Intuition: Conceptualization and Neuroscientific Study

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Abstract

Intuitive decisions are a crucial aspect of everyday life, yet intuition remains a poorly understood phenomenon in science. The study of intuition has yet to produce an integrative account of intuition and its underlying processes. Although many advances have occurred since the turn of the century, fundamental questions, such as "What is intuition?", "How is it best conceptualized?" and "How does intuition operate?" have not been answered satisfactorily. Thus, controversies span throughout the entire research. One possibility to take on these issues is to incorporate neuroscientific evidence. This thesis considers current theories about intuition and clarifies how the study of intuition can profit from (cognitive) neuroscience. For this purpose, theoretical and conceptual perspectives on intuition's definition, delineation from related phenomena, and conceptual frameworks will be introduced and discussed in light of relevant neuroscientific findings. By combining experimental psychology with neuroscience, cognitive neuroscience has the potential to uncover intuition's inner workings. The resulting evidence exposes additional information about the underlying processes of intuition and allows for conclusions about the theoretical conceptualization of intuition. As such, cognitive neuroscience can enhance the study of intuition by expanding the knowledge of intuition's underlying processes and clarifying the conceptual level through testing specific elements, examining connections to related phenomena, unifying different lines of inquiry, and informing conceptual frameworks.

1. Introduction

> "I was struck over and over by the dominance of intuition in control of our behavior. The belief that we have in ourselves as conscious controlling agents does seem to be largely illusory." (Evans, 2010)

People make decisions every day, and more often than not, people have to decide quickly, without really understanding the situation or considering the consequences of their choices. Roughly, decisions without deliberating ahead of time are called intuitive decisions. (e.g., Evans, 2010; Sinclair, 2011; Hodgkinson et al., 2008; Hodgkinson et al., 2009; Hogarth, 2010; Zander et al., 2016a). Approached from a general perspective, the concept of intuition centers around the layman's idea that people can know something without knowing how they know (Sinclair, 2011). Consequently, individuals can make successful decisions without deliberate, analytical thought, and almost all conceptualizations of intuition agree that intuition is a form of information processing distinct from analytical reasoning (Epstein, 2010). While intuition has piqued the interests of scientists throughout the history of the study of the mind across many disciplines, the conceptual development around the notion of intuition remained "meager and problematic, suffering from vague and multiple uses of the term, association with diverse experimental phenomena, and from minimal effort to integrate these in a consistent way" (Osbeck, 1999). Considering that intuition, like non-conscious cognition, has been particularly difficult to study, this is no surprise. So far, plenty of research on intuition has emphasized theoretical or behavioral accounts of what intuition is, when it is best used and how accurate it is. Yet, researchers have made strong claims about intuition's performance before advancing a proper understanding of the concept or advancing empirical studies into the processes underlying intuition (Dane & Pratt, 2007). A major problem in studying intuition is the lack of an overarching framework to organize and reconcile different views. Sinclair (2011) notes: "This void is particularly worrying as individual interpretations often do not contradict but rather focus on specific aspects of intuition, oblivious to the big picture in which they are all embedded." As a result, controversies and inaccuracies about intuition span throughout the entire field. Often studies start with different views on a definition of intuition and its distinction from related phenomena (Dane & Pratt, 2007; Glöckner & Witteman, 2010). Controversies further concern the scope and the homogeneity of the phenomenon, its properties, its working mechanism, its relatedness to affect, and its dependence on experience (Glöckner & Witteman, 2010). Because of this, empirical research on intuitive processing is still a relatively recent endeavor and in much need of conceptual clarification. That said, since the turn of the century, research on intuition has picked up speed, featuring fundamental conceptual and theoretical developments along with recent advances in neuroimaging that have produced promising avenues of inquiry into the neural correlates of intuitive decisions. Arguably, both conceptual development and empirical research on a neuroscientific level are necessary to build an integrative understanding of intuition. Demonstrating which brain regions are active during a task can be valuable for cognitive theory. Knowing where and when in the brain processing takes place can indicate correspondence in the underlying processing between and within paradigms and allow inferences about the different strategies used by the participants based on the active brain areas. Therefore, illuminating intuition's inner workings on a neural level could help to solidify and challenge cognitive theories about intuition. In turn, improved cognitive theories of intuition can better guide experimental and neuroscientific inquiry. This principle is reflected in the latest conceptual trend in the literature about intuition that suggests partitioning the concept of intuition into different types of processes and outcomes to advance conceptual clarification (Dane & Pratt, 2009; Glöckner & Witteman, 2010; Gore & Salder-Smith, 2011). These approaches stress the importance of cognitive theories of intuition to specify how some conceptual component of a model reflects on an empirical level. In other words, it highlights the importance of improving cognitive theories of intuition to allow for better hypotheses to be generated and tested more readily within experimental research than before. Synergies between the conceptual, the experimental, and the neuroscientific level of intuition research will allow for a more integrative understanding of intuition, which can provide much-needed answers to fundamental questions about intuition. Therefore, this thesis sets out to answer the following research question: *Given current theories of intuition and their problems, how can the study of intuition benefit from (cognitive) neuroscience?* In respect thereof, this thesis introduces various views on intuition and connects them to relevant neuroscientific findings in the study of intuition. In order to do so, it consists of three parts: the first part elaborates on the concept of intuition, namely its definition, properties, delineation from related phenomena, and the adopted conceptual approaches to study the phenomenon. The second part elucidates neuroscientific findings that emerged from different conceptualizations of intuition. The final part illustrates the value of cognitive neuroscience to the study of intuition by discussing the neuroscientific evidence in connection to the presented concepts and theories of intuition. A more detailed overview of how this paper is composed will be given after presenting the strategies by which the relevant literature was found and selected.

2. Methods

2.1 Search and Selection Strategy

It is important to provide a detailed account of the literature search and selection process since the composition and reasoning of the thesis draw on the reviewed literature. A comprehensive search was conducted to find the relevant literature. Research articles qualified if they were in English, peer-reviewed, related to neuroscience or intuition, and published between 1980 and 2021. The databases used for the search were: PubMed, Jstor, APA PsycINFO, WordCatDiscovery, and Google scholar. The search terms used comprised variations of intuition and neuroscience. The first 50 results per search were examined. Since most of the meaningful work in the study of intuition emerged after the turn of the century, emphasis was placed on more recent work. Initially, research concerning the neuroscientific study of intuition was aggregated and screened. Then, cognitive theories and conceptualizations connected to the neuroscientific study were analyzed. Another search was conducted specifically to find relevant general definitions, delineations from related phenomena, and conceptual frameworks of intuition. After reviewing the literature, the empirical, neuroscientific research on intuition in the context of perceptual discovery and dual processing was selected because it provided the most promising conceptualizations and significant neuroscientific findings. Together, the selected papers comprised the following topics: a general definition of intuition, delineation of intuition from implicit memory and insight, conceptualizations of intuition within dual-process frameworks, with intuition-specific frameworks and within the context of discovery, and, finally, the neuroscientific study on intuition within dual-process models and within the context of discovery. Other areas of intuition research were excluded because they either proved irrelevant to the paper's aim or the experimental, neuroscientific findings were inconclusive. On the latter's basis, the few neuroscientific articles on intuition in the context of creativity and moral judgment were excluded. Furthermore, behavioral studies about the performance of intuition alone (i.e., use and accuracy) were left out because studying intuition's performance more often than not serves to legitimize the study and the use of intuition as an explanatory construct rather than advancing an integrative understanding of the phenomenon. Finally, the philosophical notion of intuition and purely theoretical contributions disconnected to empirical research were excluded too.

2.2 Structural Overview

To elucidate how (cognitive) neuroscience research benefits the study of intuition, this paper proceeds as follows: In the first part, the theoretical and conceptual understanding of the concept of intuition is elucidated. First, in section 3.1, a general definition is put forth that comprises intuition's core characteristics. Second, in section 3.2, intuition will be delineated from the related phenomena relevant to this paper, namely insights and implicit memory. Third, three conceptual approaches to study intuition are explained in section 3.3. These encompass intuition within the frameworks of dual processing (3.3.1), within intuition-specific frameworks (3.3.2), and concerning a specific instance of intuitive decision-making in the context of perceptual discovery (3.3.3). In the second part, neuroscientific studies will be presented that zoom in on the neural correlates of intuitive decisions. Section 4.1 presents preliminary neuroscientific findings of intuitive decisions within the conceptual framework of dual processing in the domain of self-knowledge (4.1.1) and the paradigm of coordination games (4.1.2). In section 4.2, examining intuitive decisions in the context of perceptual discovery yields insights into the continuity of intuition’s underlying processing (4.2.1), the relation of intuition to priming, which is an instance of implicit memory (4.2.2), and the neural correlates of intuition-specific processing across various sensory modalities (4.2.3). In the final part (section 5.), the use of (cognitive) neuroscience to the study of intuition will be outlined in light of the following questions: “Is it accurate to conceptualize the underlying processes of intuition as continuous?”, “Are related phenomena, like insights or implicit memory, interoperable with intuitive processing or do they fundamentally differ?” and “Is the phenomenon of intuition accurately conceptualized as unitary construct?”

3. The Concept of Intuition

As part of explaining a phenomenon such as intuition, it is crucial to define what one wishes to understand (section 3.1), to determine what lies outside the phenomenon’s boundaries (section 3.2), and to specify how intuition can be investigated (section 3.3).

3.1 Defining Intuition

> “As both concept and phenomenon, intuition is alluded to by all kinds of people with an intriguing lack of coherence and consistency” (Blanchard, 1989, as cited in Sprenkle, 2005)

Few other phenomena in psychology, perhaps even in science more broadly, have so many different definitions as intuition (Epstein, 2010). Therefore, this section discusses the definition of intuition and introduces a promising integrative approach to define it. Four – hardly exhaustive - examples will exemplify the partial agreement and controversy about the definition of intuition (for some lists, see Dane & Pratt, 2007; Hodgkinson et al., 2008). First, in an online dictionary, intuition is defined as “the ability to understand something instinctively, without the need for conscious reasoning” (Lexico, n.d.). Second, in the context of perceptual discovery, intuition is defined “as the preliminary perception of coherence (pattern, meaning, structure) that is at first not consciously represented which comes to guide our thoughts toward a ‘hunch’” (Bowers et al., 1990). In experimental research, the context of perceptual discovery revolves around paradigms that focus on discoveries within perceptual stimuli (e.g., visual, semantic, or auditory stimuli), such as recognizing a specific object within a fragmented line drawing (see section 3.3). Third, according to Hogarth (2001), “the essence of intuition or intuitive responses is that they are reached with little apparent effort, and typically without conscious awareness. They involve little or no conscious deliberation”. Fourth, Klein (2003) described intuition as the “way we translate our experiences into judgments and decisions. It’s the ability to make decisions using patterns to recognize what’s going on in a situation and to recognize the typical action scripts with which to react.’’ Strictly speaking, definitions are merely a vehicle used to determine the meaning someone wants to ascribe to a term and, therefore, cannot be considered right or wrong.

Nevertheless, definitions can be assessed according to the extent they advance understanding in science. In this light, this paper introduces another approach to define intuition. Dane and Pratt (2007) suggested that as a means of conceiving a more useful definition of intuition, it proves effective to identify "the features of intuition that are 'common and central' across many definitions of intuition and across a variety of disciplinary domains."

In their review of the literature on intuition, they highlighted convergence on four main characteristics that make up the core of the construct: intuition is a "(1) non-conscious process (2) involving holistic associations (3) that are produced rapidly, which (4) result in affectively charged judgments" (Dane & Pratt, 2007). Dane and Pratt noticed in their analysis that there is a confusing tendency apparent in the literature to call both intuitive processes and their subsequent outcomes 'intuition' interchangeably. By their suggestion, the difference should be accounted for, whereby intuitive processing should be referred to as *intuiting* while the outcomes should be referred to as intuitive judgments or *intuitions* (Dane & Pratt, 2007). Intuitive judgments can become accessible to conscious awareness while intuiting, that is how one arrives at intuitive judgments, is not accessible to consciousness (Shapiro & Spence, 1997; Dane & Pratt, 2007). Further anecdotal support for this distinction can be derived from experience, namely that intuitions seem to be always accompanied by affect while it remains unclear whether intuiting always shares this trait. In consequence, the term intuition would only be used to refer to the phenomenon comprehensively, that is, when the process-outcome distinction proves irrelevant. Dane and Pratt's (2007) definition accounts for this conceptual difference. The main advantage of this definitory approach is that, based on reviewed main characteristics across many definitions, the usefulness and accuracy of other definitions of intuition can be assessed more readily. Seemingly different definitions of intuition can be compared to these main characteristics, and what is missing in some can be recognized quickly. Because of this, it is important to know what is implied by the different characteristics put forth by Dane and Pratt because definitions phrase intuition's characteristics differently. For example, the online dictionary definition contains the aspect of non-conscious processing as "without the need for conscious reasoning" (Lexico, n.d.) and could reflect intuition's speed in terming it "instinctively." Nevertheless, the affective component of intuitions and the associative nature of intuitive processing are missing. This definition would hardly be useful in a scientific context as it encompasses phenomena like insights and implicit memory processes, which supposedly differ from intuition (see section 3.2). Below, the main characteristics of the definition will be elaborated and expanded by additional features of intuition that are relevant in more recent literature.

First, intuitive processing is conceived and experienced as a nonconscious process. People cannot report on intuition's underlying cognitive processes, i.e., they are not aware of the cues they are using or how these cues are processed (e.g., applied or integrated) to reach an intuitive judgment. Thus, intuitive processing pertains to the domain of the non-conscious (Lieberman, 2000; 2007; Lieberman et al., 2004; Dane & Pratt, 2007; 2009). It seems plausible that non-conscious information processing as such and intuitive processing share additional common features (e.g., automaticity). Zander et al. (2016b) suggested that automaticity or uncontrollability is vital to intuition. Intuitive judgments cannot be intentionally controlled, i.e., they can neither be evoked at will by the individual nor ignored (e.g., Topolinski and Strack, 2009). The unintentional nature of intuitive processing indicates processing without attentional effort, and therefore, intuiting is also considered fast and effortless (Hogarth, 2001).

Second, intuitive processing is indeed notable for its speed, especially compared to deliberate thought (Hogarth, 2001; Dane & Pratt, 2007; Evans, 2008). Almost all conceptualizations reference intuition's speed (Dane & Pratt, 2007), and experimental paradigms most often implement time pressure as one variable to force intuitive judgments. Intuition is assumed to process vast amounts of information quickly due to parallel processing (Betsch, 2008).

Third, intuiting involves holistic associations. Intuitions are assumed to arise through some associative cognitive process, for example, when environmental stimuli are linked to tacit knowledge (Zander et al., 2016b). According to Dane & Pratt (2007), they are termed holistic because intuition involves associatively recognizing features and patterns beyond making connections through logical considerations. Moreover, the involvement of holistic associations indicates intuition's common connection to experience. Intuition develops over time with practice (Lieberman, 2000), and intuitions appear to incorporate non-consciously held knowledge, potentially in the form of relatively simple cognitive heuristics or more complex patterns developed through training and experience (Dane & Pratt, 2007). Yet, how dependent intuition is on experience, that is, on implicitly stored knowledge, remains to be explored.

Fourth, the outcomes of intuitive processing, namely intuitive judgments, are viewed as being affectively charged. Intuitive processing evokes some consciously experienced feeling or affective signal, which is strong enough to act upon even if no definitive reasons for the decision can be verbalized or specified. In sometimes synonymously used associations like 'gut feelings,' 'gut instincts, and 'hunches,' the tenor that intuition is linked to affect is apparent. It is salient that intuitive judgments and affect are intertwined at the outcome level. As Betsch (2008) puts it: "The output of the process is a feeling that can serve as a basis for judgments." Most probably, intuition is related to affect both at the outcome and the processing level. Intuitive judgments arise through nonconscious processing. The nonconscious processing system is "often viewed as being imbued with emotionally based content and operations" (Epstein, 2002, as cited in Epstein, 2010). Furthermore, intuitions "involve a strong tendency toward a hunch, which serves as a go-signal that is strong enough to initiate action" (Zander et al., 2016b). To no surprise, people often seem to follow their intuitive (gut) feelings in decisions (Gigerenzer, 2008).

On a final note, all four main characteristics need to be present to recognize intuition as such. Thus, the combination of these characteristics satisfies the definition of intuition and constitutes its boundary conditions.

3.2 Delineating Intuition

Cognition is complex, and on an empirical level, most of the decisions one makes involve a mixture of intuitive and nonintuitive processes. On a conceptual level, intuition can be delineated from related phenomena by its definition's boundary conditions, whereas on an empirical level, the characterization of actions and the corresponding cognitive processes as intuitive or nonintuitive is often a matter of degree (Hogarth, 2010). In real life, as in experimental settings, intuition can coincide with similar cognitive processes or related phenomena, illustrating intuition's elusiveness. In the following, intuition will be delineated from the two related phenomena, namely insights and implicit memory.

Like intuition, another intriguing phenomenon of non-analytical mental functioning is insight (Zander et al., 2016b).

> "There are situations, in which decision makers arrive at an idea or a decision not by analytically inferring the solution but by either sensing the correct solution without being able to give reasons for it, or by realizing the solution all of a sudden without being able to report on the solution process. Roughly, the former phenomenon has been called intuition, the latter insight" (Zander et al., 2016b)

Both concepts struggled to become recognized as established fields of research due to their elusiveness, and research into both developed independently of each other (Zander et al., 2016b). Yet, from a lay perspective, they appear similar as both involve non-conscious processes that lead to signals that can support problem-solving (Bowers et al., 1995). Because of this, some scholars have suggested that intuition and insight are interwoven (Bowers et al., 1995), with intuition preceding insight (Dorfman et al., 1996, Zander et al., 2016b). In contrast to intuitions, insights appear clearly to consciousness and consist of a solution, which is verbalizable and explainable (Zander et al., 2016b). With insight, a person "becomes aware of the logical relations between a problem and the answer. In the case of intuition, usually there is no insight into the logical relations" (Lieberman, 2000). Furthermore, contrary to intuitions, insights appear to be bound to the problem-solving domain (Bowden et al., 2005; Volz & von Cramon, 2006), and conscious processes can also achieve insights. For example, solving a mathematical problem involving systematic reasoning can culminate in insight

(Laborde et al., 2020). In other words, arriving at insights might be less automatic and uncontrolled as compared to arriving at intuitions. Predominantly, intuition and insight have been conceptualized differently, especially according to their unfolding. The underlying processing of insight is regarded as genuinely discontinuous (Zander et al., 2016b), whereas intuitions are assumed to unfold in a continuous, gradual manner (Bowers et al., 1990; Zander et al., 2016a). Hence, contrary to intuition research, insight research focuses on a discontinuity model, in which early sensing of a solution is typically misguided, which creates an impasse for later solution attempts. Usually, a mental restructuring process is required to arrive at a correct solution through insights. For example, in magic tricks, the first rapidly formed judgment is usually incorrect, and thus the magician manages to do magic, i.e., trick the audience. A mental restructuring of the problem must overcome the initial impasse before reaching the correct solution (insight) and figuring out how a magic trick works. As such, opposed to intuitions, insights appear to necessarily involve incubation, i.e., a gestation period preceding insight in which the mental restructuring is assumed to happen (Zander et al., 2016b). However, the sudden awareness of intuitions could also reflect a discontinuity in the underlying process. So far, the two phenomena have not been compared according to their underlying processes on a neuronal level (Zander et al., 2016b). Whether intuition and insight are two processes that can build on each other or fundamentally differ remains to be explored but presents a valuable line of inquiry where (cognitive) neuroscience can advance the study of intuition (and insight) - see section 5.

It is important to note that intuitions represent learned behavior. Learned behavior involves deep knowledge representations and prior learning or expertise. It is an important component of intuition that it develops over time with practice. For example, intuitive judgments guiding the next best move in chess are comparably fallible if executed by a chess novice but rather sophisticated in the case of a chess expert. Another example are abilities in nonverbal decoding. They develop and improve from early childhood through early adulthood, and consequently, the skill to intuitively judge mental states through body language improves (Lieberman, 2000). As such, intuition appears to rely on pre-existing knowledge, which certainly must have been acquired via some kind of learning. The knowledge incorporated in intuitive judgments is often learned without conscious awareness, such as knowledge in nonverbal decoding (Lieberman, 2000). Therefore, implicit learning and memory are often linked to intuition. Lieberman (2000) proposed that “implicit learning processes are the cognitive substrate of social intuition.” Roughly, such a view indicates that either intuition capitalizes on implicit memory processes or that social intuition, in particular, is an instance of implicit memory processes. Implicit memory becomes apparent when prior experience influences current behavior or thought without traces of conscious recollection (Volz & Zander, 2014; Zander et al., 2016a). As with implicit memory, people cannot report on intuition’s underlying cognitive processes, and both intuition and implicit memory depend on experience. Their conceptualizations coincide further in features involving associations, automaticity, and speed. Nevertheless, Volz and Zander (2014) argued that intuition and implicit memory processes differ in the signal accompanying the respective cognitive processes and the format in which information is accessed and stored. As such, the underlying neurocognitive processes ought to differ. However, the empirical relation of implicit memory and intuition remains to be explored. An initial study of Zander et al. (2016a), presented in section 4.2.2, is a first investigation of the difference between intuition and implicit memory in the case of priming, which is an instance of implicit memory processes.

3.3 Three Conceptual Approaches to Study Intuition

As mentioned before, a major problem in the study of intuition is the lack of an overarching framework that could organize or connect various lines of inquiry. Having defined intuition, explained its properties, and distinguished it from related phenomena, the question remains of how to investigate intuition and its inner workings in a reasonable way. Researchers have come up with various ways to do so. Due to the lack of consistent frameworks for intuition, researchers have either turned to existing frameworks for conceptual support, like dual-process theories (see section 3.3.1), developed intuition-specific frameworks (see section 3.3.2), or conceptualized intuition in very specific instances to allow for investigations of intuition in its most simple form (see section 3.3.3).

3.3.1 Intuition-like System 1

With the onset of dual-process theories, there has been a growing consensus that two independent systems process information (Sinclair, 2011). Almost all dual-process models distinguish two information processing systems: a fast, automatic, and unconscious system (often called System 1, see for example Stanovich & West, 2000; Evans, 2008; 2010) and another system that is slow, deliberative, and conscious (often called System 2, see for example Stanovich & West, 2000; Evans, 2008; 2010). The typified distinction between these two information processing systems parallels the common differentiation of intuition from deliberation and has served as a good starting point for studies concerned with the nature of intuitive thought. The study of intuition within dual processing hinges on two assumptions, namely that dual-process theories represent an adequate conceptual framework to study intuition and that intuition can be placed within System 1. Adopting dual-process models of information processing could allow for the much-needed "development of a more integrated and coherent account of intuition" (Hodkinson et al., 2008).

Most often than not, the mere resemblance of intuitive processing and the intuition-like System 1 processing is taken as the basis to identify intuition's place in dual-process theories. System 1 processing and intuiting converge on information processing that is primarily nonverbal, fast, associative, automatic, effortless, involves affect and parallel processing (Lieberman, 2007; Sinclair, 2011).“[I]ntuition is believed to be handled by the experiential system (System 1), a system that is ‘preconscious, rapid, automatic, holistic, primarily nonverbal, [and] intimately associated with affect’” (Pacini & Epstein, 1999, as cited in Sinclair, 2011). In dual processing, intuition is either viewed as one subtype among many processes comprising System 1 (e.g., section 4.2.1), or intuition-like System 1 processing is taken to reflect intuitive processing (e.g., section 4.2.2). Yet, the identification of intuitive processing within System 1 often remains vague. For example, Epstein suggested that “intuition is nothing more and somewhat less than the experiential system” (Epstein, 2010). In principle, relating intuition to System 1 allows the findings within the framework of dual-process theories about System 1 to be inferred onto the study of intuition. For example, System 1 is viewed as being imbued with affect, and thus intuitive processing is likely to operate on affective information (Glöckner & Witteman, 2010). For instance, as affect plays a critical role in reinforcing associative learning within System 1, it is possible, in theory, to infer a correspondent function in intuitive processing (Epstein, 2010). Overall, the proposition of dual-process perspectives to investigate intuitive processing is that improving the understanding of the operating principles of System 1 processing leads to a better understanding of intuition. Notably, researchers propose that the two modes of information processing are served by different cognitive systems that recruit distinct neural substrates (Hodkinson et al., 2008). In support of this assumption, the studies presented in section 4.2 of this paper indicated increased activation in distinct neural networks that correspond to two distinct information processing systems (Liberman, 2007; Kuo et al., 2009). Arguably, dual-process theories, therefore, serve as an advantageous proposition to corner in on the neural correlates of intuition and further the understanding of intuition.

Although the distinction of two systems by dual-process theories is supported by extensive empirical research (Yonelinas, 1994; Smith & DeCoster, 1999; Stanovich & West, 2000; Lieberman et al., 2004; Lieberman, 2007), several issues have yet to be resolved. Serious doubt has been raised about the integrity of the proposed information processing systems and the localization of intuition as a System 1 process (Glöckner & Witteman, 2010). “[E]vidence suggests that generic dual-system theory [are] currently oversimplified and misleading” (Evans, 2008). Therefore, emerging conceptual developments in dual-process theories feature multi-system approaches that suggest each system consists of many subsystems. For instance, the existence of a single homogenous System 2 that does deductive reasoning, planning, sequential decision making, explicit learning, and an abundance of other cognitive functions is debatable (Evans, 2010). It remains questionable to assume the integrity of such a system on a neurocognitive level. Just as System 2 may comprise a multitude of abilities, there may also be several System 1 functions, such as visualization, imagination, intuitive judgment, implicit learning, implicit social cognition, and many more (Evans, 2009; Gore & Sadler-Smith, 2011). Thus, investigations that merely compare System 1 to System 2 processing or experiments that equate System 1 to intuition might rely on a simplistic conceptual foundation. There is even preliminary neuroscientific evidence against the basic assumptions of distinct systems of information processing put forth by the dual-process approaches (e.g., Mega et al., 2015). In examining deliberate and intuitive judgments concerning the authenticity of facial expressions via functional magnetic resonance imaging (fMRI), Mega and colleagues (2015) found that both types of decisions recruited the same neuronal networks. Hence, the proposition that a distinct neural network serves the intuition-like system could be misguided. As such, the studies of section 4.1 can be seen as capturing instances of intuitive functioning, which need not reflect only intuitive processing nor assert support for dual-process models in the applied form. Perhaps investigating intuition (and non-conscious information processing) may necessitate a more sophisticated perspective than the one provided by generic dual-process models (Glöckner & Witteman, 2010). Either improved dual-process theories, which have yet to produce meaningful results in the study of intuition or conceptual frameworks specific to intuition could fit the bill.

3.3.2 Disaggregating Intuition

Intuition researchers can offer more sophisticated perspectives. Conceptual frameworks specific to intuition have favored partitioning intuition into different types of processes and outcomes. In some form, the decomposition of intuition echoes the multi-system approach emerging within the development of dual-process models (Gore & Sadler-Smith, 2011). As one starts to look deeper into the phenomenon of intuition, it becomes clear that more useful distinctions within the concept of intuition are necessary to account for the multi-faceted nature of intuition. Accordingly, the question is whether intuition is a homogenous phenomenon or rather a label for different cognitive processes. The most comprehensive approaches to map the multiple facets of intuition are introduced in the following.

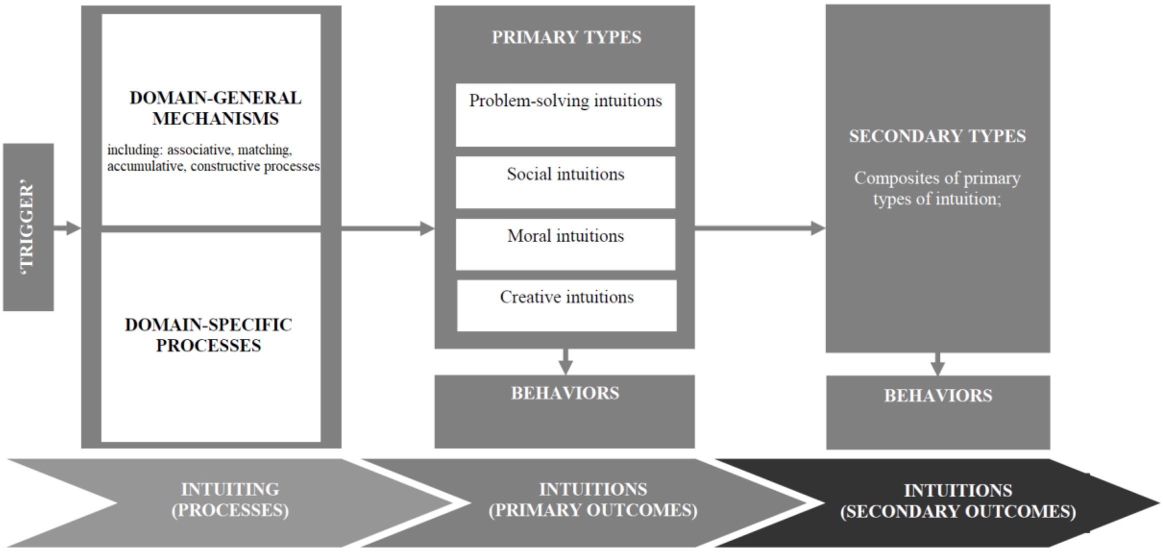
The idea that intuition represents a heterogenous phenomenon is nothing new, and many papers offer various decompositions of intuition (Dane & Pratt, 2009; Sadler-Smith, 2008; Glöckner & Witteman, 2010; Sinclair, 2010; 2011). Dane and Pratt (2007) realized that further useful distinctions are to be made within the concept of intuition, following their definition of intuition in terms of its processes and outcomes. Dane and Pratt noted that intuitions could serve at least three different functions in corresponding domains, namely “as a vehicle for problem-solving, as an input to making moral decisions, and as an instrument facilitating creativity” (Dane & Pratt, 2009). They conceptualized intuitions within ‘types’ according to domains of application. The different types of intuition, namely, problem-solving, moral, and creative intuition, are suggested to differ regarding the nature of their properties (i.e., holistic associations, affect, and speed). For example, the main difference between problem-solving and moral intuitions is that moral intuitions are assumed to involve more intense emotions, i.e., emotions with higher arousal levels (Dane & Pratt, 2009). On the other hand, creative intuitions may be characterized as slower because they might include a short incubation period, e.g., before generating a new idea (Dane & Pratt, 2009).

Focusing on intuitive processing instead, Glöckner and Witteman (2010) proposed four different mechanisms of intuitive processing: associative intuiting, matching intuiting, accumulative intuiting, and constructive intuiting. According to these authors, the different mechanisms can be distinguished according to their operating principles (see Glöckner & Witteman, 2010). The first two categories of mechanisms revolve around processes of learning and retrieval. Associative intuiting mainly deals with simple stimulus-response processes, such as classical conditioning or social learning. Matching intuitive processing involves learning exemplars, prototypes, images, and mental schemas, whereby retrieval processes compare (‘match’) the stimuli to the learned representations. The latter two categories revolve around integrating currently perceived information and information from memory. Accumulative intuiting deals with the accumulation of ‘evidence’ from both currently perceived information and memory until crossing a certain threshold to evoke intuitions. Constructive intuiting involves processing perceived and related information to construct consistent mental representations that compose corresponding intuitive judgments. It is important to note that the proposed mechanisms of intuitive processing show some overlap and are not entirely distinct (Glöckner & Witteman, 2010). Nevertheless, Glöckner and Witteman suggested that these different categories present a useful distinction and represent differences in the underlying processing. For example, associative, matching, and accumulative intuitive processes are conceived to result only in affective output (i.e., feeling), whereas constructive intuition may result in affective and cognitive output (e.g., idea).

Ultimately, the main rationale behind partitioning the concept of intuition is to account for the various facets of the phenomenon when developing an overarching framework in the study of intuition. Recognizing that the concept “intuition” may represent many different intuitive processes and outcomes allows existing and future research to account for the multi-faceted nature of intuition. Thereby the study may adopt more systematic approaches that allow for more fruitful investigations into the nature of intuitive thought. Thus far, researchers conceptualized different forms of intuition in terms of either intuitive outcomes or processes. Building on some of the presented research, Gore and Sadler-Smith (2011) proposed a more comprehensive conceptual framework that connects intuiting and intuitions (see Figure 1). They offered to subdivide intuitive processing on a conceptual level by discriminating between domain-general mechanisms and domain-specific processes. At the same time, intuitions can be partitioned into different primary and secondary types. The conceptualization of different mechanisms concerning intuitive processing will be introduced first, and afterward, the conceptualization of different intuitions.

Figure 1

Comprehensive Conceptual Framework Connecting Intuitive Processes and Outcomes



Note. A comprehensive conceptual framework presenting the disaggregation of intuition according to domain-general mechanisms, domain specific processes, primary and secondary types of intuition. Adapted from "Exploring intuition and its role in managerial decision making" by E. Dane. & M.G. Pratt, (2007) *Academy of management review*, *32*(1), 33-54. Copyright 2011 by the authors

Gore and Sadler-Smith (2011) subdivided intuitive processing into domain-general mechanisms and domain-specific processes. Domain-general mechanisms revolve around fundamental aspects of human cognition, which operate across domains and phenomena, e.g., heuristics. Hence, they are not specific to intuitive processing. Domain-general mechanisms are evoked automatically based on specific cues of the eliciting task that trigger intuitive information processing. For example, two domain-general mechanisms involved in intuiting would be 1) giving rise to rapid judgments and 2) providing affective 'data' upon encountering a trigger for non-deliberative, intuitive processing. Another proposed domain-general mechanism of intuitive processing is building complex domain-relevant mental representations via learning. The four mechanisms of intuiting proposed by Glöckner and Witteman (2010) are suggested to be domain-general (see Figure 1).

On the other hand, domain-specific processes are those that are activated autonomously within specific domains. According to Gore and Sadler-Smith (2011), domain-specific processes translate into different (primary) types of intuition. For example, intuitive processing in the domain of problem-solving involves the activation of learned patterns and schemas connected to solving a problem. In contrast, intuitive processing in the domain of moral judgments involves activating prototypes of ethical situations to respond to an ethical dilemma. They expanded Dane and Pratt's (2009) types of problem-solving, moral, and creative intuitions by the domain of social judgment (e.g., Lieberman, 2000). Composite forms of intuition are possible, and to distinguish them, Gore and Sadler-Smith (2011) termed them “secondary types.” An example of a secondary type of intuition is “entrepreneurial intuition,” proposed by Sadler-Smith et al. (2008). Entrepreneurial intuition is a composite form of intuition to the extent that it draws on all primary types. Problem-solving intuitions serve to judge the viability of business venturing propositions, moral intuitions help decide whether to invest in a deal involving ethical components, social intuitions support the decisions with whom to transact, and creative intuitions serve the generation of new ideas (Gore & Sadler-Smith, 2011). Accordingly, different secondary types are suggested to manifest in applied areas like education, healthcare, and law.

However, the usefulness of these conceptual approaches remains to be explored in detail and further examined on a practical level. The authors admit that it may be necessary to collapse or expand some of the proposed elements if the distinctions do not hold (Dane & Pratt, 2009; Glöckner & Witteman, 2010; Gore & Sadler-Smith, 2011). A detailed examination is beyond the scope of this paper, yet in light of the neuroscientific findings presented, later on, a rough sketch of its usefulness is discussed in section 5. As of yet, it remains unclear whether intuition is better conceptualized as a homogenous or heterogeneous phenomenon. Accordingly, the question is left unanswered whether intuition is a unitary construct or a mere label used for different cognitive mechanisms.

3.3.3 Intuition in the Context of Discovery

This section introduces a different approach altogether. Rather than approaching intuition by its distinction from deliberation or by subdividing the concept of intuition, a specific instance of intuitive decision-making is brought to attention. Bowers et al. (1990) conceptualized intuitions as implicitly informed judgments of coherence in the context of perceptual discovery. This proposition will be explained first. In the later part of this section, Bowers and colleagues’ conceptualization of intuitive processing as a gradual process occurring within two stages is introduced next.

Bowers et al. (1990) noted that people could recognize patterns and meaningful content in the stream of sensations they experience without conscious attention and given only a few aspects of the input. Therefore, Bowers et al. (1990) derived that people can implicitly detect meaningful content by subliminally perceiving coherence when encountering complex stimuli. They assumed that implicit perceptions of coherence could guide subsequent thought, inquiry, or behavior in the form of a hunch or hypothesis.

For example, upon examining a fragmented picture (Figure 2), people can successfully discriminate whether it represents a real object, that is, above chance level (e.g., Bowers et al., 1990; Volz & von Cramon, 2006; Topolinski & Strack, 2009). When examining the figure more closely, often an experience of a vague impression, which is not explicitly describable but instead embodied in a "gut feeling," an initial guess or a hunch precedes the recognition (Volz & von Cramon, 2006). When individuals have time, they can test various hunches until consciously recognizing that the picture is an abstract depiction of a camel. However, individuals must engage in fast information processing under time pressure and can only rely on implicit hunches whether a real object is depicted. The fast decision of whether an abstract depiction represents a real object based on an implicit, preliminary perception of coherence can be viewed as intuitive. In other words, fast, non-conscious, and holistic associations give rise to affectively charged judgments of coherence that can guide further inquiry towards a perceptual discovery (in line with Dane & Pratt, 2007). Thus, in the context of discovery, Bowers et al. (1990) defined intuitions as "preliminary perception of coherence (pattern, meaning, structure) that is at first not consciously represented which comes to guide our thoughts toward a 'hunch'." This conceptualization of intuition enabled investigating intuition "in its most simple form" (Volz & von Cramon, 2006), namely as implicitly informed judgments of coherence.

Figure 2

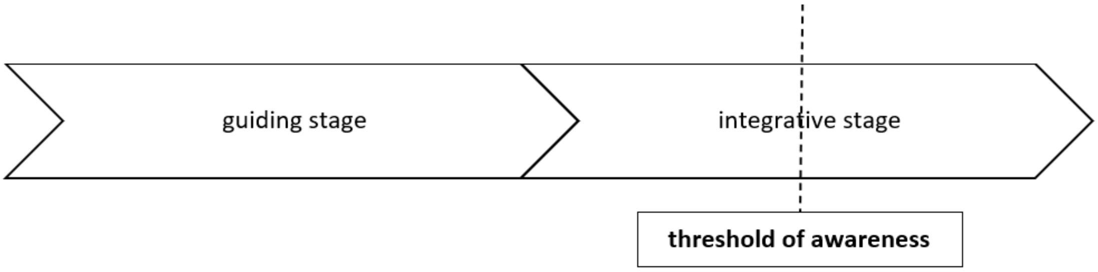
Fragmented Depiction

Note. Example of a Waterloo Gestalt Closure Stimuli (WGCT) item representing a camel. *From* "Intuition in the context of discovery." by K. S. Bowers. G. Regehr. C. Balthazard & K. Parker (1990). *Cognitive psychology*, *22*(1), 72-110. Copyright 1990 by Academic Press, Inc.

Additionally, Bowers et al. (1990) proposed conceptualizing intuitive processing within two stages (see Figure 3). In the first stage, an intuitive feeling about the coherence in question arises, termed the *guiding stage*. In the second stage, the *integrative stage*, ongoing processing converges on a plausible representation of the implicitly perceived coherence and potentially enters consciousness.

Figure 3

Two-Stage Model of Intuitive Processing



Note. A graphic representation of Bowers et al. (1990) two-stage model. In the guiding stage, an intuitive feeling arises. A plausible representation of the implicitly perceived coherence enters consciousness in the integrative stage. The integrative stage represents the processing whereby an implicit perception of coherence enters consciousness. Therefore, the threshold of awareness would be located in the integrative stage.

More specifically, in the guiding stage, relevant mnemonic networks are activated in the process of spreading activation by clues that reflect (and ultimately reveal) coherence (Bowers et al., 1990). Then, in a “graded and cumulative fashion” (Bowers et al., 1990), increasing activation in relevant mnemonic networks produces an implicit perception of coherence that is not yet verbalizable and manifests in the form of a preliminary and intuitive feeling about the coherence in question. Once sufficient activation has accumulated to cross a threshold of awareness, the implicit perception of coherence is represented in consciousness as a hunch or hypothesis. The processing by which the threshold is crossed represents the integrative stage of intuitive processing (Bowers et al., 1990; Zander et al., 2016a). As preliminary impressions of coherence gradually build over time towards a more explicit hunch or hypothesis, this is considered the continuity model of intuitive processing. Whether this model also reflects on a neural level is investigated in section 4.2.1.

In the following, these conceptual approaches are put into practice to investigate intuition.

4. Neuroscience of Intuition

In the more recent past, the field of cognitive neuroscience began to uncover the neural substrates underpinning intuition in various contexts across a range of paradigms (Lieberman et al., 2004; Kuo et al., 2009; Volz & von Cramon, 2006; 2008; Zander et al., 2016a). Illuminating intuition’s inner workings through neuroscience may improve the understanding of the underlying processes, their relation to similar or connected phenomena, and how intuition is better conceptualized. In the experimental study, intuition is primarily viewed as a viable explanatory construct in the study of decision-making. Multiple lines of evidence suggest that in experimental settings, intuitive decisions can be forced by manipulating time pressure and task difficulty (e.g., complexity) (e.g., Bowers et al. 1990; Volz & von

Cramon, 2006; Kuo et al., 2009; Zander et al., 2016a). To no surprise, all presented studies investigating the neural substrates underpinning intuition integrate some form of decision-making paradigm with participants performing complex tasks under time pressure. The selected neuroscientific literature on intuition contains two main lines of research, namely studies examining intuition in the context of perceptual discovery and studies that investigate intuition from the perspective of dual-process models. Thus far, the frameworks that partition intuition have mostly been used to analyze existing research, to categorize intuition post-study to specify and organize different lines of empirical research. The discussion of intuition-specific frameworks is reserved for section 5. Here, the neuroscientific study of intuition revolving around dual processing is presented first, and afterward, insights into intuition within the context of discovery are presented.

4.1 Intuition and Dual Processing

Since studying nonconscious cognition is complex dual-process theories serve as a helpful starting point to investigate intuition. Within the framework of dual processing, intuition is either recognized as a subsystem of System 1 (see section 4.1.1), or intuition is taken to pervade System 1 processing, whereby intuitive processing is generally equated with System 1 processing (see section 4.1.2). For the scope of this paper, the neural correlates of intuitive processing are singled out in the upcoming sections.

4.1.1 Intuitive Self-Knowledge

Social cognitive neuroscience provides a potential testbed to investigate intuition in the domain of self-knowledge. Empirical research in social cognition by Lieberman et al. (2004) has suggested the existence of at least two self-knowledge systems, namely evidence-based and intuition-based self-knowledge. Previous research in social cognition concerned with self-knowledge revolved around autobiographical memory, referred to as evidence-based self-knowledge. Lieberman et al. (2004) investigated the existence of another self-knowledge system that leads to intuition-based self-knowledge. From a phenomenological perspective existence of this dual system of self-knowledge seems evident. For example, asking a tennis novice whether he thinks he is good at tennis most probably gets him thinking about the few instances he played tennis. He might conclude based on explicit autobiographical memory that he is not too good a player. This is an example of evidence-based self-knowledge. However, when asking an expert tennis player the same question, it proves unlikely that she would retrieve memories of specific tennis-playing instances to evaluate her abilities. Instead, self-knowledge judgments in high-experience domains are expected to be based on a lot of accumulated experience, without a necessity for explicit retrieval and evaluation of autobiographical evidence. The latter is an example of intuition-based self-knowledge.

In previous research, Lieberman and colleagues described a “neurocognitive system called the C-system (for the C in reflective) that is involved in effortful and intentional social cognition” (Lieberman et al., 2002). Social cognitive neuroscience provides a promising testbed for studies of intuition because Lieberman et al. (2004) managed to demonstrate a corresponding neurocognitive system they called X-system (as in reflexive), which is involved in automatic social cognition and could reflect intuitive processing in the self-knowledge domain. The intuitive X-system and the analytic C-system represent the typical dual-process dichotomy in social cognition.

Lieberman et al. (2004) designed an experiment where participants with high and low experience in different domains of self-knowledge (soccer and acting) made self-descriptiveness judgments according to various attributes (description words). One group of professional soccer players and one group of improvisational actors had to execute these self-description judgments in 3s time while their brain activity was recorded via functional magnetic resonance imaging (fMRI). Much like in the inexperienced-tennis-player example, Lieberman et al. (2004) hypothesized that individuals within their low experience domain would deploy effortful and intentional social cognition, corresponding to instances of evidence-based self-knowledge. Relying on evidence-based self-knowledge was taken to reflect increased activation within C-system structures. In turn, individuals within their high experience domain would deploy automatic social cognition, like the expert tennis player in the example. Intuition-based self-knowledge judgments, based on accumulated experience, were taken to reflect intuitive processing corresponding to increased activation within X-system structures.

Indeed, results showed that different neural networks were active when participants made self-description judgments within their high-experience and low-experience domains (Lieberman et al., 2004). The imaging data indicated the existence of two distinct neurocognitive systems that each recruit brain regions independently of each other. When a network of brain regions is not significantly activated or significantly deactivated by another, they are recruited independently, as was the case in the experiment (Lieberman et al., 2004). The X-system structures for intuition-based self-knowledge judgments comprised the nucleus accumbens in the basal ganglia, the lateral temporal cortex, the amygdala, and the ventromedial prefrontal cortex (VMPC). Lieberman et al. (2004) suggested more specific inferences about the nature of the intuitive-based self-knowledge system based on what is known about the functions of the involved structures. Activation within the VMPC, the nucleus accumbens, and the amygdala is correlated with affective and motivational processing, supporting the X-system's assumption that affective information is processed. Furthermore, the self-description judgments within a high experience domain should involve long-term generalizations that intuition-based, automatic social cognition capitalizes on. Lieberman et al. (2004) suggested that some of the X-system’s structures are slow to form, slow to change, and relatively insensitive to new data. Structures of the X-system, such as the amygdala, are implicated in developing representations slowly on the basis of statistical generalizations of the world (Lieberman, 2000; Lieberman et al., 2002). Respectively, In the case of statistical generalizations, a new piece of data only adds incrementally to the overall representation, which evokes more minor changes the more extensive the sample. In conclusion, Lieberman et al. (2004) suggested that "intuition-based self-knowledge is (a) affective, (b) slow to form, (c) slow to change, (d) relatively insensitive to one's thoughts about oneself and behavior, and (e) relatively insensitive to explicit feedback from others" (Lieberman et al., 2004). Another hint that X-system processing might involve intuitive processing is that the reaction times of self-description judgments in the high-experience domain were significantly lower than in the low-experience domain. Additionally, according to the participant's self-reports, the intuition-based self-descriptions coincided with a feeling of knowing (Lieberman et al., 2004).

Overall, the processing of intuition-based self-knowledge shares intuition's speed and non-conscious processing, and self-knowledge judgments in the high experience domains appeared to be accompanied by affect. What's more, the underlying processing tapped into deep knowledge structures necessary to execute accurate self-description, which parallels intuition's link to experience. Little is known how the relevant information is gleaned, but holistic associations are likely to fit the bill. Intuition-based self-knowledge judgments may indeed reflect intuitive processing in the domain of self-knowledge. Therefore, this experimental paradigm could serve as a good testbed for studying intuition in the context of self-knowledge.

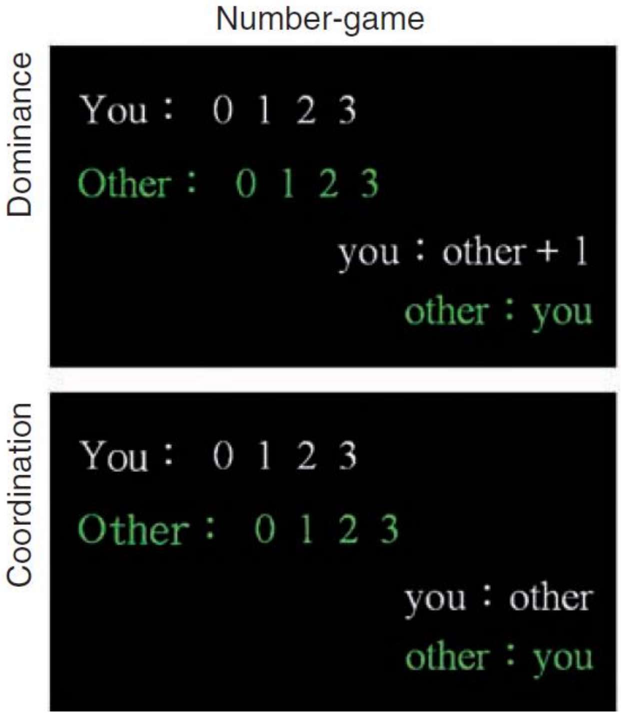
4.1.2 Intuition and Coordination Games

Another experimental paradigm that relied on a simplified version of dual-process models to investigate the neural correlates of intuitive processing was put forth by Kuo et al. (2009). Their study conceived intuition as fast and emotional processing, whereas reasoning represented slow and controlled processing within the task's context. The paradigm featured two different kinds of games (number- and box-games) that could be played in different fashions, namely as dominance-solvable games or pure coordination games. In a nutshell, dominance-solvable games had to be solved with step-by-step deliberative reasoning. Pure coordination games had to be solved intuitively because calculating which action to choose is impossible by design. The number game will be presented in both formats to explain the experiment, namely as dominance-solvable and as pure coordination game.

The dominance-solvable number game is illustrated at the top of Figure 4, and the respective pure coordination number game is shown below. In each game, two players, ‘you’ (white) and ‘other’ (green), must simultaneously pick a number from 0 to 3 without communicating. Each player’s objective is to be as close to a ‘target number’ inferred from the bottom-right corner of the screen. Whoever hits their target number gets a reward. The instruction ‘you: other’ means that the target of green is to match white’s choice. The instruction ‘you: other+1’ means that white’s target is green’s choice plus 1. For example, if white chooses 1 and green chooses 0, only white would get a reward. It is essential to follow the rules of reason in a dominance-solvable game to play successfully. In the presented situation, white’s target has to be at least 1 because choosing 0 would fail either way. In other words, for white, choosing 0 is dominated by choosing 1 and should consequently be eliminated. Accordingly, green can infer that white would never pick 0. Therefore 0 is also dominated for green and should be eliminated as an option because green’s target is to match white’s choice. Respectively, by logical inference, both players eliminate number 1 too, because according to the initial logic, white would not pick 1 as it aims to hit the target ‘other+1’. According to this line of reason, both players end up in the formal game-theoretic solution: each player chooses 3 (Kuo et al., 2009). This step-for-step solution through reasoning is inevitable for dominance-solvable games. To obtain a pure coordination game, each player's ‘target number’ becomes the other player’s choice. In this form of the game, there is no advantage of choosing one number over another, and there is no logical solution that could be inferred.

Figure 4

Example of a Number-Game



Note. Sample screens from the experiment of a number-game. Condition in the top is a dominance solvable game in the bottom a coordination game. Targets of both players are shown in the lower right corner of each screen. Adapted from “Intuition and deliberation: two systems for strategizing in the brain” by W. J. Kuo. T. Sjöström. Y. P. Wang & C. Y. Huang. (2009) *Science*, *324*(5926), 519-522. Copyright 2009 by the American Association for the Advancement of Science.

Now, Kuo et al. (2009) posited that solving the different games recruits different cognitive and neural substrates involved in information processing. Decisions in dominance-solvable games, where participants decide through reasoning, are taken to reflect deliberate processing. In pure coordination games, where participants decide intuitively by simply choosing a number that “feels” right, were taken to reflect intuitive processing. The different strategies were taken to reflect on a neural level. While participants were engaged with the games, their brain activity was recorded via fMRI.

The results showed that participants decided significantly faster when playing coordination games than playing dominance-solvable games, which the authors took to imply ‘intuitive’ processing (Kuo et al., 2009). The fMRI data indicated the insula and the anterior cingulate cortex (ACC) to be more active while participants made decisions in coordination games as opposed to dominance-solvable games. In previous research, the insula has been implicated in interoception, comprising pre-reflective and reflective representations of ongoing changes in internal bodily and feeling states (Craig, 2008). The ACC was suggested to act as a conflict monitor when tasks require attention, require novel or open-ended responses, or when cognitive uncertainty exists (MacDonald et al., 2000). Both areas were implicated in many paradigms with strong social content or emotions, such as when participants contemplate on cooperating instead of competing with another person (Decety et al., 2004) or when they judge other persons to be trustworthy instead of being untrustworthy (Winston et al., 2002). On this basis, Kuo et al. (2009) suggest that the insula and ACC might be part of a more general network contributing to a quick and flexible evaluation of complex multidimensional experiences. To what extent these findings are relevant to a more rigorous conceptualization of intuition remains to be explored. It remains an open question to what extend Kuo et al. (2009) managed to capture intuition in their study. Yet, under time pressure, decision-making in pure coordination games could serve as a viable experimental paradigm to study intuitive decision-making comprising a composite of problem-solving, social, and perhaps even moral intuition.

4.2 Intuitive Decision-Making in the Context of Discovery

As previously presented, Bowers and colleagues conceptualized intuitions as “preliminary perception of coherence (pattern, meaning, structure) that is at first not consciously represented which comes to guide our thoughts toward a ‘hunch’” (Bowers et al., 1990) and intuitive processing as occurring gradually within two stages. Various researchers followed suit and examined intuition according to this conceptualization. With modern neuroscientific imaging methods, researchers were able to investigate the neural correlates of intuitive judgments concerning an initial perception of coherence and thereby elucidate fundamental questions concerning intuition's inner workings. In the following neuroscientific data revolving around three questions is laid out. In section 4.2.1, the assumption that the gradual, continuous nature of intuitive processing reflects on a neural level is examined. Afterward, a first advance into the relation of implicit memory processes and intuition is presented in section 4.2.2. Finally, the neural correlates of intuitive decision-making in the context of discovery are aggregated in section 4.2.3.

4.2.1 Intuiting as a gradual, continuous process

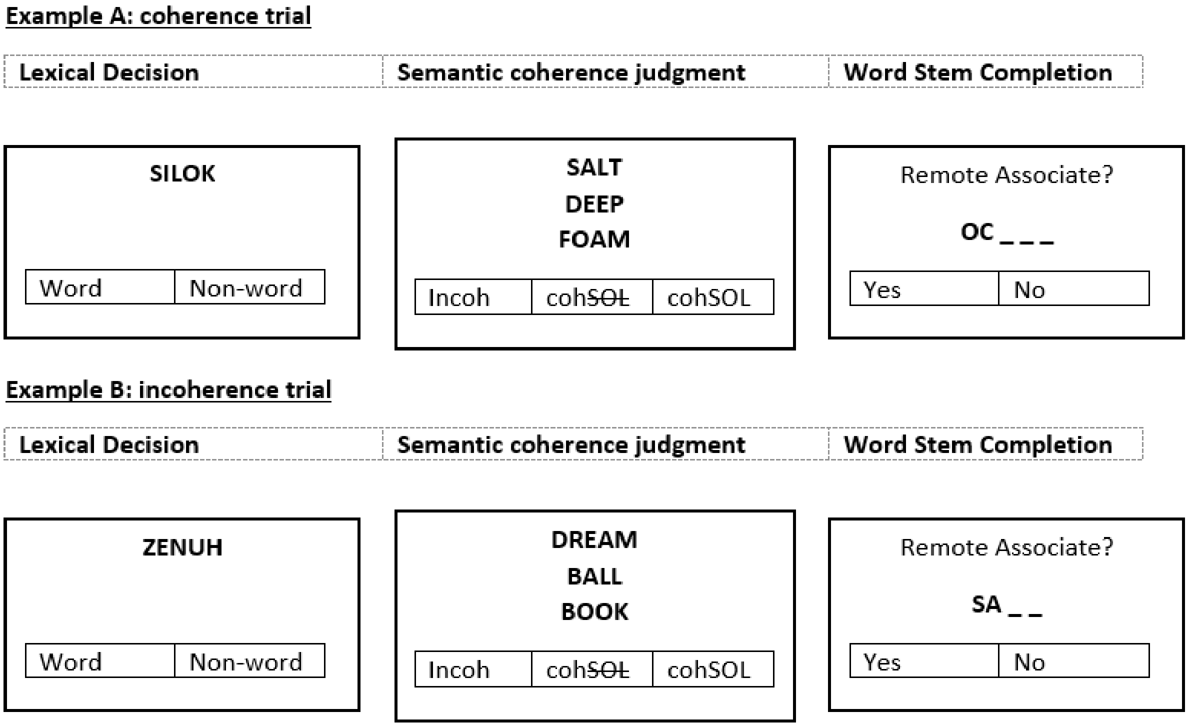
The two-stage model of intuitive processing (see Figure 3) conceptualizes intuiting as unfolding gradually across two stages. Intuitive processing in the guiding stage involves forming implicit perceptions of coherence that are not yet verbalizable. In the integrative stage, these impressions cross over a threshold of awareness and become conscious. Zander et al. (2016a) examined whether forming intuitive judgments of coherence unfolds gradually using word triad tasks and functional magnetic resonance imaging (fMRI).

In word triad tasks, participants are asked to judge whether presented word triads are coherent or incoherent. In coherent triads, the semantic relations of the three clue words converge on a fourth common associate, whereby the word triad is coherent in meaning. In incoherent word triads, the semantic relations of the clue words do not converge and are not coherent. For example, triad A "playing, credit, report" is coherent with the common associate "card," while triad B "still, pages, music" is not. In the initial study by Bowers et al. (1990), participants performing a word triad task could intuitively discriminate coherent triads from incoherent ones. That is, they could successfully discriminate coherent word triads in a matter of seconds, based on a hunch, and without explicit knowledge of the common associate. In Zander et al. (2016a) experiment, participants had to perform a modified version of the word triad task. In addition to judging if triads were coherent or incoherent, participants had to indicate whether they immediately knew the common associate or not (see semantic coherence judgment in Figure 5). Thus, the design of the experiment would allow comparing the neural correlates linked to successful implicit judgments of semantic coherence where the solution was not consciously available [situation A] to intuitive judgments of coherence that were explicitly "justified" in the form of a solution (knowing correct common associate [situation B]). Roughly, situation A, where the solution remained implicit, was taken to reflect early intuitive processing in the guiding stage, whereas situation B, being aware of the solution, was taken to reflect processing in the integrative stage. Thereby, the (dis)continuous unfolding of intuitive processes could be examined. Evidence would support a continuity model if brain activity in situation A would merely differ quantitatively from brain activity in situation B. In contrast, a genuine discontinuity could be assumed if brain activity patterns differed qualitatively.

The design of the fMRI experiment (see Figure 5) had participants perform three different tasks in each trial: First, a lexical decision task where participants had to decide whether a displayed word was a real word or a non-word. Second, a semantic coherence judgment, where they could indicate a triad to be either (a) incoherent, (b) coherent without knowing the common associate, or (c) coherent with indicating knowledge of the common associate, and third, a word stem completion to test whether participants did know the common associate.

Figure 5

Zander et al.'s (2016a) Research Design: Examples of Coherence and Incoherence Trials

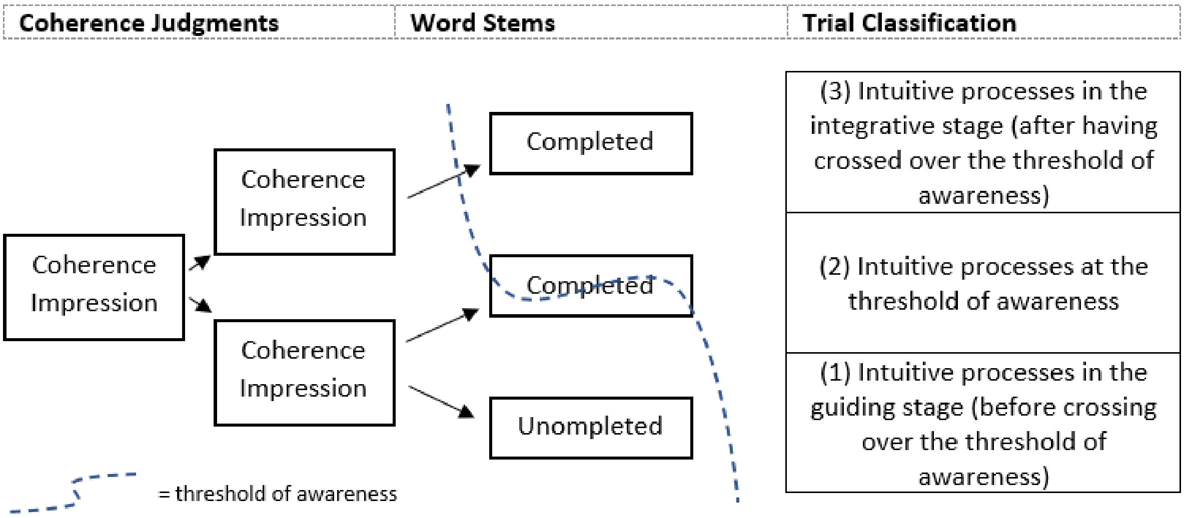


Note. Participants have to perform a lexical decision task first, then a semantic coherence judgment and finally a word stem completion. In the semantic coherence judgment participants have three response options: "Incoh" = triad is judged as incoherent; "coh~~SOL~~" = triad is judged as coherent without immediate knowledge of a common associate; "cohSOL" = triad is judged as coherent with immediate knowledge of the common associate. Example A – coherence trial: preceding lexical decision task (judge either word or nonword), semantic coherence judgment, followed by word stem completion with the first two letters of the common associate. Example B – incoherence trial: preceding lexical decision task, incoherent triad, followed by word stem completion of a semantically unrelated word. Adapted from "Intuitive decision making as a gradual process: Investigating semantic intuition-based and priming-based decisions with fMRI" by T. Zander. N. K. Horr. A. Bolte. & K. G. Volz (2016a) *Brain and behavior*, *6*(1), e00420. Copyright 2015 by the authors.

Since intuitions were operationalized as implicitly informed judgments of *coherence*, the study ensured to exclusively investigate processing corresponding to these intuitions by taking only neural correlates into account that corresponded to successful intuitive judgments (i.e., correct coherence judgments). The relevant trials comprising intuitive processing were classified threefold (see Figure 6). As processing within (1) the guiding stage or "intuitive processes below the threshold of awareness" (Zander et al., 2016a), which would correspond to those decisions judging coherence correctly indicating (b) while not being able to complete the common associate's word stem, (2) as "intuitive processes at the threshold of awareness" (Zander et al., 2016a), which would be those trials where participants judged coherence successfully indicating (b) while being able to complete the word stem of the common associate afterward, and (3) as intuitive processes in the integrative stage, when participants judged coherence successfully indicating (c) and being able to complete the word stem of the common associate. A fourth class of trials comprised successful incoherence judgments, which represent incoherent triads that were discriminated successfully and were used as a contrast to intuitive processing.

Figure 6

Classification of Relevant Trials Concerning Intuitive Judgments of Coherence

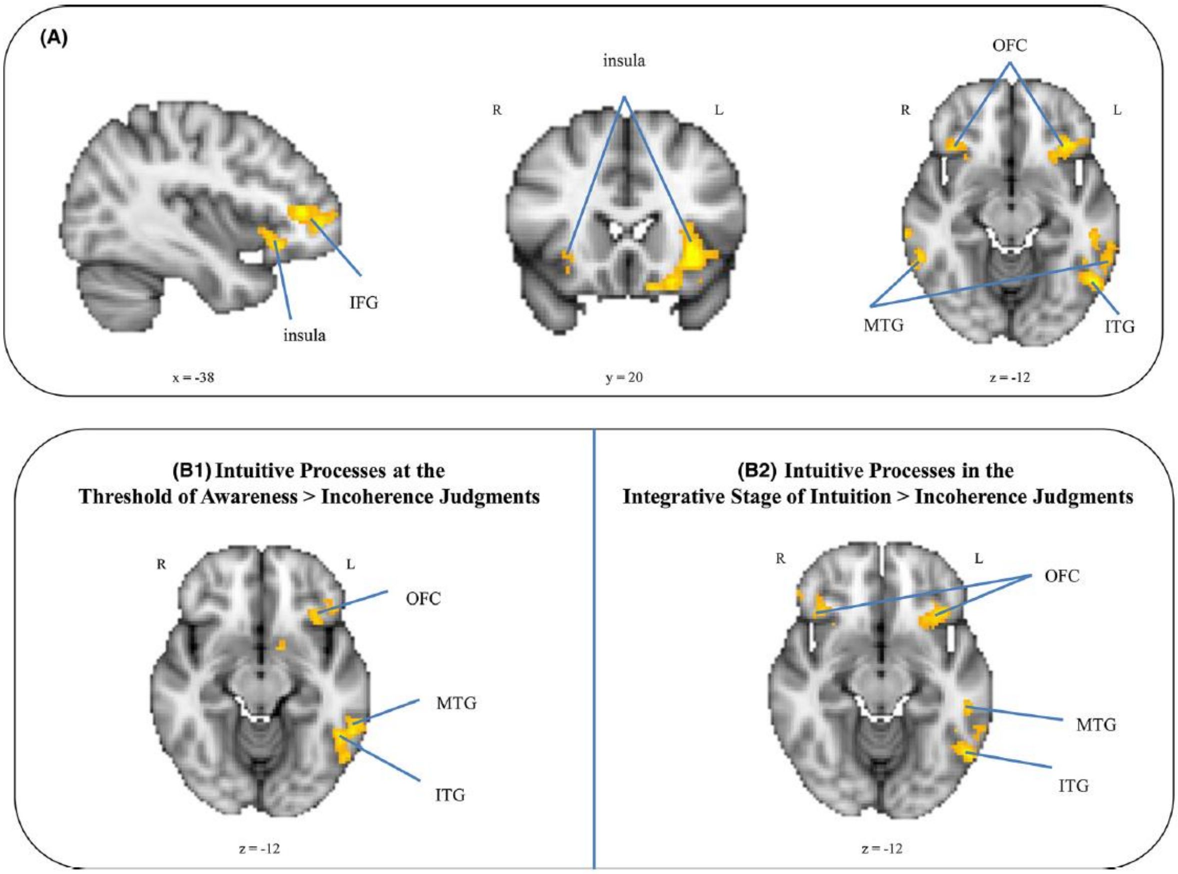


Note. The three relevant classifications of trials comprising successful intuitive judgments of semantic coherence. (1) Intuitive processes in the guiding stage: word triad is judged as coherent, but the common associate cannot be retrieved yet. (2) intuitive processes at the threshold of awareness: word triad is judged as coherent, but the common associate cannot be retrieved yet, but later in the word stem completion. (3) intuitive processes in the integrative stage: word triad is judged as coherent and common associate can be retrieved immediately and leads to successful word stem completion. Adapted from "Intuitive decision making as a gradual process: Investigating semantic intuition-based and priming-based decisions with fMRI" by T. Zander. N. K. Horr. A. Bolte. & K. G. Volz (2016a) *Brain and behavior*, *6*(1), e00420. Copyright 2015 by the authors.

To examine whether the neural activity builds quantitatively or qualitatively when forming intuitive judgments of coherence, the neural correlates corresponding to the three classifications of intuitive judgments were contrasted together and individually with the neural correlates of successful incoherence judgments. In contrasting all intuitive judgments of coherence with implicit judgments of incoherence, the results revealed "bilateral activation within the posterior OFC, within the insula, within the left IFG extending into the frontal pole, and within the left posterior part of the MTG. The temporo-occipital part of the left inferior temporal gyrus (ITG) and the anterior median prefrontal cortex (mPFC) were activated as well" (Zander et al., 2016a). This neural network is depicted in the upper part of Figure 7-A. Through the statistical analysis, Zander et al. (2016a) found that activation increased gradually within this network (see parametric contrast applied by Zander et al., 2016a). Specifically, the statistical model indicated the activated network to increase "quantitatively from instances of perceived incoherence to instances of perceived coherence." (Zander et al., 2016a). Furthermore, the contrast of the neural correlates of intuitive processes at the threshold of awareness (2) with those of incoherence judgments revealed a left-sided network of activation within the orbitofrontal cortex (OFC), the inferior frontal gyrus (IFG), the insula, the middle temporal gyrus (MTG) and the inferior temporal gyrus (ITG) (Figure 7-B1). When lowering the statistical threshold, the same left-sided network was found for the contrast between processing in the guiding stage of intuition (1) and in incoherence judgments. Notably, the contrast of neural activity corresponding to intuitive processes in the integrative stage (3) with incoherence judgments indicated that this left-sided network would have expanded to the right side, revealing bilateral activation within the IFG, the insula and the OFC (Figure 7-B2).

Figure 7

Imaging Results of Zander et al. (2016a)



(B1) Intuitive Processes at the Threshold of Awareness > Incoherence Judgments

(B2) Intuitive Processes in the Integrative Stage of Intuition > Incoherence Judgments

Note. (A) Contrast: Intutive Processes > Non-intuituive Processes. (B1) Contrast: Intuitive Processes at the Threshold of Awareness > Incoherence Judgments. (B2) Contrast: Intuitive Processes in the Integrative Stage of Intuition > Incoherence Judgments. OFC = orbito-frontal cortex, ITG = inferior temporal gyrus, IFG = inferior frontal gyrus, MTG = middle temporal gyrus. From "Intuitive decision making as a gradual process: Investigating semantic intuition-based and priming-based decisions with fMRI" by T. Zander. N. K. Horr. A. Bolte. & K. G. Volz (2016a) *Brain and behavior*, *6*(1), e00420. Copyright 2015 by the authors.

Support for the continuity model of intuitive processing was found by the indicated expansion of activation from the left-sided network, implicated in the guiding stage (1) and at the threshold of awareness (2), into the right OFC and right IFG in the integrative stage (3). The statistical analysis indicated the gradual increase of activation in the presented neural network from instances of incoherence judgments to instances of coherence judgments in different stages. As such, the imaging results “support the conceptualization of a continuity model of intuitive judgments” (Zander et al., 2016a).

On a final note, it is important to mention that controversy remains about the classifications of intuitive judgments of coherence mapped onto the two-stage model as interpreted by Zander et al. (2016a). Other researchers view intuitive judgments of coherence at the threshold of awareness (2) as already indicative of the integrative stage (e.g., Topolinski & Strack, 2009). Typical for the integrative stage, they already comprise a plausible representation of the implicitly perceived coherence that can be noticed consciously yet remains nonverbal. Explicitly solved trials (3) are excluded by other researchers studying intuition because they coincide with conceptualizations of insight (Topolinski & Strack, 2009). Explicitly solved trials may likely involve an insight into the logical, semantic relations of the coherence in question once the solution is accessed consciously, which is an aspect usually contrary to intuitive judgments. Like Zander and colleagues’ (2016a) conceptualization of intuitions in the integrative stage (explicitly solved trials), insights appear clearly to consciousness and consist of a solution, which is verbalizable and explainable. If both phenomena could be investigated within one paradigm, further exploration into the relationship between intuition and insight could be launched. The word triad tasks could present such a paradigm. Yet, instead of explicitly solved triads, perhaps another kind of coherent word triad is necessary to serve as an insight condition (see section 5.). However, intuition’s relation to another phenomenon will be explored first.

4.2.2 Implicit Memory in Priming and Intuition

To investigate the assumption that implicit memory and intuition differ, Zander et al. (2016a) added another element of the previously presented study to examine whether implicit memory, in the case of priming, and intuition, in the case of intuitive judgments of coherence, differ on a neuronal level. Interestingly, the conceptualizations of priming, which is an instance of implicit memory processes, and intuition coincide in various features. Priming is defined as “a change in the ability to identify, produce, or classify an item as a result of a previous encounter with that item or a related item” (Schacter et al., 2004). Both priming and intuition rely on some form of memory, comprise processing outside of conscious awareness, and lead to signals that are strong enough to act upon (Volz & Zander, 2014). Priming presents a suitable test case to examine differences between implicit memory processes and intuition on a neural level.

Priming encompasses the phenomenon whereby the initial encounter with a stimulus can influence the subsequent encounter with a related stimulus (Volz & Zander, 2014). For example, completing the word stem "CHA _ _" is facilitated by previously presenting the word "TABLE"' instead of presenting the word "MOUNTAIN" before. This represents a conceptual priming task. There is no overlap of perceptual information between the primer and the cues presented upon the second encounter in conceptual priming (Volz & Zander, 2014). Conceptual priming effects occur because an initial prime (e.g., table) facilitates the processing of a related solution (e.g., chair). The advantageous processing of priming is often indicated by faster reaction times for primed trials in experiments (Schacter, 2004). In some respects, conceptual priming tasks and word triad tasks resemble each other. In both, participants act on initial, nonconscious perceptions of sematic relations for which they need to access semantic memory (Volz & Zander, 2014). Zander et al. (2016a) proposed to compare conceptual priming to intuitive judgments of semantic coherence at the threshold of awareness because the latter best incorporated "some kind of internal priming processing" (Zander et al., 2016a).

Zander et al. (2016a) suggested that semantic processing concerning the coherence of word triads could be adequately represented by an account of automatic spreading activation (ASA). ASA suggests that neuronal activation elicited by the meanings of the three clue words spreads out automatically across relevant mnemonic networks and either converges on a common concept for coherent triads or diverges if the word triad is incoherent. Therefore, activation elicited by coherent triads would reflect advantageous processing. The converging activation towards a fourth common concept would make participants more susceptible for an implicit detection of coherence by "internally priming the concept, that all the distinct pieces of semantic information have in common" (Zander et al., 2016a). For incoherent triads, the automatic spreading activation was taken to diverge, and thus no advantageous processing would occur. As mentioned before, Zander et al. (2016a) suggested intuitive judgments of semantic coherence at the threshold of awareness (2) to be ideally suited to compare the priming-based and intuition-based decisions. These intuitive decisions best represented the point when the activation of the three clue words of a coherent triad converged on a familiar concept, which was taken to resemble a priming effect. As such, the comparison hinged on two assumptions. First, an account of automatic spreading activation is an adequate representation of the intuitive processing in the experiment. Second, that advantageous processing occurs for coherent triads.

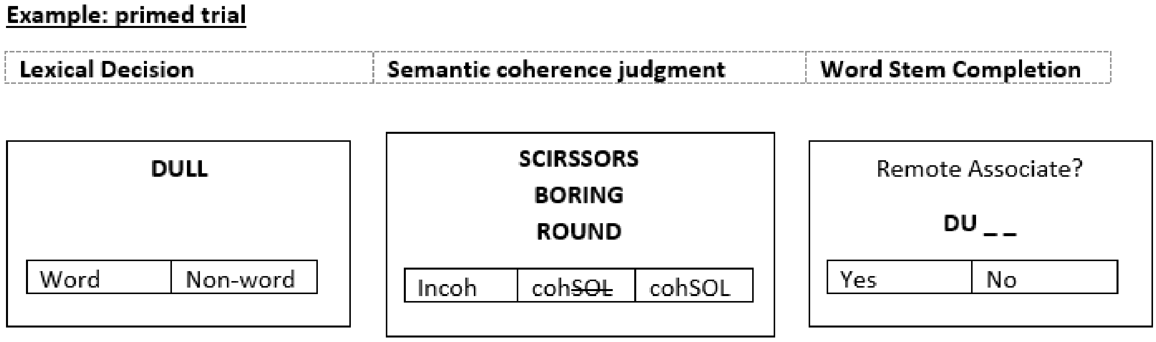
In a pre-study with the same stimulus material used in the actual study, Zander et al. (2016a) tested the assumptions. Participants had to perform a lexical decision task with either a 20ms or 1200ms delay after displaying coherent and incoherent word triads. The coherence trials involved the previous display of coherent triads (e.g., 'salt, deep, foam') followed by common associates (e.g., 'sea'), semantically unrelated words (e.g., 'desk'), or non-words (e.g., 'rabihal') (Zander et al., 2016a).

Incoherent trials involved an incoherent word triad followed by unrelated words or non-words. The resulting reaction times (RT) indicated that participants were significantly faster in successfully discriminating common associates as real words compared to unrelated words in the 20ms condition but not in the 1200ms condition. Interestingly, the results of the pre-study indicated that the advantageous effect of ASA slows down rapidly after stimulus presentation since the 1200 ms condition was coupled with no advantageous processing. At an early point in time, faster, successful discrimination of common associates was taken to reflect the advantageous processing resembling a priming effect. Therefore, ASA was considered to represent an appropriate account for the experiment.

However, besides superficial similarities, conceptual priming and intuitive processes are suggested to differ in the format of the accessed information and the signal accompanying the process (Volz & Zander, 2014). Specifically, participants in primed trials would primarily retrieve the recently activated semantic memories associated with the prime, whereas participants forming intuitive judgments of semantic coherence would have to retrieve and assess semantic relations activated by three clue words following the criterion of coherence. Furthermore, the accompanying signals (i.e., the concomitant, subjective feelings) during conceptual priming decisions were considered to result from the conscious experience of processing “ease.” (Zander et al., 2016a) On the other hand, the affective component of intuitions was suggested to result from the readout process of cue/criterion relationships triggered by the task (Volz & Zander, 2014; Zander et al., 2016a). As such, priming and intuition were suggested to recruit different cognitive processes with respective neural correlates. Therefore, neuroimaging methods were ideally suited to examine neurocognitive differences concerning the underlying processes of intuition- and priming-based decisions. To compare both within one experiment with the same task and participants, a conceptual priming procedure was integrated into the sequence of tasks as an additional condition. Consequently, the study comprised coherent, incoherent (see examples in Figure 5) and primed trials (see example in Figure 8). The primed trials were constructed according to a classical priming procedure whereby the facilitating priming effect occurs upon a second encounter with the primed concept. In primed trials, participants were primed with a concept displayed in the lexical decision task (e.g., ‘dull’), representing a synonym of one of the clue words subsequently presented in the semantic coherence judgment task (e.g., ‘boring’).

Figure 8

The Research Design's Added Dimension: Example of a Primed Trial



Note. Primed trials presented an additional condition in the same study introduced in section 4.2.1. The trial sequence was identical: lexical decision task, semantic coherence judgment, followed by a word stem completion. For primed trials, the words displayed in the lexical decision tasks constituted the prime, which was a synonym of one of the clue words of the subsequent incoherent triad in the semantic coherence judgment. Afterward, the word stem completion presented the first two letters of the initially presented prime. Adapted from "Intuitive decision making as a gradual process: Investigating semantic intuition-based and priming-based decisions with fMRI" by T. Zander. N. K. Horr. A. Bolte. & K. G. Volz (2016a) *Brain and behavior*, *6*(1), e00420. Copyright 2015 by the authors.

To allow for an accurate comparison of the underlying processes, priming- and intuition-based decisions had to be separated by design so that no confounding interaction was possible. To prevent priming effects from influencing the recognition of a potential common associate, primed trials comprised exclusively incoherent triads. Primers had to be synonyms of only clue words from incoherent word triads that were not semantically related to any potential common associates. Importantly, participants could neither recognize the priming procedure as such nor discriminate the primed trials from the incoherent trials in the experiment. Zander et al. (2016a) confirmed the intended priming effect in their study by demonstrating that participants processed primed trials faster (i.e., lower reaction times) and even judged a majority of primed trials falsely as coherent. Unfortunately, only seven of 19 participants indicated the intended priming effect. Zander et al. (2016a) compared the neural correlates of priming-based to intuition-based decisions based on the imaging data of the seven participants.

Contrasting the neural correlates of intuitive processes at the threshold of awareness with priming processes revealed activation within the left posterior OFC, the left ITG, and the right ventral tegmental area for intuiting, but no significant activation for priming (Zander et al., 2016a). Likewise, the contrast of priming-based decisions to successful incoherence judgments revealed no specific activation pattern. Instead, priming-based decisions were correlated with activity suppression in the occipital fusiform gyrus and the temporal occipital fusiform cortex, both of which are part of the temporo-occipital cortex. Notably, the neural correlates do not overlap. Particularly priming-based decisions revealed no activation of the OFC, nor of the anterior insular cortex, the IFG, the MTG, or the IFG (Zander et al., 2016). Hence, priming-based decisions are suggested to differ qualitatively on a neural level from intuition-based decisions.

These findings support the distinction between conceptual priming and intuitive processing. The typical processing “ease” in priming-based decisions (e.g., reflected in faster reaction times) is taken to manifest on a neural level by suppressed activation patterns connected to the second encounter with the primed stimulus (e.g., Schacter et al., 2004). Therefore, the experience of said processing “ease” might represent the cognitive signal accompanying priming-based decisions. In contrast, the affective component of intuition could potentially reflect an experience of processing “ease” too, but it would stem from another source. The difference in activation and location of priming- and intuition-based processing is well in line with the hypothesis that they differ in the format information is accessed. According to these findings, priming- and intuition-based decisions do not recruit the same neural networks. However, it seems likely that other “implicit memory mechanisms are a prerequisite for an intuition to occur” (Zander et al., 2016a). Frankly, the detection of semantic coherence would be impossible without accessing and processing implicitly stored information concerning the semantic relations of the words involved.

4.2.3 OFC Involvement Across Various Modalities in the Context of Discovery

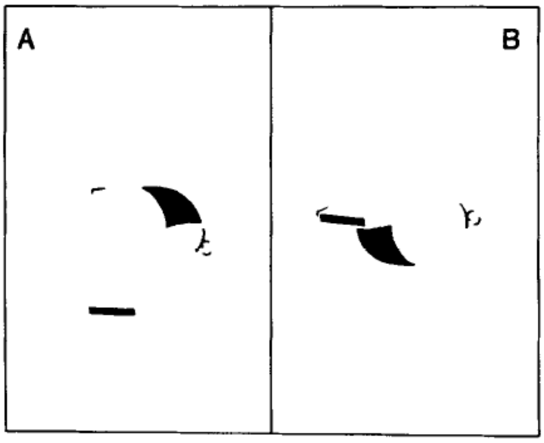
The study of Zander et al. (2016a) investigated intuitive decision-making within the context of discovery concerning judgments of semantic coherence. Their study found activation within a neural network that comprised the OFC, the insula, the IFG, the ITG, and the MTG to be correlated with successful intuitive judgments of semantic coherence (Zander et al., 2016a). In the context of discovery, the OFC appears to be of particular interest when investigating intuition (Volz & von Cramon, 2006; 2008; Luu et al., 2010, Horr et al., 2014; Zander et al., 2016a). The OFC is one of the most polymodal regions of the brain as it receives input from all sensory modalities (Kringelbach & Rolls, 2004). The OFC has been shown to be involved in emotionally driven decisions (Cohen et al., 2005), and it is proposed to play a critical role in information processing in situations with sparse input and time pressure (Bar et al., 2006). Additionally, the OFC was postulated to process the sparse input toward a coarse representation or gist (Bar et al., 2006). Furthermore, OFC activity was correlated with hypothesis testing and guessing (Elliot et al., 2000). Hence, the OFC has been proposed to act as an integrator, which processes input toward a gist-based representation, and is substantially involved in intuitive processing within a context of discovery (Volz & von Cramon, 2006; 2008; Luu et al., 2010, Horr et al., 2014; Zander et al., 2016a). Furthermore, Zander et al. (2016a) proposed the insular cortex to be involved in intuitive processing as well. The insular cortex is implicated in interoception, specifically in subjective feelings and self-awareness (e.g., Craig 2008). Therefore, in their experiment, the increased activation within the insula is taken to reflect the processing corresponding to the subjective feeling associated with the coherence judgment. (Zander et al., 2016a). In contrast, ITG and MTG involvement are not specific to intuitive processing but rather reflect semantic processing per se. Previous findings implicated them in verbal working memory processes (Bookheimer, 2002; Gernsbacher & Kaschak, 2003). The IFG is implicated in language processing too, as it "appears to represent a unique brain region involved not in decoding the meaning of individual words but in processing semantic relationships between words or phrases, or in retrieving semantic information" (Bookheimer, 2002, as cited in Zander et al., 2016a).

In the following, various other studies examine the neural correlates of intuitive decision-making in the context of discovery across different modalities, such as visual and auditory modalities. First, three studies encompass judgments of visual coherence using versions of the Waterloo Gestalt Closure Task (WGCT). Another study uses a novel paradigm to investigate intuitive coherence judgments within the auditory domain. Across the findings of these studies, a network centered around OFC activity was found to be correlated with intuitive processing. Therefore, a synopsis of the findings can deepen the understanding of the OFC's role in intuition and reveal additional information about the neural correlates of intuitive decisions in the context of discovery.

In Waterloo Gestalt Closure Tasks (WGCT), participants are asked to judge whether a "gestalt," that is, an abstract and fragmented depiction, represents a real object. Trials usually consist of coherent or incoherent gestalts. Incoherent gestalts are scrambled versions of coherent ones and do not depict a real thing. For example, in Figure 9, the incoherent gestalt is displayed left, and the coherent solution gestalt on the right represents a whistle. In Bowers et al.'s (1990) study, participants were able to discriminate visual coherence successfully under time pressure. They were able to do so successfully, namely well above chance, without being able to name the actual object the gestalts represented. Results indicated the involvement of implicitly informed coherence judgments because, albeit successful discrimination, participants could not name the real objects of the solution gestalts.

Figure 9

Waterloo Gestalt Closure Task Item



Note. Two examples of Waterloo Gestalt Closure Task (WGCT) items. Solution Gestalt (right) represents a whistle. From "Intuition in the context of discovery" by K. S. Bowers. G. Regehr. C. Balthazard & K. Parker (1990). *Cognitive psychology*, *22*(1), 72-110. Copyright 1990 by Academic Press, Inc.

To examine the neural correlates of intuitive processing of visual coherence, Volz and von Cramon (2006) used functional magnetic resonance imaging (fMRI) to measure participants' brain activity when working under time constraints on a modified version of the WGCT. Using similar pictorial stimuli as in the original study by Bowers et al. (1990), participants were asked whether the fragmented line drawings of common objects were meaningful to them. The pictorial stimuli were presented for 400 ms, and participants had 2 s to indicate their answer. The difficulty was adjusted according to the level of fragmentation. The researchers hypothesized that a mnemonic network would be activated on a neural level that signals the most likely interpretation of the fragmented input based on cues of coherence. This is comparable to the assumption of Zander et al. (2016a) that the automatic spreading activation would converge on the meaning of a common concept for coherent word triads. Volz and von Cramon (2006) contrasted the neural correlates of successful intuitive decisions (i.e., correct coherence judgment) with the neural correlates of non-intuitive decisions (i.e., correct incoherence judgments). The results revealed the anterior insula, the median OFC, the lateral portion of the amygdala, ventral occipito-temporal (VOT) regions to be activated by intuitive judgments of visual coherence (Volz & von Cramon, 2006). In previous research, activation of VOT regions was implicated with object perception processes (Sergent & Macdonald, 1992), which are not specific to intuitive processing. Instead, Volz and von Cramon proposed the median OFC to serve intuition-specific processing in the context of discovery "as detector of potential content which is derived from the critical aspects of the input." (Volz & von Cramon, 2006). The OFC is suggested to process entrant input comprising critical aspects towards gist-based representations (Barr et al., 2006). The amygdala might be involved in delivering information to the OFC about the degree to which the input matches with previously rewarded input, which in this case represents the real objects as opposed to new abstract gestalts. Supportive evidence indicates the amygdala's functional connection to the OFC (Volz & von Cramon, 2006) and its implication in emotional learning (Maren, 1999). Yet, the function of amygdala involvement in intuitive processing is only speculative at this point. In a temporal dimension, Volz & Cramon (2006) hypothesized that information entering the OFC from early information processing areas, such as VOT regions, could be projected back after being processed by the OFC to influence ongoing processing. Put in simple terms, the OFC could function as a cognitive and affective hub in forming intuitive judgments of coherence.

In a complementary study, Luu et al. (2010) investigated the temporal dimension of the network surrounding OFC activity via electroencephalography (EEG) using the same paradigm (WGCT). As expected, they found activity in the medial OFC (at around 250ms after stimulus onset) to be associated with successful intuitive judgments of visual coherence. Activity in the right temporal-parietal-occipital (TPO) region (~150ms) was found to predict medial OFC activity (Luu et al., 2010). TPO regions are also implicated in object recognition before (James et al., 2003). Furthermore, the medial OFC was found to influence subsequent TPO activity at a later point in time (~300ms) (Luu et al., 2010). This finding suggests the OFC’s role as a mediating influence in the conception of intuitive judgments of coherence and corroborates that the OFC’s output can influence the ongoing information processing in object recognition areas, like TPO or VOT regions. Specifically, the OFC’s processing towards gist-based input representations could guide the ongoing process by narrowing down the potential number of interpretations. This proposition can be further supported by the findings of Horr et al. (2014), who examined the role of the OFC in forming judgments of visual coherence via magnetoencephalography (MEG). As in the previous study, the OFC was active when participants judged coherence successfully. Interestingly, the activation increase began earlier within the OFC than in specific temporal object recognition areas (Horr et al., 2014). Moreover, the OFC remained active the longest during and after the stimulus onset.

The involvement of the OFC in forming intuitive judgments of coherence may transcend all sensory modalities. In another study, Volz et al. (2008) found supporting evidence for the involvement of the OFC in the auditory domain. They examined brain activity via fMRI of participants working on an auditory difficult-recognition paradigm. Participants were asked to perform sound categorization tasks where short sequences of distorted sounds had to be categorized according to coherence. Coherent sound trials featured distorted sound stimuli that represented meaningful auditory events (e.g., ring of a bell). Incoherent trials featured distorted sounds that did not represent any meaningful auditory events. Their results revealed rostral medial OFC and MTG activation to coincide with successful judgments of coherence. This finding solidifies the OFC’s involvement in forming intuitive judgments of coherence across modalities. On the other hand, the MTG “has been shown to be crucial for the recognition of familiar environmental sound sources and to be implicated in the retrieval of action knowledge—that is, of how a sound is likely to have been produced” (Volz et al., 2008). Therefore, MTG involvement is not considered to reflect intuition-specific processing.

In conclusion, the OFC’s involvement appears to be of particular importance in intuitive processing in the context of discovery. Across semantic, visual, and auditory modalities, the OFC was found to be involved in successful intuitive judgments of coherence (Volz & von Cramon, 2006; Volz et al., 2008; Luu et al., 2010; Horr et al., 2014; Zander et al., 2016a). The OFC’s function as a fast detector and predictor of potential content that processes entrant input towards gist-based representations and projects back to relevant recognition areas may represent a critical role in the emergence of intuitions in the context of perceptual discovery. Moreover, this region's involvement in emotionally driven decisions (Cohen et al., 2005) and the implication to play a vital role in information processing under time pressure with only coarse facets of the input available (Bar et al., 2006) makes it a prime candidate to reflect intuition-specific processing in the context of discovery. Overall, these findings align with the assumption that the initial perception of coherence embodied in affectively charged signals (e.g., gut feelings) is assumed to bias subsequent thought and inquiry. Potentially the OFC's relevance to intuitive processing transcends the context of discovery to apply to all situations of intuitive processing under time pressure with sparse input.

5. Discussion

The motivation of the presented research draws on the accepted but modern scientific view that intuition can lead to successful decisions and serve as a viable explanatory construct. Exemplified by the potential to guide accurate self-description judgments and successful implicit detection of coherence across various modalities in a matter of seconds, the efficient performance of intuition is further supported by behavioral research (e.g., Topolinski & Strack, 2009). Despite the many advances in the study of intuition, questions like "What is intuition?", "How is it best conceptualized?" and "How does intuition operate?" are not answered satisfactorily yet. Intuition is an elusive phenomenon challenging to study. Its widely accepted characterization as a fast and nonconscious process often does not yield further understanding but leaves the concept as opaque as it was. For the lack of a generally accepted definition or an overarching framework, various lines of inquiry emerged independently, and it is challenging to integrate them in a meaningful way.

As a starting point, this thesis put forth the prototypical definition of Dane and Pratt that intuition is a "non-conscious process involving holistic associations that are produced rapidly, which result in affectively charged judgments" (Dane & Pratt, 2007). The advantages of such a definition are twofold. While the main characteristics of intuition can be phrased differently and put into various contexts, all main characteristics must be present to satisfy the definition, which is conveniently applicable across multiple disciplines. Additionally, Dane and Pratt's prototypical definition can be adjusted based on additional characteristics or contexts without diluting its boundary conditions that account for the concept's core across disciplines. For example, as intuitive processing in the context of discovery is suggested to necessitate tacit knowledge, the definition could be modified towards accounting for this aspect. As a result, intuiting in the context of discovery could involve "holistic associations that are produced rapidly and incorporate tacit knowledge." Furthermore, this paper encourages the adoption and further development of the conceptual framework put forth by Gore and Sadler-Smith (2011). In the following, it will be demonstrated that this framework proves helpful to organize the field of intuition research on a conceptual level. Still, the specific cognitive processes underlying intuitions are elusive and, therefore, difficult to study. One possibility to take on this issue is to incorporate a cognitive neuroscience approach. The combination of experimental psychology and neuroscience can illuminate intuition's inner workings. Therefore, cognitive neuroscience can advance an integrative understanding and improve conceptual clarification in studying intuition. "Is it accurate to conceptualize the underlying processes of intuition as continuous?", "Are related phenomena, like insights or implicit memory, interoperable with intuitive processing or do they fundamentally differ?" and "Is the phenomenon of intuition accurately conceptualized as unitary construct?" In consideration of these questions, cognitive neuroscience approaches have the potential to put specific conceptual elements to the test, examine connections to related phenomena, and inform cognitive theories of intuition necessary to launch more specific investigations into the elusive phenomenon of intuition.

A cognitive neuroscience approach can provide an ideal testbed for conceptual elements of intuition to be examined empirically. For example, Bowers et al. (1990) conceptualized intuitive processing within the context of discovery to occur within two stages. They proposed that forming intuitions in this context unfolds continuously rather than discontinuously. The (cognitive) neuroscientific study of intuition enabled investigations into the underlying processes to examine the continuity of the underlying operations in said context. The findings of Zander et al. (2016a) indicated a quantitative increase of activation in the neural correlates corresponding to intuitive judgments of coherence. Therefore, neuroscientific evidence supports the conceptualization that intuitive processing unfolds gradually and that intuiting can be accurately mapped onto a continuity model. Future neuroscientific research could examine whether a continuity model of intuitive processing holds beyond the context of perceptual discovery. Thereby, the neuroscientific evidence could allow further conclusions about the theoretical conceptualization of intuition.

Furthermore, examining the neural correlates of intuition and related phenomena can uncover similarities and differences among the underlying processes. The concurrence of intuition and implicit memory can be examined by cognitive neuroscience. In most empirical research on intuition, intuition seems to incorporate tacit knowledge. Specifically, performing accurate, intuition-based self-descriptions or intuitively detecting coherence necessitates access to previously stored knowledge. The involvement of implicit memory is often suggested because the retrieval processes occur without traces of conscious recollection (i.e., participants cannot report on how or which information was gleaned). As such, the hypothesis that the underlying processes of implicit memory and intuition could be connected appears reasonable. As of yet, the relationship remains largely unexplored. In the case of priming, Zander et al. (2016a) were the first to demonstrate that implicit memory and intuition may be distinct processes on a neural level. They showed that the underpinned processes of intuition-based and priming-based decisions differ qualitatively on a neural level. Therefore, their research supports the proposed differences between implicit memory and intuition. Adopting cognitive neuroscience approaches allows further investigation into the relation between implicit memory and intuition. For example, Lieberman's claim could be examined that "implicit learning processes are the cognitive substrate of social intuition" (Lieberman, 2000). Lieberman (2000) proposed that social intuition and implicit learning are linked conceptually and functionally to the extent that they recruit the same neural substrates. As such, beyond assessing differences and similarities concerning the underpinned processes, the neuroscientific study of intuition could integrate disparate lines of inquiry. In this regard, insight and intuition provide another example. Both are conceived as different phenomena and have commonly been investigated separately. Traditionally, processes underlying insight have been conceptualized as discontinuous, whereas intuitive processes are taken to unfold gradually. This view could imply that there is no crosstalk between the two, although little is known about the underlying processes and the relationship between the two. So far, no study has investigated intuition and insight within one paradigm. A first hint towards such a paradigm can be extracted from the concept of explicitly solved word triads in the study of Zander et al. (2016a), which appear to coincide with conceptualizations of insight. In their study, explicitly solved trials could involve insight into the logical, semantic relations of the coherence in question once the triads solution is explicitly accessible. Thus, explicitly solved triads may lead to aha-experiences, which are typical of insights. Whether these experiences occurred in their experiment will remain unanswered as Zander and colleagues (2016a) did not include measures to capture such experiences. However, typical insight problems are different from typical word triad tasks in one important aspect. Insight problems usually misdirect the immediate retrieval process (Zander et al., 2016b), which is not the case in coherent triads. The immediate retrieval of clue words' semantic relations converges on a fourth concept. In semantically converging triads, the solution word carries the same meaning with respect to each clue word (e.g., salt, deep, foam – sea) and therefore does not misdirect immediate retrieval processes. Yet, Bowers et al. (1990) introduced another kind of coherent word triads, termed divergent triads. Unlike convergent triads, divergent triads are designed so that multiple meanings of the solution word need to be associated with the meanings of the three clue words. In other words, in divergent triads, the solution word has a different meaning concerning each clue word (e.g., age, mile, sand – stone). As such, divergent triads have the potential to serve as insight problems because the immediate retrieval is misdirected. In other words, the immediate retrieval of semantic relations of the clue words diverges. Zander et al. (2016b) proposed using converging triads as intuition and divergent triads as insight conditions to investigate both processes within one paradigm. Such a paradigm could examine whether convergent triads can evoke aha-experiences, whereas integrating neuroscientific measures could elucidate how the underlying processes of insight-based and intuition-based differ regarding their unfolding and their neural correlations. Subsequent results could challenge or solidify the predominant conceptualizations of both phenomena and their underlying processing and clarify if intuition and insight are processes that can build on each other or fundamentally differ.

Besides, uncovering the underlying processing according to the neuronal correlates of intuitive decisions can reveal which processing is specific to intuitive processing and which is task- or context-dependent. Consequently, such an analysis allows conclusions about the operating principles of intuition. Various presented studies converge on the finding that intuitive processing in the context of discovery comprises neuronal networks revolving around OFC activity. The OFC may act as an integrator that processes entrant input towards gist-based representations. In the process of forming intuitive judgments of coherence, the OFC increases in activation early on, which could reflect its function as a fast detector and predictor of potential content. At the same time, ongoing OFC activity is suggested to influence task-specific processing (e.g., object recognition or semantic processing), whereby it would guide ongoing processing within task-specific functions. As such, the OFC's role in forming intuitive coherence judgments revolves around a mediating and integrating function. OFC involvement seems to reflect intuition-specific processing related to information integration across various modalities in the context of perceptual discovery. Comparing other neural correlates with previous findings may reveal which processes may be rather task-specific than being of great significance to intuiting as such. In the context of discovery, task-specific processing in the visual domain involves VOT and TPO activity taken to reflect early visual processing and object recognition. In the semantic domain, ITG, MTG, and IFG activity are taken to reflect the processing of semantic content and its relations, whereas, in the auditory domain, MTG activity is suggested as crucial to the recognition of familiar environmental sounds. In contrast, intuitive processing was correlated with OFC activity across modalities. Therefore, the OFC is of particular interest in intuitive processing in the context of perceptual discovery and could reflect intuition's operating principle in this context. For example, the operating principle in this context may revolve around the implicit detection of coherence through information integration of relevant cues that result in a preliminary perception of coherence embodied in an affectively charged judgment that influences subsequent thought and behavior. Additionally, future investigations could examine whether OFC activity corresponds to intuitive processing in this context alone or if the findings can be replicated in different contexts. Hypotheses in other contexts should revolve around OFC involvement in intuitive processing for sparse stimulus input and time pressure situations.

The question is whether there is any brain region devoted to intuitive processing specifically. If no specific brain region is dedicated to intuitive processing, the neural correlates of intuitive decisions are suggested to vary across tasks, contexts, or, as Gore and Sadler-Smith (2011) put it, types of intuitive processes and outcomes. This would mean that the multi-faceted nature of intuition reflects on a neural level. Consequently, intuition would be better conceptualized as a heterogeneous phenomenon and should be partitioned to allow for fruitful research. Yet, it remains an open question whether the proposed primary types of intuition are consistently correlated to different neural substrates. To investigate this assumption, specific paradigms that isolate primary types of intuition would be required. Thereby the heterogeneity of intuition could be uncovered if (at least) two distinct primary types of intuition consistently indicated qualitative differences in intuition-specific processing on a neural level. For example, problem-solving intuition in the context of discovery appears to be consistently correlated to OFC involvement. In contrast, social intuition may be correlated to activity within X-system structures. Social intuition comprises the intuitive evaluation of another person's cognitive and affective state through behavioral indicators (Gore & Sadler-Smith, 2011), like facial expressions. Therefore, the X-system structures, thought to be involved in automatic social cognition, are prime candidates for the neural correlates of social intuition. Particularly, the amygdala may be of special interest as a neural correlate of social intuition, as the amygdala has been implicated in recognition of facial expressions (Adolphs & Tranel, 2003) and emotional learning (Maren, 1999). Yet, in most studies, intuitive decisions represent secondary types of intuitions. For instance, self-descriptions are a composite form of problem-solving and social intuitions. Likewise, intuitive decisions in pure coordination games represent composite forms, comprising at least problem-solving and social intuition, if not moral intuition too. On another note, it may also be likely that varying cognitive and neural substrates are recruited by intuitive processing to perform functions depending on the specific context rather than adhering to the primary types of intuition proposed by Gore and Sadler-Smith (2011). The amygdala is implicated in intuitive decisions both in the context of visual discovery and intuition-based self-knowledge (Lieberman et al., 2004; Volz & von Cramon, 2006). The amygdala's involvement may reflect similar functions across these tasks. The amygdala is suggested to evaluate input based on previously rewarded input. Therefore, the amygdala could provide affective data (though differing in content) for the intuitive decisions in both contexts. Additionally, insular cortex activity is implicated both in intuitive decisions in the context of coordination games and perceptual discovery (Volz & von Cramon, 2006; Kuo et al., 2009; Zander et al., 2016a). In both contexts, involvement of the insula is suggested to reflect the processing corresponding to subjective feelings accompanying the intuitive judgments. Potentially, involvement of the insula, the amygdala, and the OFC can be found across other types of intuition too. Nevertheless, investigating the neural correlates of primary types alone could produce meaningful findings, whereby neuroscientific evidence could inform and improve the proposed framework. In turn, an improved framework could better guide neuroscientific investigations. Within the conceptual framework, the cognitive neuroscientific study of intuition proves of excellent use as it provides an ideal testbed to examine the specific hypotheses derived from the framework.

Finally, many researchers argue that the framework of dual-process theories may help to develop a more coherent account of intuition and its underlying processes (e.g., Evans, 2010; Epstein, 2010). Yet, the central proposition to study intuition according to its distinction from deliberation may be too simplistic. Consequently, there is considerable divergence concerning the nature and functioning of intuitive processes within dual-process theories (Glöckner & Witteman, 2010). Predictions derived from generic dual-process models concerning the underlying information processing of intuition are often vague (e.g., Kuo et al., 2009). Nevertheless, a lot of meaningful research about nonconscious information processing occurred within dual-process models. Luckily, an intuition-specific framework, such as that of Gore and Sadler-Smith (2011), is compatible with dual-process theories and other conceptualizations of intuition. Existing research can be integrated, and future research on intuition from a dual-processing perspective can conveniently incorporate aspects of the framework.

Conclusion

The multi-faceted nature of intuition allows for investigations across a wide range of domains and disciplines incorporating many paradigms and levels of analysis. Therefore, an integrative understanding of the phenomenon is much needed. Establishing a general definition and developing a comprehensive conceptual framework are vital priorities. Hence, the study of intuition necessitates an interdisciplinary and systematic approach. In this regard, cognitive neuroscience can support a multidisciplinary approach by testing specific hypotheses on a neural level concerning the underlying processes. Cognitive neuroscience can illuminate intuition's inner workings by combining experimental psychology with neuroscience. The resulting evidence exposes additional information about the underlying processes of intuition and allows for conclusions about the theoretical conceptualization of intuition. For example, the proposed conceptualization of intuitive processing as a continuous, gradual process could be corroborated by neuroscientific evidence. Furthermore, using neuroscientific imaging methods within one paradigm to study intuition in connection to related phenomena has the potential to uncover the correspondence of two similar processes. To the extent that priming-based decisions differed qualitatively on a neural level from intuition-based decisions, the suggested differences of intuition and implicit memory processes could be supported. Additionally, examining the neural correlates of insight and intuition within one paradigm can elucidate whether intuition and insight are two processes that can build on each other or fundamentally differ. Here, incorporating a cognitive neuroscience approach not only has the potential to elucidate the correspondence of the underlying processing but potentially unify two lines of inquiry about non-analytic information processing. Besides, investigating the neural correlates of intuitive decisions can differentiate intuition-specific processing from context-dependent processing and subsequently corner in on the operating principles of intuition. At last, examining the neural correlates of different types of intuitive processes and outcomes across paradigms, domains and contexts can advance the development of a comprehensive conceptual framework of intuition. For instance, neuroscientific evidence can expose whether intuition is better conceptualized as unitary or nonunitary or whether conceptual elements of frameworks ought to be expanded or collapsed. In sum, cognitive neuroscience can enhance the study of intuition by expanding the knowledge of intuition's underlying processes and clarifying the conceptual level through testing specific elements, examining connections to related phenomena, unifying different lines of inquiry, and informing conceptual frameworks.

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