Chapter 2
Knowledge Production in Cognitive Neuroscience: Tests of Association, Necessity, and Sufficiency

While all domains in neuroscience might be relevant for NeuroIS research to some degree, the field of cognitive neuroscience has been identified as the major reference discipline (e.g., Dimoka et al. 2011). Cognitive neuroscience seeks to understand "how the brain works, how its structure and function affect behavior, and ultimately how the brain enables the mind" (Gazzaniga et al. 2009, p. 2).[1] In order to develop a conceptual basis for the sections to follow, we briefly discuss how cognitive neuroscience knowledge is typically produced. Appendix C provides additional information on brain functioning from a cognitive neuroscience perspective.

A central objective of cognitive neuroscience studies is to determine how a particular mental process is implemented neurologically, and to do so by identifying the regions of the brain that are involved in a specific task. Such research often relies on fMRI, which is the most significant tool in cognitive neuroscience (Gonsalves and Cohen 2010; Poldrack 2006). Indeed, Logothetis (2008) states that fMRI "is the most important imaging advance since the introduction of X-rays by Conrad Röntgen in 1895" (p. 869), and its prominence in cognitive neuroscience research bears out that view. Given the role of fMRI in the field, and supported by fMRI guidelines that Dimoka (2012) presents in *MIS Quarterly*, along with related methodological contributions (Hubert et al. 2012, 2017; Riedl et al. 2014), we will herein briefly illustrate the logic of fMRI research.[2]

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[1]Neuroscience is the scientific examination of the nervous system. While this discipline was a sub-discipline of biology in former times, it is an independent discipline today. As described in detail by leading academic societies such as the *Society for Neuroscience* or the *International Brain Research Organization*, neuroscience research refers to different levels of analysis (e.g., molecular, cellular, structural, or functional) and domains (e.g., evolutionary, medical, developmental, computational, or cognitive). As a function of both level of analysis and of domain, neuroscientists apply different research tools.

[2]Dimoka et al. (2012), Riedl et al. (2010), and Riedl and Léger (2016) discuss additional cognitive neuroscience and neurophysiological tools.

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A useful example is a situation in which a cognitive neuroscientist wants to identify the brain region(s) underlying the mental process of *disgust*. After forming a clear definition of disgust (for example, “profound dislike or annoyance caused by something sickening or offensive”, American Heritage Dictionary), a researcher needs to transform the concept of disgust into an experimental paradigm. Stimuli and tasks are major components of such a paradigm.[3] Disgust is one of the six basic human facial expressions representing emotional states; the others are anger, fear, happiness, sadness, and surprise (e.g., Gazzaniga et al. 2009). Thus, in order to identify the brain regions underlying the perception and processing of disgust, a researcher could present a range of photos of human faces to participants whose brains are being scanned, including in the photo range both images of faces expressing a disgust response, and control images of faces that convey other emotional states or no emotional state at all (i.e., neutral faces). Brain research of this design (e.g., Phillips et al. 1997) has, in fact, found that faces expressing disgust activate the insular cortex more strongly than do faces expressing other emotions (e.g., fear) or no emotion.

In contrast to classic neuroscience research (which is usually interested in brain data alone), cognitive neuroscience research is focused on both behavior and in underlying brain mechanisms. The design of fMRI experiments reflects this difference. For fMRI experiments in classic neuroscience, subjects are typically presented with visual stimuli (though there may be other stimuli such as auditory cues), and the scanner measures brain activity. For fMRI experiments in cognitive neuroscience, however, another element is added—subjects are usually presented with stimuli while the scanner measures brain activity, but participants are also required to state a behavioral response after the presentation of stimuli (e.g., a disgust evaluation using a Likert-type scale after presentation of faces showing varying levels of disgust). Based on the collection of both brain and behavioral data, the relationship between both data sets can be assessed, in this way using brain activity as a mediator between the stimulus perception and task execution, and a behavioral response.

Figure 2.1 (panel A) conceptually illustrates the transformation of a mental process (e.g., disgust) into stimuli (e.g., faces expressing disgust) and control stimuli (e.g., faces expressing other emotional states or no emotion). By contrasting the brain images acquired during the various experimental conditions (e.g., disgust vs. other emotional states, disgust vs. no emotion), it is possible to determine the brain regions associated with the investigated mental process. Brain research has found that the insular cortex plays a crucial role in the implementation of disgust (Gazzaniga et al. 2009, p. 383). The inference from a mental process to brain activity (i.e., from the corresponding stimulus and task to brain activity) is referred to as *forward inference* (Henson 2006).[4]

[3]The website http://www.cognitiveatlas.org/ describes several hundred tasks that are used in cognitive science, many of which are also used in cognitive neuroscience research.

[4]Reverse inference (i.e., an inference from neuroimaging data reported in the literature to a mental process, Poldrack 2006) is detailed in Appendix C.

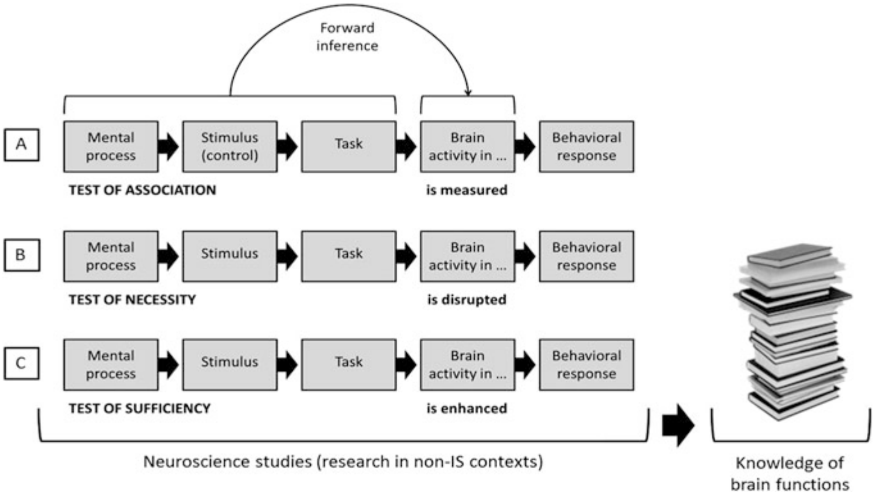

Fig. 2.1 Process of cognitive neuroscience knowledge production

Based on the logic described in Fig. 2.1 (panel A), neuroscience research has developed an impressive body of knowledge. In particular, the research has produced extensive insight into the relationship between mental processes and brain regions. As a result, an extensive knowledge base on brain functions exists today (Fig. 2.1, right), and this literature can be used by IS scholars without necessarily using neuroscience tools. In part, this knowledge is documented in online databases such as www.cognitiveatlas.org *or* www.neurosynth.org.

In our example, we indicate that activity in the insular cortex is associated with the specific mental process of disgust. However, other studies unrelated to disgust have also revealed activity in this particular region of the brain. For example, research has found that in an economic game (task), an unfair offer (stimulus) from one player (in contrast to a fair offer), elicits stronger activity in the insular cortex of the opponent's brain (Sanfey et al. 2003). Consequently, insular cortex activity is associated with unfairness. In addition to this result, a stream of research on the brain mechanisms underlying economic decision-making has found that insular cortex activity is correlated with risk (e.g., Clark et al. 2008; Mohr et al. 2010; Preuschoff et al. 2008). The cognitive neuroscience literature, therefore, provides evidence that insular cortex activity is associated with a number of mental processes such as disgust, unfairness, and risk. More generally, evidence shows that a brain region is typically activated by several mental processes (i.e., corresponding stimuli and tasks), and a single mental process (i.e., corresponding stimuli and tasks) often activates more than one brain region (e.g., Price and Friston 2005).

From an IS perspective, it is critical to understand that most knowledge that is currently documented in the cognitive neuroscience literature has been developed through *tests of association* (i.e., a mental process *correlates* with activity in a specific brain region, see Fig. 2.1) (Kable 2011). Tools such as fMRI, PET (Positron Emission Tomography), EEG (Electroencephalography), MEG (Magnetoencephalography), fNIRS (functional Near-Infrared Spectroscopy), anatomical imaging, and invasive recordings allow for a test of association, but not for the tests of necessity and sufficiency that are used less frequently in cognitive neuroscience research (Kable 2011, p. 67). In a *test of necessity*, neural activity is temporally *disrupted* in a specific brain region, and observation is used to determine whether disruption impairs the behavior that results from a specific mental process (see Fig. 2.1, panel B); tools that make such a test possible are lesion studies, TMS, and Transcranial Direct-Current Stimulation (TDCS) (cathodal) (see the Knoch et al. 2006 study on risk-taking behavior as an example of a test of necessity).[5] In a *test of sufficiency*, neural activity is temporally *enhanced* in a specific brain region in order to observe whether the enhancement leads to a specific behavior that results from the mental process (see Fig. 2.1, panel C); TDCS (anodal) makes this test possible (a study by Filmer et al. 2013 on multitasking may serve as an example for a test of sufficiency). Thus, the central point to understand is that while a test of association only measures neural activity, tests of necessity and sufficiency manipulate the neural activity. Ideally, the functional role of a brain region is established on the basis of a multi-method approach.

After a brief outline of the major processes that cognitive neuroscientists use to generate knowledge about brain functions, we demonstrate how that neuroscience knowledge can be applied in IS research without requiring neurobiological measurement.

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[5]A lesion is a localized area of damage in the brain. Thus, a lesion can be considered a "permanent disruption" of the brain region of concern.

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