Organizational Neuroscience

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Summary

Organizational neuroscience—a novel scholarly domain using neuroscience to inform management and organizational research, and vice versa—is flourishing. Still missing, however, is a comprehensive coverage of organizational neuroscience as a self-standing scientific field. A foundational account of the potential that neuroscience holds to advance management and organizational research is currently a gap. The gap can be addressed with a review of the main methods, systematizing the existing scholarly literature in the field including entrepreneurship, strategic management, and organizational behavior, among others.

Keywords: neuroscience, emotions, cognition, entrepreneurship, organizational behavior, strategic management, methods

Subjects: Business Policy and Strategy, Entrepreneurship, Ethics, Organizational Behavior, Research Methods

Introduction

In the early 21st century, neuroscience gained traction in the management and organizational disciplines, leading to the emergence of *organizational neuroscience*. Together with a growing number of scientific articles, academic journals' dedicated Special Issues, and conference workshops, the epitome of this scholarly momentum is the creation of the Organizational Neuroscience Interest Group *<http://www.aom.org/neu>* (NEU) within the Academy of Management (AOM), the leading professional body of management scholars and practitioners (Beugré et al., 2019).

Different views have been offered on what constitutes organizational neuroscience thus far. Becker and colleagues (2011) presented organizational neuroscience as a "paradigm or interpretive framework," (Becker et al., 2011, p. 937) and as a "deliberate and judicious approach to spanning the divide between neuroscience and organizational science" (Becker & Cropanzano, 2010, p. 1055). Conversely, Lee et al. (2012, p. 804) chose the term "organizational cognitive neuroscience" to capture "the cognitive neuroscientific study of organizational behaviour." Aiming to settle the discrepancy between these views and provide a more complete conceptualization, organizational neuroscience is here defined as *the scientific field that uses neuroscience insights, methods, and theory to inform and advance management and organizational research, and vice versa*.

This definition is closely aligned with NEU's institutional vision and mission, and, importantly, it puts forward organizational neuroscience as a self-standing discipline alongside more established scholarly areas in both neuroscience and management. Indeed, this notation seeks to offer a "big umbrella" approach to the use of neuroscience in management, while respecting idiosyncrasies and identities of each departing domain. This definition allows convergence under the same arena of the various features of social, cognitive, affective, and decision neuroscience, together with possible declinations of "neuroentrepreneurship," "neurostrategy," and the like, beyond organizational behavior alone. This approach provides a pragmatic, parsimonious, and shared framework to increase inclusion of organizational neuroscience among the management scholarly community at large, as well as providing a common ground to foster cross-collaboration among different domains in neuroscience, management, and organization studies.

Despite an overall enthusiasm for organizational neuroscience, the field has not been immune to skepticism and critiques. Some early works have provided critical analyses on possible theoretical and practical issues surrounding this field (e.g., Lindebaum, 2015). Yet, as the field matures, it can learn how similar challenges were addressed by cognate disciplines—the likes of neuromarketing and neuroeconomics. The intent here is to pacify these worries while avoiding either extreme, "neuro-hopes" or "neuro-hypes" (Ashkanasy et al., 2014; Jack et al., 2019). To achieve this goal, it is paramount to begin the present coverage of organizational neuroscience by answering the question: Why does management research need neuroscience?

Notwithstanding potentially epistemological chasms that might strike some readers when facing this question, management and neuroscience have more in common than what might appear at a first look. Over their histories, despite using different theoretical, methodological, contextual, and analytical tools, both disciplines have advanced toward identifying architectures, levels, and components of human psychology and behavior and toward describing their organization and interrelations with the environment. In other words, both fields are allies in the common quests of natural and social sciences: understanding behavior. Thus, neuroscience can complement management research with information on the functioning of the nervous system as a whole—composed of the central (i.e., brain and spinal cord) and peripheral (and, in particular, autonomic) systems—and its connections with psychological, social, cultural, and organizational niches. Indeed, organizational neuroscience does not provide a reductionist approach whereby organizational constructs can eventually be replaced by mere descriptions of neurobiological processes. Instead, it aims to integrate management research with a mechanistic, physiologically informed understanding of mental processes and behaviors, as they take place within organizational life or are relevant to it. In other words, armed with neuroscience insights and methods, management researchers can seek to generate more comprehensive theoretical and practical frameworks that build on objective physiological data and computations. As will be discussed, the type of information that neuroscience and its methods provide is indeed that of quantifiable, continuous data and models related to physiological substrates underlining certain mental processes and behaviors. These data are less prone to biases because they are commonly acquired beyond participants' awareness of the target process and/or construct investigated (Massaro et al., 2020).

This article aims to leverage this understanding while catering to the needs of upholding the scientific standing of both mainstream neuroscience and management. Thus, it aims to educate readers on the benefits and limitations of organizational neuroscience while mobilizing neuroscience knowledge into actionable avenues for advancing management theory and practice. The encyclopedic flavor of this work assists in providing such a blueprint, one that will offer not only foundational knowledge to novice researchers but also an updated compendium to more seasoned scholars.

In this article, the current, core methodology pertaining to organizational neuroscience is described, with particular emphasis on brain imaging methods. A discussion of existing structures to organize such methods and highlight core considerations, benefits, and limitations of the related techniques follows. Next, the state-of-the-art knowledge in organizational neuroscience is reviewed. This effort substantially differs from existing reviews of organizational neuroscience (cf., Waldman et al., 2017). Moreover, the intention here is not to repurpose knowledge exposed in neuroscience publications into a sort of conceptual management narrative. Instead, this article specifically focuses on reviewing neuroscience-related research published in acknowledged management and organizational scholarly journals. As such, the retrieved body of knowledge is systematized under traditional disciplinary domains—linked to strategic management, organizational behavior, entrepreneurship, and so forth—while analyzing key findings and considerations toward further enriching the potential of organizational neuroscience. In closing, avenues for future research and recommendations are suggested. Altogether this article aims to contribute to the growth of organizational neuroscience by offering a comprehensive outline of this novel, interdisciplinary scholarly field.

The Methods

The rise of organizational neuroscience is certainly corroborated by the advancements in neuroscience techniques that occurred in the late 20th century. Brain imaging methods in particular have comfortably acquired a secure reputation to contribute to organizational research (Murray & Antonakis, 2019). At the same time, these techniques require specialized expertise, often involving a steep learning curve for business school scholars (Waldman, 2013).

Given that detailed coverage of the multitude of neuroscience techniques that can assist management and organizational research would require a textbook length, here, the aim is to provide broad introductory coverage, while directing readers to more nuanced references whenever appropriate (see Table 1). Thus, most of the methods are presented under the paradigm of functional neuroscience and neuroimaging, the latter referring to such techniques able to “visualize the functionality” of the nervous system (Massaro, 2016). Readers are also introduced to the potential of computational methods—while not yet used in management research, theoretical and computational neuroscience offer important benefits for the administrative sciences as a whole (Churchland & Sejnowski, 1992). For example, consider “neural networks” (Dayan & Abbott, 2003), computing systems inspired by biological neural networks of the brain, which are a mainstay behind many machine learning implementations (Abraham, 2002).

Conversely, methods on nonhumans (e.g., primates or other research animals), requiring invasive procedures (e.g., intracranial recording, positron emission tomography or PET), and benchwork techniques (e.g., DNA extractions) are not discussed, given their complex ramifications and limited application among organizational scholars (Massaro, 2016). As such, this article does not describe methods related to neuropharmacology and neurogenetics, two areas generally focusing on the role of neuropeptides (e.g., hormones) and genes in the formation and functioning of the nervous system and their associations to psychology and behavior, respectively. The methods in these areas vary widely, can span from molecular biology (e.g., Polymerase Chain Reaction [PCR]) to electrophysiology techniques (e.g., patch clamp), and often require raw data acquisition involving anything from blood work to administration of exogenous substances to research participants. While the needed benchwork to extract data appears to be impractical for business scholars, an increasing number of public data sets containing information on genomics and neural biomarkers of large samples of populations are now available to scholars (e.g., UK Biobank), reducing the barrier to entry. Similarly, salivary kits to collect participants’ samples for genetic or hormonal testing are becoming more accessible; companies often offer one-stop shopping services that cover everything from the delivery of the kit to the provision of data in “readable” file formats (e.g., *.csv). Moreover, fields such as human resources and occupational research are well-placed to leverage neuropharmacology and genetics, given their accessibility to occupational health practices, which are often equipped to perform biological assessments as part of occupational screening routines.

Methods Classifications

There are different types of systems for the methodology of organizational neuroscience. The most common is *technical resolution*. This classification proposes that methods can be categorized according to a matrix based on each technique’s distinct resolutions: the ability of a given tool to discriminate between points in space (i.e., spatial resolution) and time (i.e., temporal resolution) (Menon et al., 1998). Concretely, spatial resolution defines to what granularity an object in an image (e.g., a given brain area) can be resolved: the higher the resolution the better the quality of the image. Similarly, temporal resolution refers to the ability to obtain data in relation to time. Thus, in lay terms, spatial resolution refers to the capability that a brain imaging technique has to inform exactly which area(s) of the brain is engaged, while temporal resolution describes its ability to precisely tell when the activation occurred. This concept is important, because with high-resolution tools it is possible to resolve cortical circuits in vivo (Felleman & Van Essen, 1991; Goense et al., 2016).

Another viewpoint, summarized in Table 2, indicates that organizational neuroscience methods can be classified into three functional categories according to their underlying rationale (Massaro, 2017). Thus, association methods, such as electroencephalography or functional Magnetic Resonance Imaging (fMRI), generally involve the "manipulation" of a mental state, the aligned recording of neural activity, and a correlation between the two (hence the association). Necessity tests disrupt neural activity to identify the role of a specific mental function, often offering additional interpretations beyond the simpler identification of neural correlates. Finally, sufficiency methods alter levels of neural activity and investigate whether they result in a specific behavior or mental state.

Table 1. Main Methods Used in Organizational Neuroscience Publications (2005–2020)

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
Functional magnetic resonance imaging (fMRI)	Indirect measure of neural activity via magnetic properties of hemoglobin that measures changes in oxygenated blood flow to brain regions (BOLD signal)	Spatial: up to about 1 mm^3 Temporal: about 5 s	• Strong spatial localization • Rise in popularity has seen access to greater comparative research and continual refinement of techniques for measurement and analysis	• High operating costs • Not portable • Results are not always easily translatable to biological constructs • Complex techniques for cleaning, processing, and analyzing data	• Identify “activated” brain regions during a task • Assess connectivity of regions of brain at rest, during activity, and after activity • Assess neural basis of individual differences	“Compared to personal-oriented non-inspirational messages, collective-oriented inspirational messages will lead to increased activation in the (a) pars opercularis and (b) inferior parietal lobule, regardless of whether they originate from an in-group or an out-group leader.” (Molenberghs et al., 2017)

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
Electroencephalogram (EEG)	Direct measure of neuronal activity via electrodes placed on scalp that measure electrical changes caused by neuronal firing	Spatial: up to 10–20 mm Temporal: ms	• Strong temporal resolution • Affordable • Portable equipment • Allows for realistic interaction between subjects • Longest established method	• Sensitive to other sources of electrical current (e.g., muscular activity). • Detected signals are not wholly spatially independent	• Test the timing of cognitive processes. • Test hypotheses related to known and reliable ERP signatures (e.g., N400, P300) • Test hypotheses relating to high-frequency neuronal oscillations (e.g., alpha, gamma)	“Can a discriminant function of power spectral analysis variables be defined to classify, with accuracy, those leaders exhibiting transformational leadership behaviours from those who do not?” (Waldman et al., 2011)

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
Magnetoencephalography (MEG)	Direct measure of neural activity via magnetometers near scalp that measure perturbations of magnetic fields caused by neuronal firing	Spatial: up to about 3 mm Temporal: ms	• Strong spatial and temporal resolutions • More reliable and accurate than EEG	• High operating costs • Not portable • Very sensitive to external noise • Complex and time-consuming techniques for cleaning and analyzing data	• Test the timing of cognitive processes, neuronal oscillations, and connectivity between regions • When combined with EEG, can detect more signals	“Analyze the role of specific brain regions in perceptions of fairness in organizational settings” (Beugré, 2009)
Functional near-infrared spectroscopy (fNIRS)	Indirect measure of neural activity via changes in near-infrared light absorption	Spatial: about10–20 mm Temporal: about 5 s	• Better temporal resolution than fMRI	• Lower spatial resolution than fMRI	• Test hypotheses for tasks that are not optimally suited for fMRI	“To investigate the processes underlying moral behavior, this research aimed to investigate

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
	of hemoglobin that measures changes in oxygenated blood flow to brain regions		• Low operating costs (after initial purchase) relatively to fMRI • Portable • Participant does not need to remain stationary • Allows for realistic interaction between subjects	• Can only detect activity on the cortical surface	paradigms (e.g., requiring movement or face-to-face social interaction) • Longitudinal studies, given its relatively low cost	neurophysiological and behavioral correlates of decision-making in moral contexts.” (Balconi & Fronda, 2020)
Transcranial magnetic stimulation (TMS)	Direct measure of causal relationship between neural activity and a	Spatial: accurate to about 5–10 mm	• Good temporal resolution • Portable	• It can only influence cortical	• Test whether a particular brain region might be required for	“Evaluate whether the ventromedial prefrontal cortex (VMPF) does mediate

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
	task by affecting neuronal firing (i.e., activating or suppressing of particular brain regions using electromagnetic fields)	Temporal: N/A	• Can allow for causal claims due to direct stimulation • Can both increase and decrease neuronal excitability • Noninvasive means of stimulating the brain	surfaces beneath the skull • Impact of machine noise and potential pain can affect participants • Limited coverage (researcher must select regions to test)	specific cognition and behavior • Test and resolve concerns about reverse inference.	preferential judgement." (Senior et al., 2011)
Transcranial direct-current stimulation (TdCS)	Similar to TMS but uses a current applied between electrodes	Spatial: accurate to about 10–20 cm	• Can indicate causal claims due to direct stimulation • Portable	• Less spatial and temporal resolution than TMS	• Test whether a particular brain region might be required for	"we hypothesized that cathodal (inhibitory) transcranial direct current stimulation (tDCS) will facilitate performance in a

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
		Temporal: N/A	• Well tolerated by participants • Can both increase and decrease neuronal excitability • Noninvasive means of stimulating the brain	• Side-effects (e.g., stinging sensation, headaches) last longer than with TMS • Technique continues to develop • Limited coverage (researcher must select regions to test)	specific cognition and behavior	flexible use generation task." (Chrysikou et al., 2013)
Heart rate variability (HRV)	Indirect measure of neural activity via assesses beat-to-beat changes in the heart rate over	Spatial: N/A	• Low entry costs • Portable • Access to real-time data	• Sensitive to pathological and physiological factors (e.g., respiration)	• ANS inference on behaviors, emotions, and mood	"investigating, in healthy subjects, the associations between acute mental stress and short/ultra-short

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
	time as a proxy for autonomic nervous system (ANS) activity and its effects on behavior	Temporal: milliseconds (sampling rate of 500–1,000 Hz)	• Availability of off-the-shelf wearable devices	• Sex, age, ethnicity, and physical activity can cause wide variance among subjects • Varying degree of quality and accuracy of devices	• "Well-being" correlates	term HRV features in time, frequency, and non-linear domains." (Castaldo et al., 2017)
Electrodermal activity (EDA)	Indirect measure of neural activity via changes in electrical conductance of the skin as a proxy for ANS activity	Spatial: N/A Temporal: seconds to minutes	• Portable • Participants do not always need to remain stationary	• Sex, age, ethnicity, and physical activity can cause wide variance among subjects	• Inference to emotion-related sympathetic activity	"how the chances of winning and bet size affected choice behaviour and psychophysiological arousal" (Studer & Clark, 2011)

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
				• Varying degree of quality and accuracy of devices	• Inference to behavior, emotions, attention, and mood • Understanding how sympathetic bodily arousal relates to regional brain activity	
Eye tracking	Indirect measure of mental states and processes through recording and analyzing eye movements and gaze patterns	Spatial: 0.5°–2° (VOG; less for EOG) Temporal: milliseconds (EOG; milliseconds	• Often portable • Participant does not need to remain stationary	• Usually requires a head piece, which can limit activities of the study	• Inference to attention (pop-out effect, top-down vs. bottom-up control) • Inference on behavior and cognition—not the direct	"Whether differences in social value orientation are reflected in specific patterns of information search that can be predicted across tasks." (Fiedler et al., 2013)

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
		to tens of milliseconds for VOG)		• Varying degree of quality and accuracy of devices	relationship with brain systems	
Computational Techniques/Modeling	Mathematical models, theoretical analysis, and abstractions of the brain to understand the principles that govern the development, structure, physiology, and cognitive abilities of the brain	Spatial: N/A Temporal: N/A	• Identification of scale interactions and dynamics in neural structures provides a framework for understanding the principles that govern how neural systems work • Access to latent variables that cannot be	• Complex techniques for computation	• Theoretical method for investigating the function and mechanism of the nervous system • Test hypotheses that can be directly verified by current or future biological experiments	“Compare two, or more, seemingly disparate cognitive neuroscience models to determine whether they share functional similarity.” (Ashby & Heile, 2011)

Method	Measures/ Assessments	Resolutions	Main Strengths	Main Weaknesses	Examples of Applications	Actual or Potential Use in Organizational Neuroscience Research
			directly observed from behavior			

Table 2. Functional Categories of Organizational Neuroscience Methods

Type of Test	Method
Association	Functional Magnetic Resonance Imaging
	Electroencephalography
	Heart Rate Variability
	Electrodermal Activity
	Functional Near-Infrared Spectroscopy
	Magnetoencephalography
	Neurogenetics
Necessity	Transcranial Direct Current Stimulation (cathodal)
	Transcranial Magnetic Stimulation
	Neuropharmacology
Sufficiency	Transcranial Direct Current Stimulation (anodal)
	Neuropharmacology (e.g., neurotransmitter loading)

Future research in organizational neuroscience will need to combine these perspectives into an integrated approach. Such an approach will have to both support multimodal assessments (e.g., convergence of multiple methods with different resolutions) as well as offer predictive analytic capabilities (e.g., move from correlational inferences to causal claims). As Bandettini (2015, p. 1) remarks: “as new methods for data acquisition are developed, fundamentally new questions about the brain may be asked (…) and new methods, tailored to the specific acquisition method and with the specific questions or applications in mind, are developed.”

Functional Magnetic Resonance Imaging

Functional Magnetic Resonance Imaging is one of the most fascinating and widely used imaging techniques in neuroscience research (Soares et al., 2016). Its principles were exposed in 1990 (Ogawa et al., 1990); fMRI leverages the magnetic properties of blood hemoglobin to infer functional activity in the brain. Thus, fMRI provides an indirect measure of the brain’s functional activity by measuring changes in oxygenated blood flow to different regions in the brain, with the assumption being that the regions that are receiving more oxygenated blood are those more involved in a given experimental/behavioral task or mental process.

The conceptual underpinning behind fMRI is based on evidence that when a brain region, or network of regions, is engaged in a mental activity, the relative blood flow to that (those) area(s) increases (Zago et al., 2012). As the working neurons undergo cellular metabolism, oxygenated hemoglobin is transformed into deoxygenated hemoglobin (D'Esposito et al., 1999). These states have identifiable magnetic properties that can be appreciated in what is referred to as the Blood Oxygen Level–Dependent (BOLD) signal, which allows scientists to infer which brain regions are "activated" during a task. Because fMRI is based on blood flow changes, its temporal resolution is limited by the hemodynamic response (i.e., how long it takes the blood flow to reach a certain area), which peaks about 5 seconds after the neurons begin to fire; the spatial resolution, however, is very high, usually on the order of just a few millimeters, but also can be less than a millimeter with modern scanners (Glover, 2012).

Given the high magnetic power and sensitivity of the scanners, fMRI studies require carefully designed settings and procedures. They must be conducted in a magnetically shielded suite in order to reduce disturbances that could interfere with the data. Similarly, research participants must lie still in the scanner to avoid disrupting the data acquisition with their movements. Moreover, the magnet's strength is extraordinarily high (typically between 1.5 and 3 Tesla [T], but many can be up to 7T), so there must not be any magnetic materials in the scanner room: participants and researchers must remove metal objects (jewelry, belts, etc.), and participants may be requested not to have specific types of makeup or tattoos (Callaghan et al., 2019). Given these caveats, fMRI is overall a highly safe neuroimaging technique for all involved: it is noninvasive, and it does not involve exposure to any harmful chemicals or radiation (Huettel et al., 2008). Depending on the nature of the experiment, a full fMRI protocol can take as little as 30 minutes to as long as a few hours.

Because the magnetic field reaches areas deep below the skull, it is possible to acquire high-definition images of subcortical areas. It is also good practice to include in a study design structural (anatomical) brain acquisitions (Faro & Mohamed, 2011) that can provide the basis for the co-registration process of analysis. These images are composed of small, three-dimensional "cubes" called voxels, which contain information about the imaged area obtained from the scanning. In simpler terms, one can think of a voxel as the 3D equivalent of a digital camera's pixels.

Specifically designed statistical and analytical programming packages must be used in fMRI research (see, for a review, Soares et al., 2016). For instance, recording and analyzing fMRI data requires several pre-processing techniques that are closely aligned to the research protocol and design used. The most common steps include temporal correction between slices (i.e., slice timing), spatial correction (to correct for movement of the head in the scanner), distortion correction due to inhomogeneities of magnetic fields between images, co-registration and normalization of the brain in the study to standard reference groups and anatomical scans, and temporal/spatial filtering (smoothing) to enhance signal-to-noise ratio (Massaro et al., 2020).

Overall, the use of fMRI has received ongoing positive feedback among multiple scientific communities, as shown in the popularity of fMRI publications (Logothetis, 2008). While fMRI is an excellent neuroimaging tool for research, it has received some criticisms, too, which are often amplified by detractors of organizational neuroscience (e.g., Lindebaum, 2013). For instance, one provocative study examining a dead salmon showed that without appropriate analytical steps even that fish could return fMRI-detected "brain activity" (Bennett et al., 2009). More recently, an analysis of over 40,000 fMRI studies identified issues with spurious correlations and findings interpretation (Eklund et al., 2016). Yet, many of these concerns are already known among the fMRI community of researchers, and there are several references available in the specialized literature to address them (e.g., Lindquist, 2008). For the benefit of the readers here, it shall be sufficient to remark that because the data obtained from fMRI have a complex nature and high levels of noise from multiple sources, only accurate statistical modeling and research design throughout—from sampling size to signal activity computations—can help overcome possible concerns about the quality of research findings.

Electroencephalography

Electroencephalography (EEG) is a neuroimaging technique with almost 100 years of use (da Silva, 2013). EEG techniques can be traced back to the late 19th century (Niedermeyer & Schomer, 2011): The first human EEG recording—often marked as its discovery—is attributed to the German psychiatrist Hans Berger in 1924 (Berger, 1929).

EEG is a technique in which cortical brain activity is recorded via electrodes placed on a person's scalp. These electrodes assess the electrical potentials (i.e., the brain's electrical fields) produced by neuronal activity. In contrast to fMRI, which provides an indirect indicator of brain activity (i.e., blood flow variations), EEG measures actual neural activity. Specifically, EEG captures postsynaptic hyperpolarization (i.e., inhibitory activity) or depolarization (i.e., excitatory activity) of the local population of similarly oriented layers of neurons in the cortex. After being amplified and aggregated for the local population, these signals are generally averaged based on a given experimental event, such as the presentation of a stimulus. This averaged electrical potential is referred to as an Event Related Potential (ERP).

In a typical EEG study, the placement of the electrodes follows an internationally recognized standard referred to as 10:20, meaning that the distance between electrodes is either 10% or 20% from the back, or front, of the head (Khazi et al., 2012). High-density recordings are possible, using up to 256 electrodes, which are usually attached to a cap (or net) for the convenience of placing them on the scalp. An electrolytic gel is used to improve the conductivity from the skin to the electrode; this gel, however, can leave a residue. Alternatively, so-called dry solutions are now possible; they offer a relatively quick setup time and have been found to be more tolerated by participants (Hinrichs et al., 2020).

Like fMRI, EEG recordings are susceptible to disturbances from other sources (i.e., "noise"), which include interference from electrical machinery or equipment, eye blinking, and mouth and jaw movements (Huster et al., 2014). Intriguingly, recent technological developments have allowed portable and low-cost EEG solutions, that, by ensuring ecological validity (Massaro, 2017), are greatly extending the use of EEG to a variety of contexts of relevance for organizational research and practice. For instance, the possibility of collecting data from large numbers of participants simultaneously (Krigolson et al., 2017, p. 8) is opening intriguing avenues to extend organizational neuroscience research from the individual to dyadic and team units of analyses. For one example, Stevens and Galloway (2017) used EEG data streams and advanced methods of entropy to assess across-brain patterns when teams performed coordinated tasks.

Technological advancement in the analysis of EEG data has also provided the opportunity to identify EEG correlates of organizational behaviors (Waldman et al., 2011). A notable method in this respect is called *quantitative EEG (qEEG)* (Nuwer, 1997). Here, methods of signal analysis using Fourier transforms and time-frequency analysis are applied to EEG, focusing on patterns of activity such as phase synchrony and magnitude synchrony. The qEEG method has also found increasing use in neurofeedback applications (Massaro, 2015), wherein brain activity is monitored and applied to modulate certain sensorial stimuli apt to be controlled by the research participant or user.

Magnetoencephalography

Magnetoencephalography (MEG) is similar to EEG in that it also relies on the electromagnetic signals that arise from neuronal activity. The difference between the two techniques is that MEG measures brain activity using magnets rather than electrodes. Despite being close in nature to EEG, MEG's discovery was made almost half a century later, in 1968 by the nuclear physicist David Cohen (Cohen, 1968). The initial recording devices were small and wearying to use; the more modern, helmet-like magnetometers were developed in the 1980s. When using MEG, participants sit, or lie, in a shielded room with their head placed in a scanner; wearable and slightly more portable versions of MEG are available in a "helmet" form.

Like EEG, MEG offers a direct measure of neuronal activity. MEG boasts a higher temporal resolution, of mere milliseconds, and spatial resolution (about 3 mm) than EEG because the magnetic fields are less distorted than electrical fields as they pass through the skull. The magnetic signals are weak and require superconducting sensors referred to as superconducting quantum interference devices (SQUIDs) (Hari & Salmelin, 2011). Because of these properties, MEG is ideally suited to reveal patterns of activation within and among networks of cortical areas in the human brain; moreover, MEG can assess sub-cortical activity (Singh, 2014), which can thus be directly associated to psychological states linked with "inner" regions of the brain, such as correlates of emotions in the so-called limbic system.

Another benefit of MEG is that the setup time is less cumbersome than with EEG, because there are no electrodes to place on the skull and no gel to use. To ensure accuracy in localizing the source of brain activity, MEG is often paired with anatomical imaging (e.g., MRI) to get a clear representation of the brain areas involved in a certain process or activity. As a result, this pairing of techniques may incur additional costs, on top of an already expensive procedure.

Functional Near-Infrared Spectroscopy

Functional near-infrared spectroscopy (fNIRS) is one of the most novel techniques proposed for organizational neuroscience investigations. It is a noninvasive optical imaging technique that measures changes in hemoglobin concentrations within the brain by means of hemoglobin's characteristic absorption spectra in the near-infrared range (Sangani et al., 2015). Its origins trace to 1977, when Jöbsis (1977) demonstrated the possibility of detecting changes in adult cortical oxygenation during hyperventilation by near-infrared spectroscopy. What followed, a few decades later, was the proposal that BOLD signals could be measured without fMRI. This finding led to functional applications of NIRS, with the first fNIRS human studies, adopting single-site measurements, being performed in the early 1990s (Ferrari & Quaresima, 2012).

Human tissues are relatively transparent to light in the NIR spectral window. NIR light is either absorbed by pigmented compounds or scattered in tissues and can penetrate human tissues (Delpy & Cope, 1997). Importantly, fNIRS is weakly sensitive to blood vessels larger than 1 mm because they completely absorb the light. Given that the arterial blood volume fraction is approximately 30% in a human brain (Ito et al., 2005), fNIRS offers the potential to obtain information mainly concerning oxygenation changes occurring within the venous compartment in the brain (Pinti et al., 2019). Like fMRI, fNIRS relies on the hemodynamic response. As such, its temporal resolution is similar to fMRI's, about 5 seconds; its spatial resolution, however, is lower than that of fMRI, being around 10–20 mm (Glover, 2012).

One of the major strengths of fNIRS, and one of the reasons why it is a promising technology for organizational neuroscience, is represented by the availability of relatively low-cost, portable, wireless instruments. As with EEG, these devices can be used in simultaneous brain activation studies on multiple subjects (e.g., Cui et al., 2012, Holper et al., 2012; Jiang et al., 2012). Indeed, over the years, fNIRS has made important contributions toward the understanding of how the human brain functions and its applications are continuing to grow as more researchers from diverse fields utilize the technology.

Transcranial Magnetic Stimulation

Scientists have used electricity to stimulate the brain as early as the late 1800s (Sarmiento et al., 2016). In 1939 Cerletti was the first to use electric stimulation, or electroconvulsive therapy (aka shock therapy), to treat certain mental conditions (Cerletti, 1940). Some 40 years later, Merton and Morton (1980) used electrical shocks to stimulate the motor cortex, a technique referred to as transcranial electrical stimulation (TES). However, this approach was a deeply painful and unpleasant process, so researchers began looking for more suitable and acceptable alternatives. In 1985 Barker et al. (1985) discovered that magnetic fields could stimulate the brain, which prompted the development of transcranial magnetic stimulation (TMS).

In lay terms, TMS is akin to the inverse of MEG. A transient electrical current is passed through a coil, producing a magnetic field; this coil is then placed above a particular area of the scalp so the magnetic field "travels" through the skull into a target brain area, where it manipulates the activity of the target neurons. This manipulation can either activate neurons or, if the current is pulsed repeatedly (rTMS), create a temporary "virtual lesion" (Bolognini & Ro, 2010; Walsh & Cowey, 2000). Because of its ability to activate or temporarily deactivate brain's regions, TMS is one of the few functional techniques that can causally identify which brain regions are recruited for a certain task or mental process. In other words, unlike correlational methods, TMS allows researchers to test cause-effect hypotheses, for example, that a certain brain area is responsible for a certain behavior. Unlike other methods that can make such causal attributions (e.g., lesion studies, direct neuronal stimulation), TMS is safe and noninvasive. However, it is worth noting that it can also affect cortical areas just beneath the skull (Hallet, 2007).

TMS is not a recording technique as such, but it does have good accuracy in terms of the specificity of the brain areas it stimulates, usually accurate to within a few millimeters. The duration of the effect is contingent on the stimulation; given that it relies on electromagnetic properties, the effects can be noticed almost immediately, within milliseconds (Stewart & Walsh, 2006) and can last up to a few minutes (Eche et al., 2012).

Transcranial Direct Current Stimulation

Another technique using electromagnetic stimulation is transcranial direct current stimulation (tDCS). The roots of tDCS date back well over 200 years, with Galvani and Volta's work in the late 1700s (Sarmiento et al., 2016). Yet it was not until 1998 with Priori's work (Priori et al., 1998) that tDCS was shown to affect cortical excitability (Brunoni et al., 2012).

The technique involves applying two electrodes to the scalp and running a constant, weak current between them and through the target brain area, usually for a few minutes at a time. Depending on the electrode generating the current pulse (the anode or the cathode), this stimulation can either excite or inhibit the target area (Thair et al., 2017). Like TMS, tDCS is not a recording technique; rather, it is a manipulation technique. Because it involves applying a sustained current to a brain area, compared to TMS, the spatial resolution is poorer. Moreover, because the current must be sustained, it can take minutes before effects are observed (Thair et al., 2017; Wagner et al., 2007).

Heart Rate Variability

Heart rate variability (HRV) analysis is a methodology that differs from those reviewed so far because it does not directly focus on brain activity; instead, it looks at activity of the autonomic nervous system (ANS) and its effects on behavior and cognition (Massaro & Pecchia, 2019). Among other things, the ANS assists humans in the regulation of behavior, bodily reflexes, and physiological states (Robertson et al., 2012). There are two branches of the ANS, which work complementarily to one another: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS is typically the system that prepares the body for action in response to a stimulus or event—the so-called fight-or-flight response. The PNS works to calm the body down—the rest-and-digest response.

While work by Rosenblueth and Simeone (1934) in the early 1930s paved the way for HRV, it was only in the 1970s that research exposed the intimate relationship between heart rate and the brain. This is best characterized by Lacey and Lacey (1978, p. 99), who suggested a "two-way communication between the heart and the brain": they found that as heart rate greatly decelerated, the reaction time of an individual was faster, suggesting better attention and preparation for action. As Morris and Thompson (1969) suggested, a lower heart rate is associated with tasks that require careful attention to external stimuli, whereas a higher heart rate is linked to cognitively demanding tasks. Scientists have rapidly advanced the understanding and use of HRV in behavioral research, leading to the establishment of international standards and parameters for its measurement (Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology, 1996).

For the purpose of this article, HRV analysis can be best seen as an unobtrusive way of assessing the effects of the ANS on the heart. HRV offers a measure of the fluctuation between consecutive heartbeats resulting from ANS influence (Montano et al., 1994) and can be affected, even on a short timescale, by factors such as breathing, stress, and physical activity (Castaldo et al., 2017). Indeed, with equipment that has a sampling rate between 500 and 1,000 Hertz, even small changes in heart rate can be detected easily.

While HRV is becoming a popular feature in consumer-grade fitness products, it requires several complex steps to ensure accuracy when used for research purposes. These steps include, among others, looking at acquisition of the signal, correction of abnormal beats and artifacts, computation of inter-beat intervals, and, finally, extraction of HRV features or indices. Stable detector algorithms (e.g., Pan & Tompkins, 1985) are often deployed to perform these steps and provide output visualizations for analysis, which generally include extraction of the characteristics of the heart signal and waveform classification and recognition.

The variations in heart rate can be evaluated by a number of analytical methods, each returning specific features. The simplest are the time domain indices of HRV, which quantify the amount of variability in measurements of the time period between successive heartbeats.

Frequency domain analysis is also widely used in behavioral research, and it shows how spectral power (mostly variance) distributes as a function of frequency. Some components are distinguished in a spectrum calculated from short-term recordings of 2 to 5 minutes and include High Frequency (HF; frequency activity in the 0.15–0.40 Hz range) and Low Frequency (LF; frequency activity in the 0.04–0.15 Hz range) power. Several researchers consider the LF/HF ratio as indicative of sympathetic to parasympathetic autonomic balance (Eckberg, 1997; Montano et al., 1994).

Electrodermal Activity

Electrodermal activity (EDA) is another method that relies on physiological markers to infer ANS activity. EDA refers to the electrical conductance of the skin and its changes in response to sweat secretion resulting from sympathetic neuronal activity (Critchley, 2002). Its phasic changes are often referred to as the galvanic skin responses (GSR). Like HRV, the measurement is linked to the temporal qualities being the conductance per second (siemens).

The study of electrodermal activity of the skin began in 1888 by Romain Vigouroux (Vigouroux, 1888), who examined skin conductance as a marker for clinical diagnosis, as changes in EDA in response to various stimuli were measured (Dawson, Schell, & Filion, 2000). Throughout the 20th century, however, EDA became a widely used and sensitive index of emotion-related sympathetic activity (Boucsein, 1992; Fowles et al., 1981; Venables & Christie, 1980).

This coupling enables EDA to be used as an objective neuroscience index of human behavior, such as, for example, emotional responses and conditioning. Indeed, lesion studies of patients and use of imaging techniques have “clarified the contribution of certain brain regions—implicated in emotion, attention, and cognition—to peripheral EDA responses” (Critchley, 2002, p. 132).

Eye Tracking

Eye tracking is generally a method of assessing either the point of gaze or the motion of an eye relative to the head. This information is then used to infer people’s mental states based on the rationale that that several brain regions are involved in visual processing and the coordination of eye movements (Meißner & Oll, 2019).

Two of the most established eye tracking techniques are electro-oculography (EOG) and video-oculography (VOG). EOG detects electrical activity, more specifically the voltage difference of eye movements between the cornea and retina, quantified by recordings taken from electrodes applied to the skin surface at fixed points around the eye(s) (Cowley et al., 2016). Because it measures electrical signals associated with movement, it provides high temporal resolution (milliseconds) and can even be used when the eyes are closed (e.g., during sleep or at sleep onset). However, it offers limited spatial resolution, has a drifting baseline (i.e., there is background interference to the signal not related to eye movement), and exhibits high-frequency noise, as a result of factors such as power lines or clenching of the jaw (Eggert, 2007).

Devices for VOG measurements are camera-based and track the movements of the eye via changes in features, such as the pupil, iris, sclera, eyelid, and light source reflections on the surface of the cornea. Because VOG does not require touching the participants, VOG offers a more ecologically valid data collection procedure relative to EOG and is more widely used. Compared to EOG, VOG devices provide better spatial resolution (typically 0.1–1 degrees of visual angle); with a sampling typically between 30 Hz and 1 kHz, the temporal resolution of many visual eye tracking devices is quite impressive (1 to 30 ms; Cognolato et al., 2018).

Computational Methods

Computational methods, generally referred to as computational neuroscience, are yet to be included as part of the organizational neuroscience toolkit. The roots of computational neuroscience can be traced back to 1952, when Hodgkin and Huxley were able to quantify with a formula the action potential (think of an explosion of electrical activity that is created by a depolarizing current) of a neuron (Hodgkin & Huxley, 1952). However, it was not until the seminal book *Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems* by Dayan and Abbott (2003) that a unifying understanding of computational neuroscience emerged in the literature.

In sum, computational neuroscience is best characterized by two approaches. On the one hand, theoretically, it uses experimental and analytical means to understand the structure and function of single neurons, neural circuits, or brain systems. On the other hand, computationally, it involves the simulation of numerical/analytical models and/or their experimental verification (Schutter, 2008).

While there is much potential for computational neuroscience to advance management research, the barrier to entry is substantially high. The mathematical knowledge required is extensive and without the necessary formal background, many may find it "intimidating" (Anderson, 2014). However, tools designed for computational modeling in neuroscience can assist researchers in their studies (Blundell et al., 2018). Finally, while computational neuroscience is yet to blossom in organizational research, there are several instances in which the use of machine learning and Artificial Intelligence (AI) is finding positive reception within the management scholarly community (Lévesque et al., 2020).

The Current Literature in Organizational Neuroscience

To analyze the state-of-the-art research thus far in organizational neuroscience, a literature review among some the most established management scholarly journals was performed. The journals listed in the *Financial Times* 50 list *<https://www.ft.com/content/3405a512-5cbb-11e1-8f1f-00144feabdc0#axzz4J1D8IOXa>* pertaining to management and organizational disciplines were selected; this list was later integrated with other journals generally recognized as top of the field, or outlets that specifically cover organizational neuroscience (Table 3). While practitioner-oriented journals were initially excluded, this body of knowledge was later combined with a broader search on public repositories (i.e., Google Scholar, PubMed).

Table 3. Journals Selected for the Initial Literature Search

Journals (*_FT_ List)
*Academy of Management Journal**
*Academy of Management Review**
*Administrative Science Quarterly**
*Entrepreneurship Theory and Practice**
*Human Relations**
*Human Resource Management**
*Journal of Applied Psychology**
*Journal of Business Ethics**
*Journal of Business Venturing**
*Journal of Management**
*Journal of Management Studies**
*Management Science**
*Organization Science**
*Organization Studies**
*Organizational Behavior and Human Decision Processes**
*Research Policy**
*Strategic Management Journal**
Journal of Organizational Behaviour
Journal of Management Inquiry

Journals (**FT* List)
Leadership Quarterly

Note. FT = Financial Times

The search included keywords such as “organizational neuroscience,” “neuroscience,” “fMRI,” “EEG,” “eye tracking,” “heart rate variability,” and so forth, including possible terms’ variations. While the term “organizational neuroscience” appeared in a peer-reviewed article only in 2011 (Becker & Cropanzano, 2010) an extended search was performed covering the period between 2005 and 2020.

A total of 631 papers were retrieved. The key inclusion criteria were for work that: (a) experimentally used neuroscience methods and/or (b) primarily used neuroscience theory to advance management and organizational studies. Those works that returned the search words just as pertaining to bibliographies or showed contributions with a minimal theoretical role of neuroscience were excluded. The short list amounted to 197 papers, of which, following analysis of the abstracts, 89 were retained (concordance rate among authors k = 0.87). Next, these works were clustered into more “traditional” disciplinary areas as elaborated in the following sections of this article. The areas primarily covered were *Organizational Behavior*, *Applied Psychology*, *Business Ethics*, *Entrepreneurship*, *Strategic Management*, and *Human Resources and Occupational Research*.

Organizational Behavior and Applied Psychology

Organizational behavior topics dominate the current body of works in organizational neuroscience (Becker & Cropanzano, 2010; Becker et al., 2011; Butler & Senior, 2007). Methodologically, fMRI and EEG are the most prominent techniques used in this domain (and more generally across the retrieved literature).Niven and Boorman (2016) claimed that fMRI has the potential to cover a “diverse range of organizational phenomena, including leadership, coaching, justice, social influence, Machiavellianism, decision-making, and self-control.” Waldman and colleagues (Waldman et al., 2011) pioneered a substantial body of works leveraging the properties of EEG to investigate leadership behavior in the workplace. These, however, are not the sole techniques that can help to advance investigations of organizational phenomena and actors: HRV (Matta et al., 2017), computational neuroscience (Baldassi et al., 2020; Webb et al., 2020), eye-tracking (Lohse & Johnson, 1996; Stock-Homburg et al., 2020,), and electrodermal activity (Christopoulos et al., 2016; Lajante et al., 2012) have all shown the potential to advance both organizational behavior theory and practice.

One such reason is that neuroscience investigations allow the identification of the “inner working” mechanisms of organizational actors, which in turn are useful to understand more about their behaviors and to craft possible interventions to improve them (Waytz & Mason, 2013). For example, a study using HRV by Matta and colleagues (2017) found that inconsistency of fairness, or fair treatment, had a greater impact on stress levels, assessed via

HRV, than being consistently treated in an unfair manner. Another study expanded on this topic by testing the effect of perceptions of unfair pay on healthy individuals. Falk et al. (2018) found that perceptions of unfair pay affect the productivity and health of employees: higher levels of unfairness go along with lower heart rate variability. Thus, this finding provides a physiologically informed understanding of the association between outcomes that are perceived as unfair and physiological correlates. Moreover, it has been found that in unfair outcomes, greater activation is present in areas of the brain associated with emotions, such as the anterior cingulate cortex, anterior insula, and the dorsolateral prefrontal cortex (Dulebohn et al., 2009).

One of the first and most studied areas of research in organizational behavior using neuroscience is *leadership*. Studies in leadership have covered both the examination of the leaders themselves and the effects on teams and followers (Boyatzis, 2014; Waldman et al., 2011). Charismatic leadership in particular continues to be proposed as a key area for organizational neuroscience research (Van Vugt & von Rueden, 2020). Existing works examine how followers of charismatic leaders show deactivation of prefrontal cortex activity (Schjoedt et al., 2011), the emergence of leadership following eye-tracking in teams (Gerpott et al., 2018), and how inspirational statements intertwined with a leader's group relationship show increased activation in brain areas that are typically implicated in controlling semantic information processing (Molenberghs et al., 2017), among other topics. Moreover, there are reports of strong correlations between brain activations and leadership performance (Tuncdogan et al., 2017). For instance, interconnectedness between regions of the brain focused on creativity and those associated with expressing and regulating emotions, such as those associated to right hemispheric coherence, show significant correlation with visionary communication and charismatic leadership (Waldman et al., 2011).

Other leadership research aspects have been investigated with neuroscience as well. For instance, by using EEG, researchers have been able to identify transformational leaders with 92.5% accuracy (Balthazard et al., 2012). In the same study, the authors looked at the literature differentiating transformational and nontransformational leaders: the prefrontal and frontal lobes were salient across most of the literature, but there was also inclusion of findings in the temporal, central, parietal areas, and occipital lobes. This evidence indicates that a wide neural network may be at play for a transformational leader. In a follow-up study, it was found through observing connectivity in different regions of the brain that less EEG coherence in the frontal lobes is associated with greater adaptive decision-making for military leaders (Hannah et al., 2013). Another work found that there is a marked difference in the left prefrontal cortex of leaders who displayed confidence and optimism in comparison to those leaders who did not (Peterson et al., 2008). Finally, in recall of experiences with resonant versus dissonant leaders, memories of resonant leaders are shown to activate areas associated to the mirror neuron system (MNS) and the default mode network (DMN) (Boyatzis et al., 2012). The default mode network is generally related to social cognition and activated when people are interacting with others (Raichle & Snyder, 2007). The mirror neuron system is also related to social cognition; however, it is reported to be salient in empathy and imitation as well (Decety & Michalska, 2010).

Similarly, research has found that coworkers can unwittingly mimic behavior by engaging the so-called mirror neuron system (Becker & Cropanzano, 2010). Several studies have discussed in what ways coworker dynamics can influence individuals in organizations. For instance, research has shown that preference selection is influenced by coworkers who are deemed to be socially relevant (Mason et al., 2009); that social interactions can act as a stabilizer for stress levels dependent on the support provided to colleagues (Baethge et al., 2020); and that a coworker can act as an enabler to adopt innovation based on implicit and explicit emotions (Håkonsson et al., 2016). Along with this body of research, one study has found that "Machiavellians" show enhanced activation of regions in the brain including the MNS and that these are crucial to perception of emotions (Bagozzi et al., 2013).

Another timely area of research that has recently found room in organizational neuroscience concerns gender issues. Research has shown that the "female brain" may be more attuned to social risks (Irwin, et al., 2015), as the naturally high levels of the neurotransmitter oxytocin in females may enhance trusting behavior (Ryan, 2017). This concept may have implications for several workplace scenarios in which women may be seen as more likely to treat others "as if they are trustworthy" (Irwin et al., 2015), as a result of their high levels of trust.

Similarly, research focusing on the relationship between justice information processing and neural activity has shown that this link is significantly influenced by gender differences, with greater neural activation for females than males during consideration of justice information. Specifically, researchers have found higher levels of brain activation in the ventromedial prefrontal cortex (vmPFC) and ventral striatum brain regions during procedural justice in females relative to males (Dulebohn et al., 2009). These findings suggest that females may react more to (un)fairness, even if these reactions do not seem perceptible to others through expressions and behavior changes (Dulebohn et al., 2016). While there may be certain neural differences occurring between genders, using gender as a basis of differentiation in research may create some unfavorable research biases. For instance, Halko and colleagues included only male entrepreneurs, as prior research indicated that "why women entrepreneurs are less inclined to grow their businesses" (Halko et al., 2017, p. 386).

In addition to the topics reviewed here, there is a growing body of research using neuroscience to examine a variety of behavioural constructs relevant for the workplace. Some examples include the impact of facial stigmas on interview performance (Madera & Hebl, 2011) and the use of one-time financial compensation to regain trust (Haesevoets et al., 2018).

Finally, an area of investigation that is likely to emerge in the next few years is research on emotions. Despite limited empirical research to date, researchers (Healey et al., 2017, 2018) have proposed a framework that connects neuroscience to social and environmental forces as significant components of complex emotional organizational life. More recently, Massaro (2020) advanced a theoretical model based on the combination of organizational neuroscience and Affective Events Theory (Weiss & Cropanzano, 1996) and reviewed neuroscience research on emotions with a specific look at workplace phenomena.

Business Ethics

An area of research that has seen exponential interest in using neuroscience theory and insights is the field of business ethics, generally under the broader framework of neuroethics. The term "neuroethics" is "concerned with ethical, legal and social policy implications of neuroscience, and with aspects of neuroscience research itself" (Illes & Bird, 2006, p. 511). Thus, the focus is not only on the research and findings associated with ethical research topics, such as morality and justice (Cropanzano et al., 2017; Massaro & Becker, 2015), but also on the ethical use of organizational neuroscience research, findings, and implementations (Robertson et al., 2017).

As regards the first aspect, research has indicated activation of specific brain regions in moral dilemmas or situations—of note, the vmPFC and amygdalae—likely acting as sites for socially inappropriate behaviors and to assess reward or punishment (e.g., Greene & Haidt, 2002). In a meta-analysis of 123 data sets, researchers found that the medial prefrontal cortex, lateral orbitofrontal cortex, amygdala, temporoparietal junction, precuneus, and anterior insula were all areas activated in and/or associated with moral tasks (Eres et al., 2018). Building on these insights, Orlitzky (2017) suggested that a dual system is involved and responsible in shaping moral judgement. Concurrently, Cropanzano et al. (2017) proposed a framework that untangles key processes of deontic justice: the use of justice rules to assess events, cognitive empathy, and affective empathy.

Waldman and colleagues have also found that the interaction between moral relativism (i.e., having ethical principles that adapt to situations) and idealism (i.e., an absolute attempt to do no harm to others, regardless of situation) in a leader may mediate "the effects of the brain's default mode network—in the prediction of ethical leadership" (Waldman et al., 2017, p. 1285). This finding was later supported by studies looking at the balance between the Task Positive Network (TPN) and DMN for ethical leadership (Rochford et al., 2017), which proposed the opportunity to encourage ethical awareness training involving engagement of the DMN.

Finally, in examining learning strategies appropriate for moral decision-making, Christopoulos et al. (2017) explored via a computational neuroscience approach how differently valuation of choice is updated in dynamic environments. They suggested that it is important for organizations to understand such strategies in order to design systems and processes to "support or encourage desirable moral behaviours" (p. 710).

Entrepreneurship

Entrepreneurship is another recent area of interest in organizational neuroscience, although as recently as 2014 it had no empirical neuroscience studies published (Nicolaou & Shane, 2014; Nofal et al., 2018). It is not that the literature was quiet on recommendations: the early 2000s showed calls for using fMRI and EEG to infer correlates relevant for entrepreneurial cognition (Baron & Ward, 2004). Yet a decade later, even behavioral experimental approaches were still considered rare among the literature in entrepreneurship (Williams et al., 2019).

Thus, de Holan stated that more research was needed in this respect to grow “neuroentrepreneurship,” arguing that “we cannot afford to keep ignoring the foundational micro-antecedent of any human decision” (de Holan, 2014, p. 3). More recently, Massaro et al. (2020) expanded on this view by putting forward a methodological framework to conduct neuroimaging research in entrepreneurship.

Yet, in the past few years, despite framed under a “biology of entrepreneurship” perspective, several studies have been performed within the organizational neuroscience remit by identifying neurobiological markers for entrepreneurs (e.g., Eckhardt & Shane, 2010; Nicolaou et al., 2021; Shane, 2003; Shane & Venkataraman, 2000; White et al., 2007;). For instance, Bönte and colleagues (2015) found a significant association between prenatal testosterone exposure (PTE) and entrepreneurial intent. PTE results in “masculine patterns,” one of which is evident in the behavior of risk taking. This is an important finding for entrepreneurs that resonates with general human behaviors: People have biases in loss aversion—namely, when making choices for themselves, they will take a less risky option in comparison to when deciding for others (Andersson et al., 2016).

More recently, empirical work using fMRI has begun to appear in the entrepreneurship literature. By using fMRI, Shane and colleagues (2020) found that high passion of entrepreneurs (specifically founders of a start-up) could increase the engagement of investors watching the pitch by 39%. This finding corroborates the body of emerging research on the effect that passion can have in a pitch setting to influence funding decisions (e.g., Murnieks et al., 2016).

Passion indeed has a strong association with entrepreneurs’ perception of their ventures or start-ups. In another fMRI study, entrepreneurs and parents were monitored to understand in what ways reward, self-regulation, and confidence were associated with their bonding to the venture or the children (Lahti et al., 2019) Parents and entrepreneurs showed similar neural correlates of bonding, suggesting that founding entrepreneurs relate to their ventures as parents relate to their children.

Strategic Management

Another rather recent field contributing to organizational neuroscience is strategic management research. Powell suggested that “in strategic management, neuroscience offers new opportunities for strategy researchers to validate constructs, test theories, measure variables, and generate ideas, and it may offer ways to improve strategy practice” (Powell, 2011, p. 1495).

Laureiro-Martínez et al. (2015) used fMRI to look at attention and decision-making performance and found that consistently high performance depends on the ability to shift between exploitation and exploration, which in turn depends on stronger activation of brain regions responsible for attentional and cognitive control. In another case, research using heart rate measures has suggested that focusing on and projecting positive emotions can influence and encourage teams in exploration of alternate ideas and solutions (Håkonsson et al., 2016).

Human Resources and Occupational Research

Human resources (HR) and occupational research has traditionally had a variety of works using biologically informed methods or paradigms. Even though little organizational neuroscience research was found in a search of the selected HR journals, the field has accommodated neuroscience by investigating topics such as stress at work and employees' emotional responses. Unlike other areas of research, the focus has been primarily on biomarkers rather than brain imaging methods (Schulte & Hauser, 2012; Soo-Quee Koh & Choon-Huat Koh, 2007). This is likely due to the familiarity and facility of HR and occupational researchers with occupational health assessments that often provide opportunities to gather data from blood work or laboratory assays.

For example, in looking at cortisol assessments, Lundberg and Hellström (2002), analyzed the relationship between workload and morning salivary cortisol in women. They found positive correlations between the amount of overtime at work and morning salivary cortisol, with workers having excessive overtime reporting cortisol levels almost twice as high as those of women with moderate overtime or normal working hours. Building on this evidence, Elfering et al. (2017) also found an impact of job demands and control on weekend cortisol levels, with this effect being fully mediated by after-work fatigue. Similarly, Klumb et al. (2017) assessed variations in negative social interactions at work and at home along with workers' affect and cortisol levels, finding that only women showed a tendency for slowed decline of cortisol levels on more socially stressful days.

Research in the occupational domain has also seen increasing use of ANS measurements. For instance, McLaren (1997) compared male police officers with clerical workers on heart rate, blood pressure, and self-reported levels of stress and arousal, and found that clerical workers reported higher levels of stress and the police officers reported higher levels of arousal. in a comparable setting, Krick and Felfe (2020) revealed a positive effect of mindful intervention among police officers on heart rate variability coupled with a stronger reduction of psychological strain, health complaints, and negative affect.

Organizational Neuroscience Research Practice

It would be wrong here to not cover some concerns of the second aspect of neuroethics previously mentioned. For a review of common pitfalls in organizational neuroscience research thus far, readers can consult the work of Jack et al. (2019).

There has been a substantial critique of the use of neuroscience in organizational research—cautioning against it being a "panacea" and exposing concerns about a reductionist approach unsuitable to investigate organizational life (Lindebaum, 2015; Tracey & Schluppeck, 2014).

This body of work generally contends that organizational neuroscience may have little regard for the sensitivities of collecting data using neuroimaging techniques and risk of “reverse engineering” management constructs; moreover, it often confronts the quality and reproducibility of fMRI studies (e.g., Lindebaum, 2015). This position has, in turn, resulted in backlash from many supporters of organizational neuroscience (Ashkanasy, 2013; Butler et al., 2017; Cropanzano & Becker, 2013; Healey & Hodgkinson, 2014), and heeded calls for taking a more balanced approach. Overall, as it is apparent that organizational neuroscience is gaining acceptance and interest, it is important to reiterate that reductionists’ attempts are beyond the scope of the field and that, if dealt with appropriately, most of the methodological issues exposed so far in organizational neuroscience can be (and should have been) addressed with existing knowledge from mainstream neuroscience.

Phua and Christopoulos (2014) raised three issues that historically have led to misinterpretation of neuroscience in understanding behavior and that can offer a good platform to emulate for greater acceptance of organizational neuroscience. First, they recommend the need to look at how psychological models can work, not just which brain regions are activated; second, they recommend caution in using reverse inference—that is, inferring that a certain cognitive or behavioral process during the observation of brain activation has a direct and definitive involvement; and, third, they emphasize ensuring scholarly responsibility in appropriately dealing with complexity of neuroscience data sets and experimental designs.

Discussion and Opportunities for Future Research

The research evidence presented in this article puts forward organizational neuroscience as a thriving, novel scholarly field that, despite still being parceled across domains and topics, covers a variety of themes of interest for management and organizational research at large. Moving forward, researchers are tasked to build on such evidence and further advance research within an integrative, interdisciplinary approach. Indeed, as virtually any behavior and mental state can be associated with some neuro-physiological correlate, research opportunities are countless. While researchers must be attentive not to merely concept-monger established neuroscience evidence in management narrative, there are several opportunities to provide innovative contributions to both theory and practice.

For instance, management research at large can focus on identifying discrete biomarkers for emotions in the workplace. This avenue will be particularly appropriate as it would fully leverage the ability of neuroscience to capture data beyond participants’ awareness. Similarly, by using neuroimaging it will be possible to tackle important issues affecting contemporary businesses, such as assessing neural responses on entrepreneurial evaluations to expose potential judgement biases. Cross-fertilizing with neuroeconomics, strategic management will benefit by further extending the boundaries of behavioral strategy. For instance, valuable research questions involve investigating the neural micro foundations of dynamic capabilities. Similarly, research in organizational behavior and applied psychology will benefit by further researching team dynamics, possibly using multimodalities with wearables on HRV and EDA to complement recent EEG evidence. Finally, as anticipated throughout this article, many of the methods reviewed here—computational neuroscience above others–have been used in just a few publications in mainstream management journals, thus offering space for novel works to appear.

Within these thriving opportunities, managerial and organizational scholars can also take a more active role in neuroscience. For instance, many tasks and protocols used in mainstream neuroscience offer stylized facts, largely due to noise-reduction constraints. However, still little is known about the ability of these stimuli to fully reproduce real-life organizational settings. The task for organizational neuroscientists is to work jointly with organizational and neuroscience scholars and practitioners to validate protocols that can either confirm existing procedures or create new stimuli specifically apt to investigating the workplace. Correspondingly, by reflecting the importance of ecological validity, conducting research on settings that are more natural to the corporate environment offers intriguing opportunities for neuroscientists to move their research outside of the lab. Given the increasing number of commercially available wearable tools, spanning from EEG caps to HRV devices, this seems to be a highly promising and accessible avenue.

More broadly, organizational neuroscience can contribute to increasing movements of open science. Sharing data sets and preregistering protocols will offer further validity to research, minimize doubts of researchers, and ensure that the field can develop rigorously. In such a way, organizational neuroscience will also offer a natural entry point for management scholarship at large to take part in more extensive dialogues with other social, behavioural, and natural disciplines.

In conclusion, just as it was nearly impossible to cover all the benefits, issues, and technicalities of neuroscience methods, it is challenging to present the countless research opportunities that will populate organizational neuroscience in the years to come. To facilitate this research avenue, this article comprehensively reviewed the emerging field of organizational neuroscience. Specifically, the related methods were discussed and existing knowledge in the field was systematized. While organizational neuroscience has received increased attention, enthusiasm, and scrutiny, it is still in an infant stage. It is therefore fundamental for both novice and more seasoned researchers to become familiar with the foundation of this field and appreciate the more complete theoretical and methodological potential that neuroscience puts forward to advance management and organizational studies.

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