The Neural Basis of Intuitive Decision Making

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ABSTRACT

Understanding the neural mechanisms of intuitive decision making is an important social and economic issue which may contribute to optimizing the managerial procedures and to support the evaluation of intuitive critical decisions made under pressure of time. The review aims to discuss the cognitive and affective processes underlying intuition, the differences between the neural correlates underlying rational and intuitive process of decision making as well as the possible differences in neural mechanisms of expert *versus* 'non-expert' intuition. Since the research concerning intuition are relatively new on the ground of neuroscience, the current state of knowledge is very limited and answers for many questions are unclear. However, the following review distinguish several neural correlates that are assumed to be specific for the intuitive process, the intuitive decision making and even for the expert intuition.

Keywords: Intuition, Decision Making, Neural Mechanisms, Expert Intuition

INTRODUCTION

The upcoming Conceptual Age is highly related to the increased demand for 'open-minded' individuals enable to initiate groundbreaking changes in economic and life crucial areas, including not only scientific and technological development but also improvement of human well-being and social functioning. Since the environmental and cognitive demands are constantly high, there is a sustained need for quickness, accuracy, reliability and innovation in decision making and problem solving in constraints of time pressure, ambiguity, and cognitive load experienced by an individual.

Consequently, within the organizational practices and in the work environment there is an increasing social emphasis on the so called 'right-brain-driven' skills and abilities, among which intuition is typically mentioned (Pink, 2005). In the same time, the real economic need for professionalism and reliability is equally important. The efficiency of the 'expert intuition' has become the vivid issue for managers and organizational leaders (e.g. Akinci and Sadler-Smith, 2012; Hodgkinson et al., 2009; Dane and Pratt, 2007), particularly those holding positions in institutions in which critical decisions are made under a pressure of time (e.g. hospitals, fire departments, etc.).

Understanding the phenomenon of the intuition at the neural level of the human brain could shed a light on the frames of intuition reliability and, thus, provide scientific evidences useful for optimizing the managerial procedures regarding human resources and solving organizational problems. It could also lead to the development of procedures, special trainings and even supporting devices aimed to enhance the effectiveness of decision making and problem solving, and to reduce the risk of errors in choices that have life-and-death consequences.

WHAT IS THE INTUITION?

According to the current psychological knowledge, two parallel cognitive systems responsible for information processing may be distinguished (e.g. Kahneman, 2003; Stanovich and West, 2000; Epstein, 2003; Epstein, 1991). System 1 (Stanovich and West, 2000), similarly as the Experiential System (Epstein, 1991), is holistic, automatic, relatively fast, effortless, and based on associations. On the contrary, System II proposed by Stanovich and West (2000), similarly as the Rational System (Epstein, 1991), is analytic, voluntary, controlled, effortful (i.e. demanding cognitive capacity) and based on rules of logical reasoning. Importantly, according to the cognitive-experiential self-theory, the Experiential System, based on associations, encodes reality in concrete images, metaphors and narratives, while the Rational System, based on cause-and-effect connections, encodes reality in abstract symbols, words and numbers (Epstein, 2003). It seems that this basic distinction may significantly contribute to the understanding of intuition.

The concept of System 1 and System 2, together with the Herbert Simon theory of bounded rationality (Simon, 1972; Simon, 2000), have become a basis for psychological research of Daniel Kahneman's and Amos Tversky's (Kahneman, 2003; Kahneman and Tversky, 1973) which are considered as one of the most significant for explaining intuitive judgment and decision making. According to Kahneman (2003) there are two generic modes of cognitive processing: the intuitive (automatic) one and the deliberate (controlled) one. The intuitive system (System 1) has some characteristics common with perception, e.g. the intuitive thoughts/ impressions are appearing spontaneously and effortlessly like the percepts (Kahneman, 2003). However, whereas perception refers rather to processing of 'primary' information, intuition refers to processing of complex information patterns (see Ilg et al., 2007). These patterns are based on conceptual representations which are associated and recognized in the intuitive process, what in consequence leads to judgments and decisions considered as intuitive. Similarly like the percepts, the intuitive 'hunches' are unlikely to verbalize (Sadler-Smith and Shefy, 2004) what means that not only the process is unconscious, but the effect (intuitive 'gist of coherence') is often hard to explain.

According to Kahneman (2003), conceptual representations play a significant role in intuition because they facilitate the quick processes based on the simplified rules of reasoning (heuristics). Due to their high accessibility, these simplified rules of reasoning, based on associations between patterns stored in memory, can easily lead to erroneous intuitive judgement and decisions. The same problem occurs in case of intuitive decisions governed by habits (Kahneman, 2003). Does it mean that intuition is often misleading? Apart from the Kahneman's 'heuristics and biases' approach to study intuition, there is a naturalistic decision making approach which confirms the reliability of at least the expert intuition (Kahneman and Klein, 2009). In contrary to the heuristic-based intuition, the expert one is skill-based. According to Kahneman and Klein (2009) both types of intuition should be considered as recognitions of the memory-stored patterns, which are driven by the situational cue. It is important to note that the cue which initiate the recognition process often remains unknown for an individual. The skilled-intuition is acquired when an individual has an opportunity to learn the relevant cues (even if he/she is unaware of them) which are provided by the environment in similar situations and valid to these situations (Kahneman and Klein, 2009). The process of acquiring expertise, including learning of intuitive skills, requires the sufficient regularity of the environment (i.e. stable relationship between cues and events/outcomes of actions), the sufficient amount of time an individual has spent in this environment as well as some personal characteristics (motivation, intellectual capabilities which enable to learn patterns, etc.). In accordance with these assumptions, the creative intuition is also based on the ability to find the valid patterns of associations in the memory, although the patterns are relatively hard to find (Kahneman and Klein, 2009). Noteworthy, the patterns can be find and learned also in the poorly regular environment providing low-valid situational cues. Recognizing these patterns through the intuitive process may lead to the improvement of performance, but sometimes these intuitions are misleading and unreliable. The affective evaluation of stimulus/situation also has an impact on the intuitive process, e.g. through so called 'framing effect' and affect heuristics. As noted by Kahneman (2003), every situation requires the affective evaluation which is not necessarily conscious, but influences the attitude or behavior. For instance, in the framing effect there are processed the emotions related to risk resulting from the loss-and-gain situation. These emotional impact may also be either reliable or misleading. Hence, it is important to note that the heuristic-based and other non-professional intuitions can be accurate. Nevertheless, due to the fact that such processing is less trustworthy, these intuitions are called the 'imperfect intuitions' (Kahneman and Klein, 2009).

WHAT DIFFERENTIATES INTUITION FROM RATIONAL PROCESS?

Since the information processing and pattern-matching related to intuition proceed fast and automatically, the intuition is considered as unconscious. However, not only intuition but also the rational process is based on information and patterns stored in memory. While the deliberate process is conscious and evaluated by an individual, the intuitive one is beyond individual's awareness and, thereby, cues, mechanisms, and outcomes are not consciously evaluated. Which cognitive operations involved in intuitive process should be considered as unconscious? Do all of these operations are always unconscious? How do the rapid and unconscious intuitive assessments and recognitions occur?

Conscious *versus* Unconscious Processing and Recognition of Patterns

A lot of evidences from neuroscientific research indicate that many of the cognitive operations are processed in the brain (also in the cortex) specifically in distinct locations, and that most of these activities occur independently, automatically, and unconsciously (see Roser and Gazaniga, 2004). For instance, the studies on perceptual illusions have shown that two processes may proceed independently and simultaneously in the visuomotor cortex: one allowing for the stimulus perception, and the second linked to the stimulus response (e.g Aglioti et al., 1995). Alike, also experiments concerning the subliminal stimuli processing as well as studies of patients with neglect or blindsight have shown that stimuli that are not consciously perceived still have a great impact on behavior (for review see Roser and Gazaniga, 2004). Thus, the intuitive information processing should be regarded as mainly unconscious because the cognitive processes may occur beyond the awareness in some kind of 'parallel processor of the brain' which constantly generates the novel combinations of patterns, regardless the attentional control (see Dietrich, 2004). In fact, not only the pattern-matching may proceed unconsciously, but also the intuitive recognition. As it may be assumed on the basis of results obtained by Voss and Paller (2009), so called 'implicit recognition' is qualitatively different from the explicit one, because it is characterized by different electrical brain activity. This EEG study has shown that 'unconscious', i.e. implicit recognition is correlated with the specific frontal-occipital negative brain potential, occurring about 200-400 ms after stimulus onset, which is distinct from the positive potentials occurring as a effect of explicit recognition (Voss and Paller, 2009). Hence, it may be hypothesized that recognition in the intuitive process is implicit and, therefore, it results only in 'preliminary perception of coherence' in the consciousness (Volz and von Cramon, 2006).

Since even the recognition appears to occur beyond the awareness, how does the effect of these processes is consciously realized?

Top-down Attentional Control – Facilitation of Preconscious 'Gist' and Conscious Understanding

Interestingly, both the 'preliminary perception of coherence' and the 'real' consciousness are considered as related with top-down mechanism of attention (see Segalowitz, 2007; Dehaene and Naccache, 2001). The 'preliminary perception of coherence' may be explained by the model originally proposed by Bar (2003) and subsequently expanded by Kveraga et al. (2007) which concerns preconscious 'top-down' attentional facilitation. According to this model, information previously noticed in the stimulus-driven attentional process are transferred from the visual cortex to the prefrontal cortex, and subsequently, may be transferred back at the very early stage of the perceptual process (see Segalowitz, 2007). Because the previously perceived information have been associated and integrated with other information (in the prefrontal cortex, PFC), the following top-down process may provide some 'gist' of the subsequent stimulus before it is perceived. According to this theory, the intuition (as well as priming) would be a consequence of the feedback from 'top-down' attention which helps to predict the environment. In turn, becoming aware/conscious of the information processing that occurs in the one's brain may be explained by 'The Hypothesis of Global Neuronal Workspace' (Dehaene and Naccache, 2001) which assumes the top-down attentional amplification. According to this hypothesis, information are constantly and unconsciously processed in the cerebral networks and they become conscious when are 'amplified by top-down attention into a coherent activity at the scale of the whole brain'. Thus, attention 'serves' as a 'prerequisite of consciousness' and the process become conscious when neurons are activated for sufficient duration/with sufficient intensity, taking into account the information specificity and the brain network involved. Activation of PFC and anterior cingulate cortex (ACC) is particularly important to spread the activity within various neural networks and make the process conscious (see Dehaene and Naccache, 2001).

Cognitive Underlyings of Intuitive Process – Perception, Attention, Memory, and Learning

Does the learning process underlying intuition has to be conscious? The knowledge about environmental patterns (i.e. connections between the cue and the following situation or between behavior and its consequences) as well as knowledge-specific patterns (in case of expert intuition) can be acquired through explicit and implicit learning (e.g. Sadler-Smith and Shefy, 2004). The unintentional learning process, resulting e.g. from stimuli processed beyond attentional control, but also from involuntary observations and information gained by context, often provides the basis for intuitive process. The implicit learning process may results from processing of stimuli which have never been under attentional control. In fact, a lot of stimuli and information which are matched and learned in the unconscious intuitive process and stand for a basis of an intuitive hunch, are perceived unconsciously. All stimuli that are too weak or not enough valid to raise the attention in bottom-up process may be perceived unconsciously, i.e. beyond attentional control. To this group belong also all stimuli appearing on the periphery of the visual field, subliminal stimuli (i.e. with too short exposure time to be consciously perceived) including microexpressions, as well as all stimuli that are habituated. It is important to note, that similarly like in case of stimuli which are attentionally controlled, also in case of stimuli which are perceived beyond awareness, there is always an environmental feedback (which also can be unconscious), thus the intuitive process may occur. It does not mean that the stimuli which are perceived with attentional effort may not subserve intuitive process. However, not all stimuli have to be perceived with the awareness.

Not only stimuli processed beyond attentional control, but also those gathered in involuntary observations or considered as contextual information, can be learned unconsciously and provide basis for the intuitive process. For instance, some more complex information that serve as a context in the explicit learning process, although are processed with some extent of the attentional control may never be analyzed in the rational process. The same problem occurs in case of some consequences of decisions and behaviors - not all of them are rationally analyzed, but still are processed and learned unconsciously. These stimuli can be unconsciously associated with other stimuli or situational consequences and, thus, contribute to intuitive process.

As it is known, different neural networks are involved in explicit memory (hippocampus and cerebral cortex) and implicit memory (cortical networks specific to the selected cognitive operation such as e.g. perception) (see Voss and Paller, 2009). Similarly, there are differences between neural activity during explicit versus implicit learning and their retrieval for the memory. For instance, striatum is linked with the implicit learning, whereas ACC and medial prefrontal cortex (MPFC) is linked with the explicit component of learning (Destrebacqz et al., 2005). Also the specific electrical neural activity - fronto-occipital synchronized low gamma range - has been indicated as typical for unconscious learning, i.e. different from oscillatory synchrony in the gamma band specific for conscious learning (Chaumon et al., 2009). Hence, it may be hypothesised that intuitive processing of information which are implicitly learned is linked with different neural correlates than intuitive processing of information learned in explicit process.

Affective Underlying of Intuitive Process

The latter component which is strictly linked to the intuitive process and seems to be crucial for intuitive outcome, is the affective component of stimulus which also can be unconscious (e.g. Kahneman, 2003). The so called ‘gut feeling’ is so important that some researchers have even distinguished the ‘intuition as feeling’ from the ‘intuition as expertise’ (e.g. Sadler-Smith and Shefy, 2004). Both the affective reactions that are genetically or evolutionarily determined as well as the emotional associations provided through the emotional memory have an significant impact on the intuitive process. For the first time, the strong influence of emotions on the intuitive process has been empirically confirmed by Antonio Damasio’s research team (Bechara et al., 1997). The studies conducted with the *Iowa Gambling Task* on the group of healthy participants has shown that the skin conductance (somatic reaction) appears prior to the reaction when the risk of loss is unconsciously anticipated. Interestingly, authors have observed that the somatic reaction (somatic marker of intuition) does not occur in individuals with ventromedial prefrontal cortex (VMPFC) damages (Bechara et al., 1997). These results indicate that VMPFC is engaged in, not necessarily conscious, processing of gain-and-loss and that its damages may impair the decision making, including intuitive decision making. Despite the VMPFC, some older structures of the limbic brain system are engaged in emotional processing and, thus, may influence the intuitive process. Among these structures the amygdala nuclei seems to be the most important, because it is strictly involved in emotional memory (e.g. McGaugh, 2004) as well as in reactions to unconditionally affective stimuli (including the evolutionary-based ones) (see e.g. LeDoux, 2000; LeDoux, 2007). It is also linked with the implicit emotional learning (Phelps and LeDoux, 2005). Additionally, as the intuitive process is influenced by the loss-and-gain processing (see Kahneman, 2003), also the reward brain system (especially nucleus accumbens) can be involved in intuitive process. Hence, the intuitive process seems to be strongly influenced by the VMPFC and the limbic brain system, including the reward circuit.

It seems that intuition is the mode of information processing in which not only the previously learned patterns are processed and recognized unconsciously, but also the learning of these patterns as well as the perception of the environmental cues may be implicit and proceed beyond awareness and attention. It is not clear if the quality and correctness of intuitive processes is not evaluated at all (as it is suggested by Kahneman, 2003) or if the brain cognitive control system (mid-dorsolateral prefrontal cortex, mDLPFC) can be activated beyond consciousness as it is indicated by Luu and Passingham (2007). Additionally, there are also some evidences that not only executive brain networks, but also default-mode networks (DMN) are involved in unconscious monitoring system (De Pisapia et al., 2012).

Hence, it is assumed that intuitive process engage the same cognitive operations like the rational process, but at least some of them are processed unconsciously. As it is indicated by the neuroscientific findings, at the neuronal level of the brain some of these operations in intuitive process are linked to the same neuronal circuit as in case of deliberate process, but some of them differ between explicit and implicit processes (e.g. memory circuits; see Voss and Paller, 2009). There are also some neural structures typical for conscious processing and some that may be specific for intuitive process. Thus, in order to reveal the neural underlying of intuition it is necessary to carefully analyze the current neuroscientific knowledge.

NEURAL CORRELATES OF INTUITIVE PROCESS

In order to discuss the neural correlates of intuition, particularly these related to intuitive decision making and problem solving, it is necessary to distinguish various mechanisms related to intuition and the intuition types. One of the most comprehensive model of intuition, proposed by Gore and Sadler-Smith (2011) discriminates between domain-general mechanisms of intuition (e.g. accumulation of knowledge, associating and matching patterns, influence of affect, and somatic response) and domain-specific mechanisms (e.g. expert pattern recognition, insight, empathic perception, etc.). According to authors, the domain-general mechanisms underlie all intuitive processes, whereas the domain-specific ones are linked with various types of intuitive outcomes. These outcomes are differentiated regarding the type of cognitive operation, i.e. there are problem-solving intuitions (demanding expertise), social intuitions, moral intuitions, and creative intuitions. Additionally, there are also secondary types of intuition which consist of few primary intuition types. The value of this model is that it allows for distinguishing neural correlates of the primary types of intuitions. According to Gore and Sadler-Smith (2011) the problem-solving intuition is related to the changes in activity of the orbitofrontal cortex (OFC), ventral occipito-temporal regions and posterior hippocampus. The creative intuition is related to the changes in activity of the anterior superior temporal gyrus (aSTG) and diffuse neural networks; while the social intuition - with the activity of lateral temporal cortex, Von Economo neurons and mirror neurons. Finally, the moral intuition is related to activity of the VMPFC, amygdala and basal ganglia.

However, the aforementioned framework is not sufficient to the comprehensive understanding of intuitive process. Firstly, it does not provide the neural mechanisms of domain-general processes which constitute a core of all intuitive types. Secondly, the primary types of intuition, arbitrarily distinguished by authors, are rarely present in this pure form in the real-life activities. For instance, the problem-solving intuition is specific not only for experts, and, what is more, it can be creative or can apply to the social or moral situations. Furthermore, there are other cognitive processes that may be intuitive (e.g. intuitive perception, intuitive judgment, intuitive decision making) which may refer to all primary types of intuition (see Gore and Sadler-Smith, 2011) and are omitted in this model. Thirdly, the aforementioned framework does not take into account the individuals' level of experience which can influence the neural processes related to intuition. Similarly, it does not distinguish between the intuitive process based on patterns learned in explicit manner, including both the automatized processes and the well-learned information which are then unconsciously associated with others, and the intuitive process based on information learned in implicit manner. Taking into account all these factors, it may be fruitful to analyze the neural correlates of intuition in different context.

Besides the aforementioned model, there is a lot of theories that differentiate between intuition as a ‘holistic hunch’ (leading to novel combination of information and subserved by subconscious synthesis) and ‘automated expertise’ (leading to feeling of familiarity and subserved by ‘partially subconscious replay’ of past learned situation-specific experiences) (e.g. Miller and Ireland, 2005). This set of theories may be considered as distinguishing between creative intuitive process of combining information in novel patterns (which may be basis for decisions or problem solving) versus automated process based on subconscious activation of patterns which were learned in explicit manner. Such theories may contribute to unrevealing the basis of intuition, especially when linked with theories concerning the level of expertise. For example, according to the model of Baylor (2001) individuals with moderate level of experience have tendency to use rather rational process of decision making than the intuitive one, whether in case of both: the inexperienced individuals and individuals with high-level of experience the tendency is opposite. Although the expert intuition is sometimes considered as ‘not fundamentally different from other types’ of intuition ‘except it is based on explicit learning’ (e.g. Glöckner and Witteman, 2010) it may differ at the neural level of the human brain.

Thus, the article aims to distinguish the neural correlates of the intuitive ‘core’ and to reveal if there are some differences between expert and non-expert intuitive decision making.

Differences in Neural Activity Between Rational and Intuitive Process

The fMRI study conducted by Kuo et al. (2009) indicates the difference between neural structures activated during playing games which require deliberate problem solving versus ones requiring quick and intuitive decisions (coordination games). Logical reasoning appeared to be correlated with the increased activity of middle frontal gyrus, precuneus and inferior parietal lobule (IPL), but it is worth to note that the activity of precuneus and parietal lobule may be related to the working memory process (e.g. LaBar et al., 1999). In the contrary, the intuitive process appeared to be correlated with the increased activity of insula and ACC. Additionally, the activity of insula was positively correlated with the lack of effort during game, what is interesting, because insula is involved also in motor control and in reactions for stimuli considered as valid (see Kuo et al., 2009). Interestingly, the fMRI study of Ilg et al. (2007) indicates that in case of semantic coherence judgment task, the intuitive judgment (when compared with the explicit judgments) are associated with increased neural activity in heteromodal association areas in bilateral IPL and right superior temporal sulcus/cortex (rSTS). As it has been already mentioned, the activity of IPL is related to many cognitive functions, including working memory processing (e.g. LaBar et al., 1999). Moreover it is also associated with mathematical operations and semantic processing of words (see Kuo et al, 2009). Hence, the IPL activity in both deliberate and intuitive process may be related to the tasks specificity. Referring to the study of Kuo et al. (2009), the activity of IPL could be noticed in deliberate problem solving compared with intuitive decision making, because the coordination games could not require as much working memory load. In fact, the bilateral IPL activation may slightly stronger enhanced heteromodal associations processing in intuitive processing than in rational one. This associative intuitive processing seems to be strongly related to the activity of rSTS which, according to Ilg et al. (2007), is linked with the unconscious processing of weak and remote semantic associates and in consequence with ‘facilitating the integration of distantly related semantic information into a coherent representation’ (see Ilg et al., 2007).

Interestingly, different pattern of neural activity has been observed in relation to the intuitive perception judgments (Waterloo Gestalt Closure Task; Voltz and von Cramon, 2006; Luu et al. 2010). The results of fMRI study conducted by Voltz and von Cramon (2006) indicate that intuitive perceptual judgments, when compared with non-intuitive ones, are characterized by increased activity of medial orbitofrontal cortex (mOFC), lateral nuclei of amygdala, anterior insula and central occipito-temporal regions. Similarly, the study of Luu et al. (2010), conducted with the use of 256-channels EEG, has shown the increased electrical activity in mOFC area and temporo-parieto-occipital area (rTPO). Increased activation of such structures as mOFC, amygdala and insula may be easily understand, because they are deeply engaged in processing of emotional information provided by stimuli/situation and, thus, may be often engaged in intuitive processing (see e.g. Purves et al., 2008; Lieberman, 2007). Interestingly, in the study of Luu et al. (2010), the mOFC activity, which has appeared about 250 ms after stimulus exposure, has been preceded by the activity in rTPO (occurring about 150 ms after stimulus exposure) and, subsequently, has an feedback influence on rTPO activity about 300 ms after stimulus exposure. The results suggest that the mOFC activity occurs before full identification of the stimulus in the rTPO, providing an ‘initial perception of gist’ which influences development of the percept/recognizing the stimulus. This finding may be regarded as consistent with the theory regarding the 'top-down' attentional facilitation (see Segalowitz, 2007) which claims that PFC is involved in 'initial perception of gist'.

However, this set of studies provides at least two more important information about the intuitive process. Firstly, the brain areas activated in intuitive process seems to differ depending the type of processed material. In semantic intuitive judgments the increased activity occurs in rSTS and heteromodal association area in IPL (regions involved in processing of semantic associations), whereas in perceptual intuitive judgments the increased activity occurs, among others, in central occipito-temporal regions linked to processing visual information (see Voltz and von Cramon, 2006). Secondly, the structures activated in both types of the aforementioned studies, when taken altogether, correspond to almost all primary intuitive types distinguished by Gore and Sadler-Smith (2011), i.e. problem-solving intuitions, creative intuitions and moral intuitions. To the better understanding of these neuroscientific data concerning intuition, it is worth to analyse what has been noted by Evans (2003), i.e. that System 1, distinguished by Stanovich and West (2000), is in fact 'a set of autonomous subsystems' and is not constrained with the capacity of the working memory. According to Ilg et al. (2007) intuitive process may be related to the activation of various domain-specific (i.e. specific for the stimulus type) association areas in the neocortex which lead to the conscious 'impression of coherence' being a basis of judgment, decision or problem-solving. Hence, it might be hypothesized that the neural substrates of intuition depends rather on stimulus type/modality than the distinguished outcome and that the discrepancy between neural structures activated in intuitive processing of various type of tasks may be caused by different patterns of activation related to different cognitive domains of input information.

Right and Left Hemisphere

Regardless the domain-specific/task-specific hypothesis regarding the neural correlates of intuition, it is often assumed that intuition is driven mostly by the right hemisphere of the brain (Pink, 2005). It is based mainly on the hypothesis of lateralization which has been disseminated in the 70s. of the XX century by Mintzberg (see Hodgkinson et al., 2009). This hypothesis, concerning the neural basis of managerial decisions, refers to the concept of dual-system of information processing and assumes that the rational process is related mostly to the activity of the left hemisphere, whereas the intuitive one is related to the activity of right hemisphere. It is worth to note that the hypothesis of lateralization is considered as oversimplified. Nevertheless, results of some neuroscientific studies are partially consistent with the hypothesis of the right-sided lateralization of intuitive process. For instance, the activation of right STS (Ilg et al., 2007) and right TPO (Luu et al., 2010) are linked with intuitive process, whereas e.g. left PFC activity is linked with the awareness of relation between presented stimuli (see Dehaene and Naccache, 2001). Moreover, the intuitive hunches are considered as hard to verbalize (Sadler-Smith and Shefy, 2004), while the brain areas responsible for the verbalization (Broca's area in the inferior frontal gyrus) reveal the left-side asymmetry (see Cantalupo and Hopkins, 2001), i.e. the left hemisphere is more involved in the verbalization. Thus, it may be assumed that although the lateralization hypothesis of intuition is untrue as too rigid and oversimplified, to some extent the activity of the right hemisphere is more specific for the unconscious, intuitive process.

Intuitive Decision Making

Both neuroscientific findings and theoretical frameworks concerning neural underlyings of intuition indicate that different brain structures are correlated with intuitive process regarding different stimuli domain (e.g. visual vs. semantic). Moreover, although the neural mechanisms of intuition not necessarily can be differentiated between e.g. moral and social intuition type (as it has been proposed by Gore and Sadler-Smith, 2011), there still may be some differences regarding the type of cognitive operation (e.g. perception, judgment, decision making and problem solving). Unfortunately, because intuition is a relatively new area of interest for neuroscience, the existing studies rarely take into consideration the type of intuitive operation. Additionally, the decision making process is very complicated and, thus, it involves many complex brain mechanisms. Moreover, it is assumed that most of the so called 'rational decisions' require both intuitive and deliberate processes, therefore some of the neural structures activated during rational decision making are involved in intuitive processing (see Purves et al., 2008). For instance, in case of many managerial decisions, as well as decision made by fire commanders, medical rescuers, air traffic controllers and other professionals whose decisions have life-and-death-consequences, the pure logical reasoning is often not sufficient to make the right decision. Thus, individuals often have to take into account their previous experiences, learned values and emotions which are provided in the intuitive process. For all of these reasons, it is hard to differentiate between neural mechanisms of intuitive and rational decision making.

Despite the huge social and economic demand for the knowledge regarding the intuitive process of complex decision making, there is a real shortage of this kind of studies, especially neuroscientific ones. Due to this reason the intuitive decision making is studied often with the use of eyetracking method. Results of such studies reveal, for instance, that the fixation time is shorter in case of intuitive decision making than in case of rational one (e.g. Horstmann et al., 2009). Additionally, it is indicated that managerial-like decisions are often made on the basis of intuition and only rarely, when there is enough time, are further supported by logical reasoning (Horstmann et al., 2009; Glöckner and Betsch, 2008). Thus, most of these decision are at least partially based on intuitive process. Since the eyetracking studies are limited to the observations of perception process (amount of fixations and their duration) and related reasoning about attentional process, it is necessary to analyze neuroimaging studies in order to obtain information about what is crucial in the intuitive decision making.

Neuroscientific studies of intuition concern either rapid and simple decisions and judgments or solving relatively simple problems (see Kuo et al, 2009; Luu et al., 2010, Voltz and von Cramon, 2006). Merely few studies refer to the more complex decisions resembling those which are made in everyday life. Even less aims to differentiate the intuitive process from the rational one. For instance, it is known that neural structures such as VMPFC and ventral striatum are engaged in intuitive process (see Gore and Sadler-Smith, 2011). Nonetheless, as they are involved in executive process of reward evaluation and anticipation of loss or gain, there are crucial for almost every decision process and, therefore, often are linked also to rational decision making (see Purves et al. 2008). Additional explanation for this interference of two processes can be provided by studies regarding complex social decision making.

On the ground of social cognitive neuroscience, Lieberman (2007) claims that basal ganglia (caudate and putamen), amygdala, VMPFC, lateral temporal cortex (including posterior STS, pSTS), and dorsal ACC (dACC) should be regarded as the neural correlates of the automatic (intuitive) processing system supporting social actions and cognition as well as related decisions (so called *X-system*). On the contrary, lateral PFC (LPFC), dorsomedial PFC (DMPFC), middle temporal cortex, medial and lateral parietal cortex, and rostral ACC (rACC) should be considered as parts of the *C-system* involved in the controlled processing supporting social cognition and related decisions. Lieberman (2000) considers intuition, including intuitive social decision making, as strictly related to the implicit learning and, thus, correlated with the activity of such basal ganglia structures as caudate nucleus and putamen (i.e. parts of striatum). Despite striatum is recognized as linked with emotional processing and evaluation of loss and gain (e.g. Seymour et al., 2007), it is also involved in implicit learning (see Liberman, 2000). Moreover, basal ganglia has many associations with cortex. There are five neural circuits connecting striatum with cortex: (1) motor circuit (connections with somatosensory cortex), (2) limbic circuit (anterior cingulate, amygdala, hippocampus and thalamus) related to shifts of attention and evaluation of situation, (3) circuit involving DLPFC and posterior parietal cortex, related to working memory, (4) circuit involving OFC and ACC, related to the emotional evaluation of situation, and (5) oculomotor circuit related to saccadic eye movement (see Liberman, 2000). Many of these structures is strictly involved in deliberate decision making (see Purves et al., 2008). Therefore, activation of striatum not only provides implicit learning during the intuitive social 'actions' and 'cognitions', but also may impact on deliberate complex cognitive operations such as decision making.

The process of mutual influence between intuitive and deliberate decision making is interestingly explained by Glöckner and Betsch (2008). According to their integrative model of decision making the intuitive (i.e. automatic and holistic) process underlying decisions appears always. In various complex, multi-choices decisions (e.g. selection of plans, preferential choice, etc.), similarly like in case of images with changing figure/ground relationship (e.g. 'Rubinian vase'), the preferred mental representation/preferred choice is automatically identified and the observed information are modified to fit it, so that the feeling of consistency occurs. If the level of consistency does not exceed the certain threshold (i.e. there is no evidences strong enough to support one of the option), the deliberate process starts. Such assumptions are to some extent consistent with the preliminary 'top-down' attentional facilitation model of intuition provided by Bar (2003) and Kveraga et al. (2007).

Expert Intuition – Neural Correlates of Expertise

At the field of neuroscience the problem of distinguishing between rationality and intuition in decision making is relatively new. The knowledge about neural basis of these processes is very limited and answers for many questions are unclear. The problem of intuition is often concerned only at the level of human perception and simple judgment. However, the review of the current state of knowledge not only indicates that some of the neural structures activated during decision making are involved in the intuitive process. A lot of the theoretical frameworks and empirical studies aim to explain the influence of expertise level on the efficiency of intuitive decision making (e.g. Baylor, 2001; Hogarth, 2002; Moxley et al., 2012). There are also some evidences leading to an assumption that the activation of neural structures may differ between the 'expert' intuition versus 'non-expert' intuition.

According to the model of Baylor (2001) there is an U-shape relation between level of expertise and intuitive/rational decision making. This model distinguishes the immature intuition which is often a basis of specific-subject decisions made by beginners and the mature intuition often underlying decisions made by experts. It is also assumed in this model that rational decision making is specific to decision makers with medium level of expertise. For the first time the expert intuition has been distinguished in the 80's of the XXth century by Herbert Simon and has been understood as 'analyses frozen into habit' (see Hodgkinson et al., 2009). This understanding has changed and currently the expert intuition is explained rather in terms of well-developed structures of specific knowledge (e.g. Baylor, 2001). Such knowledge structures relevant to the domain have an impact on the increasement of the accuracy level of intuitive decisions (see Dane and Pratt, 2007).

Despite the fact that among researchers there is no consensus whether the expert intuition is qualitatively different from the 'non-expert' one (see Glöckner and Witteman, 2010), at least some specificity at the neural level may occur. For instance, the neuroscientific findings indicate that the neural activity during problem solving differs depending the level of individual's expertise (e.g. Duan et al., 2012; Wan et al., 2011). Both aforementioned studies concern intuitive next-move generation either in chess game (Duan et al., 2012) or in board game 'shogi' which is similar to chess (Wan et al., 2011). The results obtained by Duan et al. (2012) indicate that chess masters exhibit the smaller grey-matter volume in the caudate nucleus and enhanced integration between activity of caudate and DMN in the resting state fMRI. Moreover, activity in such parts of DMN as posterior cingulate cortex (PCC) and angular gyrus is increased in professionals when compared to novice (Duan et al., 2012). The fMRI study conducted by Wan et al. (2011) has shown the increased activity in caudate and in precuneus (i.e. area in parietal lobule which is classified as a part of DMN) during quick and intuitive next-movement generation in shogi game in experts when compared to amateur players. Since the activity of precuneus, considered as related to recognition from memory has occurred during perception of board patterns (Wan et al., 2011) it may be related to unconscious processing and recognition of patterns. Generally, the DMN seems to be involved in imagination, task planning, theory of minds (imaging the perspective of others in order to predict their behaviour) and processing of self-related information stored in episodic memory, and its activity decrease during goal-directed cognitive task (see Duan et al., 2012). On the contrary, the caudate nucleus has appeared to be this part of the neural circuit which is involved in generation (association and implementation) of patterns (Wan et al., 2011). Activation of caudate is linked, among others, with development of associations between stimulus and reaction, processing of goal-directed behaviors and automatic processing of skills (see Duan et al., 2012). Interestingly, the increased activity of caudate is considered as specific to intuitive generation of movement, because it has not occurred during deliberate generation of movement (Wan et al., 2011). Taking this findings into consideration, it seems that expert intuition is related to the enhanced activity of DMN (especially precuneus, PCC and angular gyrus) at the first stage of the process (imagination and recognition of self-experienced and observed patterns) and the activity of caudate at the second stage of the process (associating the patterns with the current situation?). With gaining the level of expertise, the connections between DMN and caudate are enhanced, thus it may be hypothesized that the neural structures belonging to DMN are related to expertise. If so, the activity of DMN and its enhanced connections with caudate might be considered as the 'markers' of the expert intuition.

It is worth to note that according to some authors (e.g. Moxley et al., 2012) chess and other board games are not necessarily good tasks to study intuition - neither the expert nor the 'non-expert' one. Another drawback of studies on board games it that this type of task does not allow for distinguishing between 'holistic' either 'creative' process of combining/synthesizing divergent information in new way and 'automated expertise' based on previously learned information (see Miller and Ireland, 2005). Because it is very likely that, for instance in case of managerial decisions, the holistic, generative intuition is useful when exploring for new technologies and strategies, whereas the 'automatised' intuition is more useful when exploiting the existing ones (see Miller and Ireland, 2005; Dane and Pratt, 2007). Hence, in order to improve the managerial strategies it is important to verify whether both processes are distinct at the neural level and whether both of them are related to intuition. Due to this facts, additional neuroscientific studies, conducted with the use of other type of tasks, are needed to support the existing assumptions regarding neural correlates of expert intuition.

CONCLUSIONS

In the recent years, due to various social and economic changes, the issue of intuition and problems regarding intuitive decision making have become particularly important (see e.g. Hodgkinson et al., 2009; Moxley et al., 2012). Nonetheless, it is still hard to define the intuitive process and specify which conscious and unconscious cognitive and emotional processes underlie intuition. The aim of this review is to shed a light on these operations and its neural correlates, with a special regard to the intuitive decision making as well as the expert *versus* 'non-expert' intuitions.

On the basis of the current state of knowledge it is assumed that intuition may be explained in terms of unconscious recognition and matching of patterns which are learned in explicit or in implicit manner, and based on cues perceived either with attentional control or beyond awareness. The review indicates that some neural structures correlated with intuition differ regarding the stimuli/information modality. For instance, it has been shown that activity of rSTS and heteromodal association areas in bilateral IPL are linked with intuitive semantic judgments (e.g. Ilg et al., 2007), whereas the rTPO-mOFC reentrant circuit is linked rather with intuitive perceptual judgments (e.g. Luu et al., 2010; Voltz and von Cramon, 2006). Besides, amygdala nuclei, ventral striatum, and anterior insula are indicated in relatively high number of analyzed research (e.g. Volz and von Cramon, 2006; Lieberman, 2007; Kuo et al., 2009). Thus, it is assumed that these structures, related e.g. with emotional processing and implicit learning, are common for all types of intuitive process.

It is also indicated that ventral striatum (particularly caudate and putamen) and VMPFC, although activated also during deliberate decision process, are most likely related to intuitive decision making (see e.g. Purves et al., 2008; Lieberman, 2000; Glöckner i Betsch, 2008). Moreover, the conducted review of the current state of knowledge suggests that the activation of neural structures differs between the expert intuition versus 'non-expert' intuition. Although there is only few neuroscientific studies regarding this issue, it seems that the enhanced connectivity between DMN (particularly precuneus) and caudate as well as the increased activity in such DMN structures as precuneus, PCC and angular gyrus are specific for professional intuitive skills (Duan et al., 2012; Wan et al., 2011). Alike, the existing findings suggest that there is a difference between 'creative'/'holistic' *versus* 'automatized' intuition. There are some reports showing that the activity of aSTG is a hallmark of creative intuition (see Gore and Sadler-Smith, 2011). Unfortunately, due to very limited state of knowledge it is impossible to verify if there are some neural mechanisms specific for e.g. holistic expert intuition.

Finally, it is noteworthy that all the aforementioned mechanisms, as assumed on the basis of relatively few neuroscientific findings conducted in various paradigms, need to be carefully studied and verified in the future investigations. Nevertheless, highlighting the neural basis of various intuitive processes seems to be very promising for managerial practices. This issue is an area of deep interest for the management and psychology, as it has been already suggested that under some specific conditions intuitive organizational decisions may be more relevant than these made in the deliberate process (e.g. Glöckner and Witteman, 2010; Miller and Ireland, 2005; Khatri and Ng, 2000).

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