COGNITIVE NEUROSCIENCE AND PSYCHOLOGY —A NEW QUALITY IN RESEARCH*

The research findings in cognitive neuroscience reveal the existence of neural networks encompassing certain brain structures, which perform particular cognitive functions. We can discover the sequence in which particular structures operate as well as the time profile of their functioning with reference to specific situations, activities undertaken, and tasks performed. In psychology the profiles of functioning of those structures can be perceived as parts of research process in two ways. In the classic perspective they are seen as correlates of various theoretical constructs describing cognitive processes (Hancock and Szalma 2003) and within the frames of these constructs they constitute new elements complementing the process of research. Brain structure profiles revealed in such an approach serve only as fillers of existing theoretical constructs and, simultaneously, retain the role of their correlates. The other, bolder approach postulates eliminating theoretical constructs used presently from the research process. It seems that the latter approach is essential for the cognitive neuroscience. It focuses on examining how the neural systems involved in executing tasks (activities) function. The main aim of this approach to psychology is determining the relationship between the content of activity undertaken by an individual, the structure as well as the content of behavioral activity and neural systems activity. In the neuroscience approach a possibility arises which allows replacing the criterion of behavioural efficiency with the efficiency of neural processes, which are closely linked to certain neural structures and their functioning. This constitutes the salience of new opportunities created by the neuroscience approach. The traditional approach based on behavioural indices had to contain a number of simplifications and lacked clarity. Vague and ambiguous terms such as "resources" (e.g. "attention resources", "memory resources") lie at the basis of the approach. The introduction of a non-invasive method to measure neural networks activity allows us to determine and describe precisely the

* This polemic paper is partly based on our paper Fafrowicz, M. and Marek, T. (2007). Quo vadis, neuroergonomics? *Ergonomics*, 50, 11, 1941-1949, which was supported by grant from the Polish Ministry of Science and Higher Education (N106 034 31/3110) (2006-2009).

networks of brain structures, which are involved in the execution of particular activity. The majority of researchers studying the field of implementation of neuroscience findings to psychology agree that theoretical constructs, or as Hancock and Szalma (2003) put it 'psychological constructs' used to explain and study how an individual functions are poor and of low quality. The findings of neuroscience are perceived by them as a unique opportunity to fill the already existing theoretical constructs with new content (Sarter and Sarter 2003, Szalma and Hancock 2002, Scerbo *et al*. 2003). The majority of researchers (authors) propose reconstructing existing psychological constructs.

Following a prevalent belief, Hancock and Szalma (2003) write quoting the opinion of Sarter and Sarter (2003) that "... to fully benefit from the approaches of cognitive neuroscience, researchers and practitioners must be willing to embrace a reductionistic approach. This would involve reducing higher level, multidimensional psychological constructs to underlying cognitive activity closely tied to brain activity (...) however, that our understanding of psychological constructs such as mental workload requires psychological analysis that is not necessarily enhanced by correlating performance with psychophysiological data. The latter have value, but do not replace the former." Such a stance seems highly reasonable at first sight.

New empirical data in the domain of neuroscience allow us to reconstruct the existing psychological constructs and at the same time they form an additional area of variables explaining the rules responsible for the functioning of the processes which these constructs describe (beside, e.g., the areas of behavioural data, physiological correlates which do not concern neural networks and systems). However, a detailed analysis complicates the matter. It is highly likely that neuroscience and its research findings will contribute to a total reconstruction of our opinion on so called cognitive processes and theoretical constructs linked to them. This reconstruction can be far-reaching and it can ultimately lead to the replacement of present, ambiguous psychological constructs which lack reliable foundations to be fully operational for the variables analysed with clear, precise and fully operational (in the sense of precise measurement) neural functions, to which particular parameters characterising human behaviour can be assigned.

RESEARCH IN PSYCHOLOGY —THE TRADITIONAL VERSUS NEUROSCIENCE PERSPECTIVE

In the classic perspective, mental, cognitive and emotional functions, in principle, in the form of simple common sense dimensions constituted the departure point of research. Such approach resulted from the absence of suitable research methods and led to overly general, imprecise explanations of studied phenomena. As a result of neuroscience research we receive a more precise, analytical picture of the parameters on which mental functions and behaviours of individuals depend. The relationships between neural structures activity and behavioural activity indicators, because of the precision and reliability of the measurement, adopt the character of functional relationships, and not only correlational, as in the classic approach. Consequently, statistical relationships are replaced with functional ones. In this way, behavioural, cognitive and emotional activity is directly linked to the activity of neural structures.

The neuroscience approach concentrates on studying structures, and their functions become the subject of the study, whereas the traditional approach determines the functions on the basis of behavioural indicators. Thus, the two approaches—the traditional and neuroscience one deal with completely different functions. From the classic perspective, functions are perceived as theoretical constructs generally proposed by psychologists. The subject of the research is a number of behavioural correlates of hypothetical cognitive processes. From the neuroscience perspective, functions of particular neural structures are the subject matter. These functions may or may not be convergent with the functions (theoretical constructs) defined by psychology.

The reconstruction and revision of many psychological concepts (theoretical constructs) in the light of research carried out within the frames of neuroscience may, ultimately, lead to disappearance of these constructs. The explanation of the mechanisms behind human behaviour is likely to lead to a situation in which constructs will become useless. Thus, the patterns known from the history of other branches of science will be repeated. Physics is a good example illustrating this situation. The theoretical construct "ether" existed in physics for years. The construct was present because scientists had difficulty explaining the nature of radio waves. After the nature of radio waves had been discovered, the theoretical construct "ether" ceased to exist and disappeared from the area of scientific concepts.

Research methods applied in neuroscience are already useful in determining the neural nature of certain parameters and dimensions of human behaviour. They allow us to recognise the neural nature of so called mental functions. According to many researchers (e.g. Hancock and Szalma 2003) neuroscience research (on a basic, primary level) and the analyses on a higher level will result in the reconstruction of present theoretical constructs (e.g. resources) and in their new form they will continue to be used as a means of explaining human behaviour. Nevertheless, it is our opinion that the theoretical construct "resources" will disappear from science in the future. We will be talking about certain functions performed by particular neural networks, which, depending on the conditions, will offer a resultant outcome.

It seems that the years to come will form a transition period in which many researchers and practitioners will be undertaking attempts to reformulate theoretical constructs. It is very likely that such attempts will fail to bring satisfactory results. The research carried out so far has already shown that certain functions which were not taken into account in multidimensional constructs are beginning to emerge.

Analysing research findings in neuroscience we can conclude that these findings are very often completely new discoveries. While measuring the activity of neural structures, studying their connections and relationships and how they join to form systems, we discover new functions or new phenomena, which have not been present in theoretical constructs so far. It seems obvious that an attempt to introduce these new functions and phenomena into the already existing theoretical constructs will, in the end, destroy the constructs. New findings in neuroscience which are introduced to the existing psychological constructs behave like a Trojan horse leading to the destruction of these constructs from inside. The multidimensional character of the constructs stressed by many authors does not, as might be expected, mean that these constructs guarantee precise description of the reality. The dimensions used to create the constructs are simplified, which neuroscience reveals with clarity.

Let us look at the area of attention research. The phenomenon of attention in the light of research conducted with the use of neuroimaging technique reveals that it is a system very complex in comparison with how it is depicted with the use of psychological constructs. As a result of the research based on neuroimaging we are aware of many extensive networks of brain regions that subserve different aspects of attentional control. PET and fMRI research revealed that (e.g. Posner and Petersen 1990): 1. The attention system is a distinctly isolated anatomic-functional system of the brain. 2. The system is constructed on the basis of the neuronal network. 3. The separate brain structures constituting the attentional system are responsible for the different functions of attention. Various anatomic functional brain structures interact within attentional network. Three different anatomic-functional subsystems of attention have been distinguished (e.g. Posner and Petersen 1990, Berger and Posner 2006, Posner and Raichle 1996). These are: 1. The orienting subsystem responsible for orientation and for shifting attention. 2. The vigilance subsystem which is responsible for maintaining the appropriate level of alertness. 3. The executive subsystem responsible for recognition, identification, planning, decision making, error detection, novel responses, dangerous conditions and overcoming habitual actions (Norman and Shallice, 1986). Each of these subsystems basing on specific structures joined in neural networks is responsible for executing complex, manifold operations.

The orientating subsystem executes the operations of the attention disengagement, shifting of attention index, and attention engagement. According to the latest research, there are separate neural networks responsible for shifting and maintaining attention with reference to locations, features, and objects (Corbetta *et al*. 2000, Corbetta and Shulman 2002, Hopfinger *et al*. 2000, Liu *et al*. 2003, Vandenberghe *et al*. 2001, Yantis *et al*. 2002). A similar situation occurs in the case of attention processes in respect to linguistic abilities. Neuroimaging has suggested separate systems for syntactic and semantic processing (Myachykow and Posner 2005).

Attention function is closely related to the phenomenon of the inhibition of return (Posner *et al*. 1985). The phenomenon and the underlying neural mechanisms play a significant role in goal-directed behaviours. The mechanism, inhibition of return, aims at protecting against taking in information from the same area from which information has already been absorbed. In their experiment Posner and Cohen (1984) proved that inhibition operated with respect to locations. Their findings were later confirmed in other numerous research projects (e.g. Klein 2000, Lupianez *et al*. 1999). Recently Grison with a group of researchers (Grison *et al*. 2005) has demonstrated that this phenomenon applies also to objects. According to their research, in the case of locations and objects, different mechanisms which are operated by distinct neural systems underlie the inhibition of return phenomenon.

The executive attention system comprises the mechanisms for monitoring and resolving conflict among responses, thoughts, and feelings (Raz 2004). This network is related also to the subjective impression of mental effort (Fernandez-Duque *et al*. 2000).

The anterior cingulate cortex (ACC) is recognized as a node element of executive attention network. Strong neuronal connections of ACC to limbic, association and motor cortex explain how activation of this structure influences complex cognitive, motor and emotional functions such as selective attention, motivation or goal-directed behaviour. According to brain activation studies, ACC is also responsible for error processing and responds specifically to occurrences of conflict and error detection.

Several studies have shown activation of the anterior cingulate gyrus and supplementary motor area, the orbitofrontal cortex, the dorsolateral prefrontal cortex, the basal ganglia and the thalamus during effortful cognitive processing, conflict resolution, error detection, and emotional control (Bush *et al*. 2000; Fernandez-Duque *et al*. 2000; Posner and Fan 2004). In the opinion of Carter and colleagues (Carter *et al.* 1999), the anterior cingulate cortex plays the main role in conflict monitoring. However, the anterior cingulate cortex and lateral frontal one are areas of the dopamine receptors system activity (Posner and Fan 2004). It suggests that these structures are involved in learning processes. A growing body of research shows that several different functional zones of anterior cingulate cortex are involved in a wide spectrum of mental functions (Marek *et al*. 2007, 2008; Fafrowicz and Marek 2007, 2008). All this research data shed light on attention as a much more complex phenomenon than it has been assumed to be in traditional psychological constructs.

Additionally, the attention neural networks go about their business through an orchestration of facilitating and inhibitory processes. Each attention operation is associated with activation of some structures and inhibition of others. For instance, during activity of the vigilance attention network, the executive attention subsystem is inhibited, whereas the orienting and the vigilance attention subsystems show stronger activation. The vigilance and orienting attention subsystems inhibit the activity of the executive attention subsystem (e.g. Marek *et al*. 2004).

As a consequence of the discoveries discussed here briefly (we named only a few), theoretical constructs describing attention which have been in use so far are being reduced to empty words.

In the light of recent neuroscience findings the majority of psychological constructs is seen as a combination of extremely simplified dimensions, a combination forming a system which is unable to absorb new discoveries due to its oversimplicity (which in the light of neuroscience findings is appalling). Models proposed which resort to constructs are too simple to absorb the complexity of new discoveries.

CONCLUSIONS

1. Despite their multidimensional character, psychological constructs constituting the basis for research until now, describe the mechanisms of an individual's functioning in a simplistic and imprecise manner, which contrasts sharply with the description we obtain as a result of the neuroscience research in neural mechanisms responsible for human behaviour.

2. Imprecision of measurement, together with ineffective operationalisation of the variables studied, which are defined on the basis of constructs, is in contrast to high precision ensured by neuromeasures.

3. High complexity of neural mechanisms underlying human behaviour and cognitive processes is revealed in research conducted with the use of neuroimaging techniques or measuring the activity of single neural cells; results of this research cannot be incorporated into relatively simple (in the conceptual sense) constructs.

4. Uselessness (in the sense of low explanator potential) of constructs in the situation when neural mechanisms and structures responsible for certain processes or phenomena concerning behavioural, emotional, and cognitive activity together with their precisely measured profiles are known.

5. Precise measurements, on the one hand, and capturing the direct relationship between neural structure and mechanism and behavioural, cognitive and emotional effect, on the other hand, which neuroscience has introduced are the main features heralding changes in psychological research.

6. A new neural research paradigm which is implemented to psychology signals the beginning of the process of building a new system of knowledge. Both the research paradigm and the emerging system of knowledge are entirely different from the paradigm and the knowledge system which are based on traditional psychological constructs. By means of constructs we only describe reality. We create a construct whose purpose is introducing order in this reality, usually in accordance with already assumed dimensions. In neuroscience research we aim at explaining a neural mechanism underlying studied phenomenon. Although there is every likelihood that research which resort to psychological construct will continue, this research will have very little in common with the research conducted within the frames of neuroscience.

REFERENCES

Berger, A. and Posner, M. I. (2006). Attention and human performance: A cognitive neuroscience approach. In: *International Encyclopedia of Ergonomics and Human Factors*, W. Karwowski (Ed.), pp. 594-599 (London and New York: Taylor & Francis).

Bush, G., Luu, P., Posner, M.I. (2000). Cognitive and emotional influences in the anterior cingulate cortex. *Trends in Cognitive Sciences*, 4, 215-222.

Carter, C.S., Botvinick, M.M., Cohen, J.D. (1999). The contribution of the anterior cingulate cortex to executive processes in cognition. *Reviews in Neuroscience*, 10, 49-57.

Corbetta, M., Kincade, J., Ollinger, J.M., McAvoy, M.P. And Shulman, G.L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience*, 3, 292-297.

Corbetta, M. and Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, 3, 201-215.

Fafrowicz, M., Marek, T. (2007). Quo vadis, neuroergonomics? *Ergonomics*, 50, 11, 1941-1949.

Fafrowicz, M., Marek, T. (2007). Neuronal attention networks, task demands, and human error. *Occupational Ergonomics*, 7 (2) 73-81.

Fafrowicz, M., Marek, T. (2008). Attention, selection for action, error processing, and safety. In: *Ergonomics and psychology: Developments in theory and practice*, O. Y. Chebykin, G. Bedny, W. Karwowski (Eds), pp. 203-218 (New York: CRC Press).

Fernandez-Duque, D., Baird, J.A., Posner, M.I. (2000). Executive attention and metacognitive regulation. *Conscious Cognition*, 9, 288-307.

Grison, S., Kessler, K., Paul, M. A., Jordan, H. and Tipper, S. P. (2005). Object- and location-based inhibition in goal-directed action. In: *Attention in Action*, G.W. Humphreys and M. J. Riddoch (Eds), pp. 171-208 (Hove and New York: Psychology Press).

Hancock, P. A. and Szalma, J.L. (2003). The future of neuroergonomics. *Theoretical Issues in Ergonomics Science*, 4, 238-249.

Hopfinger, J.B, Buonocore, M.H. and Mangun, G.R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, 3, 284-291.

Klein, R.M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, 4, 138-147.

Liu, T., Slotnick, S.D., Serences, J.T. and Yantis, S. (2003). Cortical mechanisms of feature-based attentional control. *Cerebral Cortex*, 13, 1334-1343.

Lupianez, J., Tudela, P. and Rueda, C. (1999) Inhibitory control in attentional orientation: a review about inhibition of return. *Cognitiva*, 11, 23-44.

Marek, T., Fafrowicz, M. and Pokorski, J. (2004). Mechanisms of visual attention and driver error. *Ergonomia: An International Journal of Human Factors and Ergonomics*, 26, 201-208.

Marek, T., Fafrowicz, M., Golonka, K., Mojsa-Kaja, J., Oginska, H., Tucholska, K. (2007). Neuroergonomics, neuroadaptive technologies, human error, and executive neuronal network. In: *Ergonomics in Contemporary Enterprise*, W: L. M. Pacholski, S. Trzcieliński (Eds), pp. 13-27 (Madison: IEA Press).

Marek, T., Fafrowicz, M., Golonka, K., Mojsa-Kaja, J., Tucholska, K., Oginska, H., Orzechowski, T., Urbanik, A. (2008). Changes of the anterior cingulated cortex activity due to prolonged simulated driving—an fMRI case study. In *Conference Proceedings. 2008 Applied Human Factors and Ergonomics Conference (AHFE)*, W. Karwowski, G. Salvendy (Eds) (USA Publishing).

Myachykow, A. and Posner, M.I. (2005). Attention in language. In: *Neurobiology of Attention*, L. Itti, G. Rees and J.K. Tsotsos (Eds), pp. 324-329 (Amsterdam: Elsevier).

Norman, D.A., Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In: *Consciousness and Self-Regulation*, R.J. Davidson, G.E. Schwartz, D. Shapiro (Eds), pp. 1-18 (New York: Plenum).

Posner, M. I. and Cohen, Y. (1984). Components of visual orienting. In: *Attention and Performance X*, H. Bouma and D. G. Bouwhuis (Eds), pp. 531-556 (Hillsdale, NJ: Lawrence Erlbaum Associates Inc.).

Posner, M.I., Fan, J. (2004). Attention as an organ system. In Topics in Integrative Neuroscience: From Cells to Cognition, J.R. Pomerantz and M.C. Crair (Eds) (Cambridge UK: Cambridge University Press).

Posner, M. I. and Petersen, S. E. (1990). The attention system of the human brain. *Annual Reviews of Neurosciences*, 13, 25-42.

Posner, M. I., Rafal, R. D., Choate, L. S. and Vaughan, J. (1985). Inhibition of return: Neural bias and function. *Cognitive Neuropsychology*, 2, 211-228.

Posner, M. I. and Raichle, M. E. (1996). *Images of Mind* (New York: Scientific American Library).

Raz, A. (2004). Anatomy of attentional networks. *The Anatomical Record*, 281B, 21-36.

Sarter, N. and Sarter, M. (2003). Neuroergonomics: opportunities and challenges of merging cognitive neuroscience with cognitive ergonomics. *Theoretical Issues in Ergonomics Science*, 4, 142-150.

Scerbo, M.W., Freeman, F.G. and Mikulka, P. J. (2003). A brain-based system for adaptive automation. *Theoretical Issues in Ergonomics Science*, 4, 200-219.

Szalma, J.L. and Hancock, P. A. (2002). On mental resources and performance under stress, Unpublished white paper, University of Central Florida.

Vandenberghe, R., Gitelman, D.R., Parrish, T.B. and Mesulam, M.M. (2001). Location- or feature-based targeting of peripheral attention. *Neuroimage*, 14, 37-47.

Yantis, S., Schwartzbach, J., Serences, J.T., Carlson, R.L., Steinmetz, M.A., Pekar, J.J. and Courtney, S.M. (2002). Transient activity in human parietal cortex during attentional shifts. *Nature Neuroscience*, 5, 995-1002.

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PSYCHOLOGY AND BIOLOGY NEED EACH OTHER

The issue that Laurence Pervin raised in his paper, also present in its title: *The relationship between biology and psychology*, touches one of the challenges psychology has been confronted with at the turn of the 20th and 21st