert Jaušovec and Ksenija Jaušovec

A central problem in brain research is the amount of collected data. The situation is to some extent bizarre: on the one hand, we are trying to increase the amount of data by increasing sampling rates, the number of channels, etc., while on the other, we are trying to reduce the collected data by down sampling, averaging, and similar procedures. This second step is necessary because of technical reasons (e.g., computing time), but also to make the data comprehensible and applicable to the brain or cognitive model we are using. For this second step, beside linear methods, there are not many other options which would meet the complex relationship between cognition and brain activity. Recently, dynamic causal modeling (DCM) has been introduced into EEG/MEG research (David, Harrison, & Friston, 2005; Friston, 2003). In DCM, one views the brain as a dynamic network of interacting sources that produces observable responses. DCM is not an exploratory technique; it does not explore all possible models: DCM tests specific models of connectivity and, through model selection, can provide evidence in favor of one model relative to others. In my opinion, a promising approach which could be also relevant for future individual differences research.

Almira Kustubayeva

As mentioned earlier, more complex and sophisticated approaches to the study of brain functions will be critical for understanding individual differences. Each modern neuroscience method (fMRI, PET, MEG, EEG and others) has its own advantages and disadvantages. The combination of different methods could help understand brain function as a complex system. Improvements of statistical analysis in demonstrating the synthesis of interrelations between brain areas, and spatial and temporal integration have advantages for this approach. Such techniques include component analysis in fMRI, nonlinear dynamics, and analysis of coherence in the EEG.

Aljoscha C. Neubauer and Andreas Fink

The advancement as well as the technical/methodical refinement of modern neuroimaging techniques (such as fMRI, PET or EEG) facilitates the investigation of brain activity patterns during the performance of a broad range of different cognitive tasks. So far neuroscientific studies have yielded valuable insights into possible brain correlates underlying different personality and ability variables. For instance, neuroimaging studies in the field of intelligence research have produced evidence of structural (Jung & Haier, 2007) or functional (Neubauer, Fink, & Grabner, 2006) brain correlates of (individual differences) in intelligence. Moreover, neuroscientific research has contributed to demystifying insight (Bowden, Jung-Beeman, Fleck, & Kounios, 2005) or creative thinking (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007) that has long been grounded solely on anecdotical reports.

Each of the available neuroscientific measurement methods has its pros and cons regarding the particular context of the study of different facets of cognitive thinking. The primary advantage of fMRI lies in its high spatial accuracy, but it does not allow for the study of cognition with high temporal resolution (as opposed to EEG techniques). The observed changes in brain activity (e.g., from a pre-stimulus reference condition to an activation interval) occur rather slowly, thereby complicating the analysis of time-related brain activity patterns during the process of cognitive thinking. EEG techniques, in contrast, allow for a fine-grained temporal analysis of brain activation that is observed in response to a particular cognitive event (e.g., immediately prior to the production of an original idea). Furthermore, in analyzing the functional cooperation (or functional coupling, respectively) between different cortical areas, EEG techniques have turned out to be a valuable tool in the study of cognition. Hence, future neuroscientific studies in the field of personality and cognition will benefit from a combined use of different measurement methods.

Another critical point in the neuroscientific study of cognition is that most of the experimental tasks are comparatively simple or basic types of tasks that have to be modified (or simplified, respectively) in order to be reasonably applicable in neurophysiological measurements. Thus, the employed tasks can only be indicative of basic or elementary aspects of cognitive thinking and performance in these tasks might not be generalizable to “real-life” creative or intellectual achievements. The investigation of cognitive processes in the neuroscientific laboratory is additionally complicated by the fact that participants (unlike to their natural environment) are required to respond to stimuli while they are mounted with an electrode cap sitting in a shielded EEG cabin or lying supine in the fMRI scanner. These situations bear some important restrictions like rather high noise levels in the scanner or the necessity to avoid gross movements, especially eye movements which restrict the collection of additional potentially important behavioral information like, e.g., the analysis of eye movement or gaze behavior. Thus, future research in this field is challenged by the investigation of brain activity in response to more complex cognitive tasks, combined with other methods like eye-tracking.

In addition, neuroscientific research would gain in importance if the functional meaning of brain activation as measured by means of different methods like EEG, fMRI or NIRS is more carefully understood. Currently, it is not well understood how different indicators of brain function like some EEG parameters, the hemodynamic response in NIRS and the BOLD signal in fMRT are related to one another. Sometimes even conflicting interpretations exist, e.g., regarding the interpretation of event-related alpha synchronization in the EEG (e.g., Klimesch, Sauseng, & Hanslmayr, 2007). This concerns the validity of physiological activation parameters, but another important issue is the reliability and the long-term stability of the diverse parameters. Neurophysiological brain activation parameters, in our view, can be regarded as useful individual differences variable if and only if they display some stability over shorter (weeks) and longer (months) time-intervals. In our knowledge, such data have been collected rarely, mostly for EEG parameters (e.g., Neuper, Grabner, Fink, & Neubauer, 2005).

That way neuroscientific measurement methods can – along with behavioral or psychometric research methods – be a valuable and powerful tool in the study of cognition in as much as they could contribute to a deeper and much more fine-grained scientific understanding of different psychological or cognitive processes.

3. Can ability and personality be assigned to separate brain systems?

Todd S. Braver and Tal Yarkoni

Yes and No. We do agree with the general sense that *specific* abilities or personality dimensions appear to segregate spatially. To some extent, one might argue that many of the major dimensions of personality (e.g., extraversion and neuroticism) appear to primarily reflect variability in subcortical or systems-level structure and function (e.g., differential distribution or density of neurotransmitter receptors, differences in amygdala volume, etc.), whereas differences in cognitive ability are more likely to reflect variability in the structure and function of cortical structures such as the prefrontal cortex. But we disagree with the notion that a *general* distinction between ability and personality can be made. For example, Openness to Experience is generally thought of as a personality dimension, yet it predicts a wide range of cognitive abilities moderately well (DeYoung, Peterson, & Higgins, 2005). We see no a priori reason to suppose that individual differences in ability and personality should have qualitatively different neural substrates.

Norbert Jaušovec and Ksenija Jaušovec

Personality, intelligence, emotions etc., are models, psychologists have designed to enable the study of the human psyche. I would be surprised that nature and evolution has followed the same schema in developing the human brain. From a psychometric perspective, ability is the most well defined psychological construct and there is little question as to the validity of IQ tests. For instance, in a survey of more than 10,000 investigations, Ghiselli (1966) showed that the single best predictor of any job was an intelligence test. Thus, one would expect that we could easily observe differences also on the level of brain activity. However, as was shown in this book section, the reality is more complex, and we can only say that those who are brighter while solving problems show less brain activity than those who are of average ability. In the field of personality matters are different. Until the past few years, there was little consensus concerning the structure of personality, there is still some uncertainity concerning how personality should be measured. Most often, personality is measured using questionnaires, and there has been a growing acceptance of a five-factor model of personality. The diverse and sometimes contradicting findings of research into the biological bases of personality traits make a generalization rather difficult. It is possible that the biological theories may be improved through discriminating multiple systems underpinning traits, or in analyzing brain activity of persons with different personality and ability structures – different configuration of traits within the individual.

In a recent study conducted in our lab (Jaušovec & Jaušovec, 2007), it was found that the highest contribution to the observed differences between personality subtypes was provided by female overcontrolled neurotics. Based on these findings, one could hypothesize that differences in brain activity between personality subtypes are only observed in relation to a specific configuration of some traits and gender. In females, a low level of emotional intelligence in combination with neuroticism and hostility seem to be a prominent candidate for study. Further research should therefore focus on comparing brain activity of individuals of opposite sexes with a similar structure of personality traits having the highest impact on individual differences (e.g., emotional intelligence, neuroticism, agreeableness), while equalizing the other dimensions (including also the level of verbal and performance intelligence). Such an approach would mean a combination between the dimensional, or variable-centered, approach and the typological, or person-centered, approach to personality, and in our opinion could provide additional insight into the brain-activity–personality relation.

Almira Kustubayeva

As mentioned in chapter 9, according to B. Teplov, the abilities are an integral complex of psychophysiological, psychological, and social characteristics. V. D. Shadrikov described the intellectual abilities in terms of Anokhin's functional systems. From this point of view, psychometric intelligence, creativity, learning ability, and cognitive styles are the properties of the psychical functional system that is regulated by the feedback principle. B. M. Velichkovskii suggested the Grand Design model of intelligence – the levels of cognitive organization and behavior regulation are based on Bernstein's theory of movement construction levels. Ability and personality are two psychological dimensions that have shown correlations in numerous studies with psychometric measurements. Individual differences of properties of higher nervous system have been correlated with cognitive abilities. Assuming that ability and personality belong to common regulation brain systems, or executive control systems, they are supported by overlapping nonspecific brain systems, as well as some differences in specific functional brain areas. According to Posner et al. (1997), different cognitive skills may have common activation of the relevant brain areas during task performance through attention.

4. Does research in neuroscience clearly discriminate mechanisms for attention from mechanisms for executive control of attention?

Todd S. Braver and Tal Yarkoni

We do not think so. There remains a good deal of confusion and debate as to where attention ends and executive control begins. For example, many attention researchers distinguish between ventral and dorsal attentional brain networks, ignoring the marked degree of overlap of these networks with putative executive control networks; conversely, many working memory and executive control researchers (unfortunately, including ourselves) often speak of *the* cognitive control network as if it was a monolithic system with a single function. When researchers ascribe functional roles to more circumscribed chunks of brain tissue, confusion also often arises; for example, is the dorsolateral prefrontal cortex better characterized as a region that supports top-down control over attention, manipulation of information actively maintained in working memory, or inhibition of interference (or even some other function, such as action planning)? To some degree, these conceptions overlap (Postle, 2006), and in any case, it is not clear which, if any, is *the* fundamental operation the region supports. A second issue, that often gets glossed over, is the distinction between the source and the site (or target) of attentional effects. We do believe there is something to the general notion that posterior perceptually-oriented cortical (and subcortical) regions are likely to serve as the site of top-down attentional effects.

Furthermore, a cognitive system as complex as our own must have some way of representing and manipulating goal-relevant information independently of moment-by-moment changes in visuospatial attention. It is plausible to suppose that something like a rostral-caudal gradient exists, so that long-term and medium-term goals are maintained in relatively anterior cortical regions (e.g., anterior portions of lateral prefrontal and parietal cortex), while more posterior regions of these same networks might be engaged by the execution of shorter-term action plans consistent with these goals. One component of this shorter-term action plan may be the direction of frontoparietal attentional systems to focus on specific aspects of the world as needed. We just do not think that this kind of story is sufficiently well worked out at present.

Almira Kustubayeva

Luria discriminated mechanisms of involuntary attention that children developed in earlier childhood and voluntary attentional processes that developed later. A. Uhtomskii suggested “dominance theory”. The dominant area of excitatory processes subordinates a surrounding inhibitory area so as to govern and execute our behavior. I. P. Pavlov described the mechanism of the orienting reflex as involuntary attention and called it the “What is it?” reflex. The orienting reflex is easy to observe as a large spreading alpha desynchronization in EEG. Sokolov explained the desynchronization effect by a special form activation of neurons, which has been called “novelty neurons”. The combination of “Novelty detectors/neurons” and “neurons of identity” determines enhancement of orienting reflex (OR). Sokolov, Lyytinen, Sponks, and Näätänen (2002) brought in the term of “conditioned OR” – referring to a voluntary form of OR to a significant stimulus. Unconditioned and conditioned OR (corresponding with involuntary/voluntary attention) may both contribute to the Mismatch Negativity (negative potential evoked by a deviant stimulus) mechanism. Näätänen & Michie (1979) proposed two components of MMN: sensory-specific (automatic) and frontal generator (attention switch, voluntary control). The interaction of voluntary vs. involuntary attention involves prefrontal cortex activity functioning as control system. Behterev, Orbeli, Anohkin, and Kropotov have described attention as a multilevel organization in which nonspecific activation influences on tonus of attention and frontal area regulate the direction of attention. Kropotov (2008) revealed the role of inhibition in developmental impairments in ADHD children (children were shown to exhibit lower amplitudes of GO and NOGO P300 components in comparison to normal groups).

Prefrontal cortex has been implicated in executive function by many authors. Three areas – the ventromedial (VMPFC)-orbitofrontal cortex (OFC), dorsolateral prefrontal (DLPFC), and the anterior cingulate cortex (ACC) – were identified: VMPFC and OFC as emotional processing, reward and inhibition processes, and decision-making; DLPFC as attentional, selective and sustained attention, novelty processing, choice, working memory, and language function; ACC as division of attention, and both cognitive and emotional regulation (Banfield and Vohs, 2004). fMRI studies (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) described attentional networks for alerting, orienting and executive attention based on a different anatomy. Alerting attention is sensitivity to incoming stimuli provided by activation of locus coeruleus, right frontal, and parietal cortex. Orienting attention (selection of information) is associated with superior parietal cortex, temporal parietal junction, frontal eye fields, and superior colliculus. Executive attention is "supervisory" in that it guides our thoughts, emotion, and behavior, via the anterior cingulate, lateral ventral, prefrontal cortex, and basal ganglia (Posner & Rothbart, 2007). Neuroscience models provide the distinction between executive attention and other attentional systems.

5. How does work on brain motivation systems contribute to understanding individual differences in executive control?

Todd S. Braver and Tal Yarkoni

If one conceptualizes executive control not only as the *capacity* to exert control over one's own thought and action but also as the *prioritization* of such goals, then it follows that motivation and executive control are intimately linked. For example, most people's performance at most cognitive tasks can be at least transiently enhanced by offering an incentive for good performance (e.g., money). Likewise, some studies, including our own, have found that such manipulations can enhance activation in brain cognitive control systems (Locke & Braver, 2008). Furthermore, from a neuroanatomical perspective, there is already strong evidence to suggest a high degree of overlap in components of brain motivation and cognitive control systems (e.g., the midbrain dopamine system).

In an ecological context, one of the central questions any complex organism faces is how to regulate the rate at which it expends energy on cognitively demanding activities. For reasons that are not presently understood, the deployment of executive control appears to have important cognitive (and potentially, energetic) costs associated with it. Thus, the extent to which such processes are engaged may crucially depend upon a cost–benefit analysis. Affective-motivational signals (e.g., the presence of reward or punishment cues) may provide the necessary signal to elicit increased engaged of control, based on a higher estimate of utility or value for such processes. From an individual differences standpoint, this sets up a number of very interesting research questions: Why are some people seemingly indefatigable, and able to maintain a high level of control over extended periods, and without exogenous feedback regarding performance success (or other types of reward/punishment signals). Conversely, why do some people, even those who may have the *capacity* for a high level of performance, tend not to reach such levels under low-motivation conditions? Why are some people more highly motivated by the presence of exogenous reward cues than others? The study of such questions using cognitive neuroscience techniques is still in its infancy, but we view this as one of the most promising areas of research to open up in recent years.

Almira Kustubayeva

A brain motivation system and its role in individual differences were described by P. V. Simonov in the classic book "Motivated Brain" and by Simonov, Ershov, and Bastow (1991) in a chapter on "Motivational nucleus of personality". Assuming 3 types of needs – biological, social, and intellectual – Simonov provided examples of how different types of brain damage can influence a hierarchy of needs. Some EEG studies also relate motivation and personality. Knyazev and Slobodskaya

(2003) suggested that alpha oscillations reflect inhibitory control (attention). Alpha is reciprocally related to slow oscillations, including delta (as motivational system activity) and theta (as emotional system). Fast and slow rhythms play different roles in BAS and BIS systems. fMRI studies showed increasing activity in brain areas responsible for executive control–dorsolateral prefrontal cortex (DLPFC) – during a reward condition (Pochon et al., 2002; Taylor et al., 2004). Locke and Braver (2008) found that a reward-incentive condition, compared with penalty-incentive and baseline conditions, activated the participant's cognitive strategy, which was associated with primarily right posterior and prefrontal cortex (RLPFC). Reward expectancy and sensitivity to reward were correlated with activity in reward-related regions, including the subcallosal gyrus, the OFC, and the caudate nucleus. BAS was also correlated with sustained activity in the right frontopolar cortex. So, motivation is a complex construct that is related to brain functional state, together with emotion influences on executive control.

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