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How Organizational Cognitive Neuroscience Can Deepen Understanding of Managerial Decision-making: A Review of the Recent Literature and Future Directions

Michael J.R. Butler, Holly L.R. O'Broin, Nick Lee[1] and Carl Senior[2]

Aston Business School, Aston University, Aston Triangle, Birmingham, B4 7ET, UK, [1]School of Business and Economics, Loughborough University, Loughborough LE11 3TU, UK, and [2]Life and Health Sciences, Aston University, Aston Triangle, Birmingham, B4 7ET, UK
Corresponding author email: m.j.r.butler@aston.ac.uk

There is growing interest in exploring the potential links between human biology and management and organization studies, which is bringing greater attention to bear on the place of mental processes in explaining human behaviour and effectiveness. The authors define this new field as organizational cognitive neuroscience (OCN), which is in the exploratory phase of its emergence and diffusion. It is clear that there are methodological debates and issues associated with OCN research, and the aim of this paper is to illuminate these concerns, and provide a roadmap for rigorous and relevant future work in the area. To this end, the current reach of OCN is investigated by the systematic review methodology, revealing three clusters of activity, covering the fields of economics, marketing and organizational behaviour. Among these clusters, organizational behaviour seems to be an outlier, owing to its far greater variety of empirical work, which the authors argue is largely a result of the plurality of research methods that have taken root within this field. Nevertheless, all three clusters contribute to a greater understanding of the biological mechanisms that mediate choice and decision-making. The paper concludes that OCN research has already provided important insights regarding the boundaries surrounding human freedom to act in various domains and, in turn, self-determination to influence the workplace. However, there is much to be done, and emerging research of significant interest is highlighted.

Introduction

There is a growing biological interest within management and organization studies. Hannah *et al.* (2013, p. 406) term this a 'cognitive revolution', which has brought greater attention to bear on understanding how the mental processes of people may explain their behaviours and effectiveness. They go on to argue that, to date, 'this revolution has been limited largely to conjecture of what occurs inside the "black box" of leaders' (Hannah *et al.* 2013, p. 406), and suggest a similar revolution in methodology. For Hannah *et al.* (2013), this represents a multidisciplinary and multi-method approach to the conceptualization of management and organizations. Like many similar reports, Hannah *et al.* (2013) focus on neuroimaging research. However, there is a far wider diversity of methods and potential contributions available to researchers in the area (Lee *et al.* 2012; Senior *et al.* 2011), and the research reviewed in the present paper reveals this.

It is remarkable that practitioners appear to be running ahead of academics, quickly developing services based on neuroscientific technology. This has caused disquiet in academic spheres (e.g. editorials in *Nature Neuroscience* (July 2004) and *The Lancet Neurology* (September 2004)). Practitioners themselves have begun to raise concerns about the rush towards the use of highly technical tools such as neuroimaging, without an associated understanding of the scientific method (Watts 2014). In this context, it is incumbent on the academic community to research, share – and, perhaps most importantly, to critique – the underpinning assumptions and research findings related to what we term 'organizational cognitive neuroscience' (OCN). To this end, the present review brings together contemporary empirical research findings to contribute to the consolidation of the OCN field at this stage of its development.

In 2007, we noted that there was little coherence to the research that was appearing across various outlets and disciplines, melding methods and theories from cognitive neuroscience to research questions of interest to management and organization studies. In an attempt to provide coherence to the emerging discipline, we introduced the notion of OCN and edited a Special Issue of the *Annals of the New York Academy of Science* to serve as a starting point (Senior and Butler 2007). The definition of OCN was framed by the development of social cognitive neuroscience (Ochsner and Lieberman 2001). This was appropriate because OCN is a more applied form of social cognitive neuroscience. Lieberman's (2006) definition of social cognitive neuroscience is embedded in the social sciences, and includes the study of the processes in the human brain that allow people to understand themselves and others. Importantly, studies within this context are not restricted by methodology such as brain imaging (although it is certainly the most well-known technique used in social cognitive neuroscience). Similarly, OCN was first defined as:

> applying neuroscientific methods to analyse and understand human behaviour within the applied setting of organizations. This may be at the individual, group, organizational, inter-organizational and societal levels. Organizational cognitive neuroscience draws together all the fields of business and management, including their operation in the wider social world. It does this in order to integrate understanding about human behaviour in organizations and, as a consequence, to more fully understand social behaviour. (Butler and Senior 2007, pp. 8–9.)

However, later work expanded this definition, and helped avoid what would have been an unintended emphasis on method:

> The organizational cognitive neuroscience approach . . . is not concerned with only the application of neuroscience methodologies to organizational research questions. Instead, the term 'organizational cognitive neuroscience' designates a genuinely multidisciplinary approach, in terms of both theory and method . . . organizational cognitive neuroscience is not simply the study of brain systems themselves but may also incorporate the use of prior knowledge of brain systems to develop new hypotheses about organizationally relevant issues. Thus, it both provides a more inclusive scope and more clearly defines the key cross-disciplinary nature of organizational cognitive neuroscience, in that research in this area may contribute both to organizational and cognitive neuroscientific knowledge. (Senior *et al*. 2011, p. 805).

The present systematic review focuses on academic research related to OCN that has been reported within the last eight years (from 2007) to reveal how the field is developing. In keeping with the spirit of OCN, the review takes a multidisciplinary approach by drawing on the fields of social cognitive neuroscience, evolutionary psychology and management and organizations. Specifically, the objectives of the review were to: identify the range of current research within OCN and its implications for the field of management and organizations, focus on empirical studies, because it is here that data are being produced which are driving the theoretical understanding of OCN, and critically highlight the potential contribution of OCN.

In this paper, we first acknowledge and discuss the methodological debates and issues associated with OCN. This is followed by an outline of the methodology that was adopted for the systematic review. The empirical literature identified for review is found to be clustered around three subject areas: economics, marketing and organizational behaviour. Overarching contributions are considered, as are future emerging research directions within these three key areas.

Methodological debates and issues

In keeping with the method's dominance, there is a focus on particular concerns when conducting neuroimaging work, and especially functional magnetic resonance neuroimaging (fMRI) based research (Hedgcock and Rao 2009). There are studies that use alternative research methods (e.g. measuring hormone levels using salivary assays), and they possess their own unique caveats. How researchers are tackling the concerns is also considered.

Neuroimaging has attracted most concerns from those critical of neuroscientific research in business and other fields (Lindebaum 2013; Poldrack 2006). While the discussion often refers specifically to fMRI, these issues are relevant to all neuroimaging research (Lee *et al.* 2012). Rozenblit and Keil (2002) seek to limit the expectations for the explanatory depth of fMRI. This is partly because the technology is still in its relative infancy, currently there is no instrument that can record every aspect of any human decision-making at a cortical level (Giere 2006), and because there are methodological issues.

Esch *et al.* (2012) highlight the dichotomy of inferential needs across both practitioners and scientists as a significant methodological issue. In contrast to neuroscientists who may be interested primarily in mapping brain areas to mental processes, more applied researchers (e.g. consumer researchers), are focused on 'reverse inference' – reasoning backwards from specific brain activation to particular mental functions (Poldrack 2006). Poldrack (2006, p. 60) warns: 'It is crucial to note that this kind of "reverse inference" is not deductively valid, but rather reflects the logical fallacy of affirming the consequent.' He goes on to specify when reverse inference might be useful: 'in the discovery of interesting new facts about underlying mechanisms. Indeed, philosophers have argued that this kind of reasoning (termed "abductive inference" by Pierce), is an essential tool for scientific discovery.' (Poldrack 2006, p. 60). The discovery of new facts, however, is dependent on showing brain activation in a particular location: 'If a region is activated by a large number of cognitive processes, then activation in that region provides relatively weak evidence of the engagement of the cognitive process; conversely, if the region is activated relatively selectively by the specific process of interest, then one can infer with substantial confidence that process is engaged given activation in the region' (Poldrack 2006, p. 60). To date, however, brain imaging studies tend to provide a macro picture of activations occurring in the brain, which has the potential to result in false conclusions about which processes are engaged (Poldrack 2006).

Poldrack (2006, p. 60) suggests overcoming the limitation by moving to a more micro picture of activations. The opening of databases containing imaging results made accessible through the internet may allow researchers to build up a more complex understanding of micro activations. This in turn may facilitate the formulation of specific research questions at the micro level: 'By searching for studies that show activation in a particular location, one could potentially formulate an estimate of the selectivity of activation in that region.' Such databases are becoming realistically usable less than ten years after Poldrack's (2006) suggestion (see the OpenfMRI project initiated by Poldrack *et al*. (2013): http://www.openfmri.org).

Another issue is the overinterpretation of cerebral activation data. Hedgcock and Rao (2009) point out that the brain is a plastic organ, and it is likely that several cortical regions interact in decision-making in ways that are difficult to separate using instruments such as fMRI, which take measurements once every few seconds. It is incumbent on researchers to acknowledge limitations in designing and interpreting neuroimaging research. Tom *et al.* (2007), for example, use neuroimaging to test predictions from prospect theory that risk aversion for mixed gambles can be attributed to sensitivity to losses. However, they are careful to note that, although observed individual differences may be related to naturally occurring differences in dopaminergic function, the relationship between genetic variation in the dopaminergic system and impulsivity and risk-taking remains largely unknown.

Other studies are indicative of a larger body of contemporary cognitive neuroscience that has seen the emergence of more ecologically founded approaches. The innovative work of Montague *et al.* (2002) has linked two scanners to understand the neural structures that are implicated in the exchange of social dyad. Kanai *et al.* (2012) carried out a volumetric analysis (which is one of the other metrics that can be extracted from the fMRI scanner) to reveal that certain structures of the brain change in size as an effect of the degree of social interaction. Such work exemplifies the caveat that there are few cognitive neuroscientists who would consider the single brain scan to be the definitive approach to adopt. The results of fMRI procedures should always be used in conjunction with other technologies to guard against issues such as reverse inference. When such a position is taken, fMRI has deepened our understanding of human cognition and decision process (Senior *et al.* 2011). Take, for example, the work of Brian Knutson at Stanford University (Knutson *et al.* 2007, 2008c), which revealed the differential contributions of discrete aspects of the sub-cortical networks that are involved with the appraisal and eventual purchase intention of certain goods. He found that high-value vs low-value goods differentially activate such a network. This provides a direct insight into the neural underpinnings of appraisal of the so-called Veblen goods (Veblen 1899). This has also contributed to understanding of the behaviour that occurs within a market exchange (Smidts *et al.* 2014) and has been used to understand more about the pathologies that may occur within such exchanges (Wu *et al.* 2012).

More pragmatic concerns about neuroimgaging research often focus on the typically small sample sizes, which may restrict research quality or rigour. Dimoka (2010), for example, scanned 15 subjects after a behavioural lab experiment with 117 students of a major US university. Dulebohn *et al.* (2009) scanned slightly more participants (24 students: 12 male, 12 female) who met their research selection criteria. Small sample sizes are driven by fMRI-based research being costly, complex and invasive (Hedgcock and Rao 2009). The cost requires access to equipment typically available only at major universities or medical centres, along with trained personnel. The complexity emerges from the development of stimuli, the conduct of the study, and the collection, processing and analysis of large amounts of data. The invasiveness of the fMRI procedure means that the setting and the task are (like most laboratory experiments) removed from actual real choice situations – because participants are in a generally unnatural situation, often subject to discomfort and some level of stress. Sample sizes of 1000 or more are unlikely to be possible in a single neuroimaging study. (Hedgcock and Rao 2009.)

Recognizing that sample size is an important problem which may have an impact on ecological validity, the neuroscience community offers three counter arguments. First, Dulebohn *et al.* (2009), for example, argue that small sample sizes are common in fMRI studies, citing two *Science* articles (Eisenberger *et al.* 2003; Gehring and Willoughby 2002). Dulebohn *et al.* (2009) also argue that the studies yield important and valid research findings. Second, as a means of increasing sample size, open access databases of fMRI data sets (e.g. the OpenfMRI project), which will ensure that data are available to the wider community, are beginning to develop. Third, cognitive neuroscientists are driving technological innovation (Burgess 2013; Vul *et al.* 2009), aimed at improving methodologies and their inferential capabilities. Technological innovation has also seen insights into human cognitive function and clinical therapy (Senior and Lee 2013). Take, for example, an electroencephalogram trace (between 6 and 10 Hz or Theta band) that indicates a successful response to pharmacological intervention in patients suffering from severe clinical depression (Broadway *et al.* 2012). In light of the money lost every year to industry as a result of such illnesses, this development has the potential to influence organizational practice, and can be applied to understand more about the nature of reward processing in general (Juckel *et al.* 2012; Knutson *et al.* 2008b).

While much of the above discussion covered issues that are of particular concern to fMRI and other neuroimgaging research methods, studies that which use alternative research methods (e.g. measuring hormone levels using salivary assays) possess their own unique caveats. Take Apicella *et al.* (2008), who note that, if salivary testosterone is collected on only one day, claims about causality cannot be made, nor can the salivary testosterone measures be discussed as reflecting stable, trait-level values. They also note that the use of students as participants may limit the ecological validity of the study, because the results may not translate to other socioeconomic groups (although this latter issue is not unique to OCN research).

In contrast to Apicella *et al.*'s (2008) study, Coates and Herbert (2008) did get access to practitioners in their working environment, specifically, traders in a midsized trading floor in the City of London (260 traders). Coates and Herbert (2008) were also given access over a two-week period (including trial sampling). They followed 17 traders for eight consecutive business days, taking saliva samples twice per day. At each sampling time, traders recorded a variety of other information, including their profit and loss. Though there was a small sample, the trading floor 'was typical of most in terms of its physical setup; the assets traded; and the age, sex, and income distribution of the traders.' (Coates and Herbert 2008, p. 6167).

As with neuroimgaging research methods, small sample sizes are an issue. Verbeke *et al.*'s (2014) first study had 64 salespeople as subjects, their second 73 sales representatives, and they acknowledge that these studies are small. They counter by arguing that they 'employed a hypothesis-driven approach, targeting only two genes and based on theory from biology and psychology, which reduces the need for large sample sizes' (Verbeke *et al*. 2014, p. 11). Potential findings should always be interpreted in terms of the specific limitations that the study methodology brings with it.

Systematic review methodology

The previous section has critiqued the debates and issues surrounding the emergence of neuroimaging and alternative research methods. To gain an understanding of how far OCN research has explained human behaviour and effectiveness in management and organizations, a systematic review of the literature was conducted, following Tranfield *et al.*'s (2003) methodology. This includes a commitment to make the literature review replicable, scientific and transparent, and establishing a number of steps to frame the enquiry and present the results. The reason for taking this particular approach in relation to OCN is that (like most emerging disciplines) the field of research lacks clear paradigmatic consensus. An illustration of this is that OCN literature is spread across a number of specific fields of study, which may hinder researchers from gaining a coherent overview of the field. Indeed, during the review process, over a third of the articles that were considered through the inclusion/exclusion criteria came from a snowball process, rather than the database searches focused on business or psychology. This first stage of consideration did not identify articles that were published in neuroscience or general science journals. In short, there is a wide variety of ways in which OCN is defined and used in the literature, as well as a range of ways in which they are researched.

The first stage of the review procedure identified keywords related to cognitive neuroscience and management and organization sciences (Table 1). The keywords were divided into primary and secondary search terms. Primary search terms referred to the theoretical or methodological approaches either used or referred to; in this context, cognitive neuroscience and evolutionary psychology. Secondary search terms concerned the subject area discussed or investigated; management, business, organization and leadership. The search strings were applied to two search engines (EBESCO and the Thomson ISI Web of Knowledge Social Sciences Division) to identify relevant articles from both management and psychology literature. The database searches were limited to English language peer-reviewed journals. At this early stage of the process, the date of publication was unrestricted, and this resulted in identifying 657 articles.

Following the first stage, filter criteria were applied to reduce the number of articles for inclusion in the review. Specifically, articles were only included if the title, abstract, keyword or subject category referenced cognitive neuroscience as applied to management and organization sciences. In addition, articles were included if their full text included detailed discussion of cognitive neuroscience techniques instead of a brief mention as part of theory development. This was operationalized by avoiding articles that only briefly highlighted cognitive neuroscience in a cursory way, for example, in a one-line reference to the topic. Articles were also excluded if they used the terms 'management' or 'organization', but not in relation to organizational contexts: for instance, functional organization of the prefrontal cortex or the use of neural networks in waste-water management. This second, more focused, stage of consideration resulted in the retention of 57 articles for further study.

The third stage of the review procedure involved backward and forward snowballing applied to the reference lists of the remaining 57 articles. This ensured that important works in the field were included that might have been missed for a variety of reasons, including being published in unindexed sources such as book chapters. These articles were subjected to the decision criteria identified in stage two. A further 112 articles were included, bringing the total sample of papers to 169.

Fourth, we further restricted the search to empirical articles only, to enable a focus on methods and research findings, rather than speculative theory. 67 articles were retained after this stage. Finally, to fit with our research objective of focusing on academic research related to OCN that has been published from 2007, the date when the notion of OCN was introduced (Senior and Butler 2007), we only selected those articles published over the last eight years. This focus enables an analysis of how the OCN field is developing. That said, it is important to note here that the phrase 'organizational cognitive neuroscience' was not used as a selection criterion, given that the term is subsumed in other terms.

The review procedure was completed in 2013 (33 empirical articles were found) and replicated at the end of 2014 (seven more articles had been published, making a revised total of 40 articles). The 2014 review revealed that there has been a special issue published in the *Frontiers in Human Neuroscience* on the theme of Society, Organizations and the Brain: building towards a unified cognitive neuroscience perspective. This led to the inclusion of one extra article in the marketing cluster (Verbeke *et al.* 2014), making 34 articles in total. In addition, from the *Frontiers in Human Neuroscience* special issue, we have included an empirical article related to new developments in scanning methodology (Burgess 2013) and others that are related to our argument (Butler 2014; Foxall 2014). A further six articles were also found across a range of journals (Bakalash and Riemer 2013; Laureiro-Martinez *et al.* 2014; Minas *et al.* 2014; Pynta *et al.* 2014; Ravaja *et al.* 2013; Waegeman *et al.* 2014).

Table 1. Review procedure that was carried out for current report: based on Tranfield et al.'s (2003) methodology

Stage	Activity	Number of articles
1	Keyword search terms	657
2	Decision criteria to reduce the number of articles	57
3	Backward and forward snowballing to ensure that important works in the field were included	169
4	Empirical articles were selected for in-depth review of methods and research findings	40
	In 2014, replicated stages 1–4 one year after initial review to capture newly published articles	
5	Structured the sample around the emergent subject clusters: economics, marketing and organizational behaviour	40

During the last stage of the review procedure, after a close reading of the 40 empirical articles, the sample was structured into three clusters. These emergent clusters were defined by the literature itself and reflected the subject areas of economics (15 articles), marketing (13 articles) and organizational behaviour (12 articles). It is not surprising that economics and marketing emerged as clusters, given that neuroeconomics and neuromarketing are themselves well-known research areas. The 40 empirical articles are reviewed in detail and set in the context of the breadth of literature published about OCN. It is the three clusters of economics, marketing and organizational behaviour that will inform the subsequent discussion of OCN research from 2007 to the end of 2014.

Neuroscientific studies of economic decision-making

Organizational cognitive neuroscience research has made a number of inroads into understanding economic decision-making since 2007. Such research has suggested that, contrary to the assumptions of completely rational expectations, financial markets may also be influenced by the biological traits of traders (Coates *et al.* 2009). Even so, despite the potential for improving understanding of how economic decisions are made, there remains scant literature in the field of biological economics and risk preferences (Coates *et al.* 2009). Our review reveals two clear lines of investigation within the economics cluster (see Table 2). The first consists of a set of articles using physiology-based research methods to explore differences in hormone levels such as cortisol and testosterone. The second, and comparatively much larger, consists of 12 articles adopting neuroimaging methodology.

Within the studies that have examined hormonal effects, researchers have been concerned with the association between different levels of particular hormones and economic behaviour, specifically financial risk preferences. These studies have resulted in a number of potentially interesting discoveries. Such studies build on previous research that explores the rationality of traders as economic agents and the conditions under which more information is beneficial or harmful to agents when making trading decisions (Dow and Rahi 2003). Apicella *et al.* (2008) report that men with testosterone levels that were one standard deviation above the mean invested almost 12% more of their portfolio in a risky financial game compared with men with average levels. Similarly, Coates and Herbert (2008) attempt to explain why people get caught up in stock market bubbles and crashes. They find that cortisol rises in a market crash, which increases risk aversion, exaggerating the market's downward direction. Testosterone, however, rises in a bubble, which increases risk-taking behaviour, exaggerating the market's upward direction. In a second study, Coates *et al.* (2009) suggest that the traits signalled by morphological differences in finger symmetry – which is a well-established indirect metric for differences in developmental testosterone levels (Lutchmaya *et al.* 2004) – are likely to confer the greatest advantage in high-frequency trading, an occupation that requires risk-taking, vigilance and quick reactions. Sociobiological research is an exciting area, which can be introduced to management and organizational scholarship. As Coates *et al.* (2009, p. 623) argue:

> biological traits may derive in part from traders' prenatal exposure to androgenic steroids. Prenatal androgens have organizing effects on the developing brain, increasing its later sensitivity to the activational effects of circulating testosterone. According to both animal and human studies, these effects may include increased confidence, risk preferences, and search persistence, as well as heightened vigilance and quickened reaction times.

While perhaps abstruse to many business researchers, from a biological perspective such a position is unsurprising, building on well-established prior work published in mainstream scientific

Table 2. Empirical articles from 2007 to the end of 2014 for the economics cluster

Number	Methodology	Theoretical contribution	Authors (date)
3	Hormones, e.g. cortisol and testosterone	Financial risk preferences	Apicella *et al.* (2008)
			Coates and Herbert (2008)
			Coates *et al.* (2009)
12	Neuroimaging	Trust and distrust	Dimoka (2010)
		Distinctiveness of procedural and distributive justice	Dulebohn *et al.* (2009)
		Equity and efficiency	Hsu *et al.* (2008)
		Influence of reward cues on financial risk taking	Knutson *et al.* (2008a)
		Neural correlates of trust	Krueger *et al.* (2007)
		Frontopolar cortex and decision-making efficiency	Laureiro-Martinez *et al.* (2014)
		Neural gender differences in online trust	Riedl *et al.* (2010)
		Fairness and unfairness circuit activation	Tabibnia *et al.* (2008)
		Loss aversion in decision-making under risk	Tom *et al.* (2007)
		Individual differences in self-control in a time discounting task	Waegeman *et al.* (2014)
		Neural substrates of probabilistic and interpersonal decision-making	Weber and Huettel (2008)
		Neural mechanism for discounting losses	Xu *et al.* (2009)

journals such as *Nature*, which links testosterone, search behaviour and persistence (Rogers 1972).

While hormone research has resulted in a number of advances in our understanding of economic decision-making, the majority of empirical studies use neuroimaging methods. Dimoka (2010) and Krueger *et al.* (2007) show that trust and distrust activate distinct brain networks, which underpin distinct behavioural outcomes. Dimoka (2010) concludes that the greatest potential of fMRI is to justify theoretical propositions such as the distinction and the relationship between trust and distrust. Riedl *et al.* (2010) found that most of the cortical regions that are responsive to tasks relating to trustworthiness differ between women and men, with more brain areas activated in women than men, suggesting that the neural mechanisms that mediate empathizing may be used to predict gender differences. Tabibnia *et al.* (2008) investigate the role of emotions to understand the positive impact of fairness providing evidence that fair offers lead to higher happiness ratings and activation in several reward regions of the brain.

Neuroimaging is also used to identify the possible substrates that may mediate decision-making processes in the brain related to prospective decision-making, outcomes that are either probabilistic or delayed (Weber and Huettel 2008). Weber and Huettel (2008) show that there are differences in the patterns of brain activation associated with risky and intertemporal choices, suggesting that the two domains use distinct sets of cognitive processes. Specifically, Weber and Huettel (2008) found that choices involving risk evoked greater activation in posterior parietal and lateral prefrontal cortices. Conversely, they found that choices involving delay evoked greater activation in the posterior cingulate cortex and the striatum. Weber and Huettel (2008) also found that activation of regions associated with reward evaluation predicted more risky choices. In contrast, brain regions that are activated in control processes predicted more delayed behavioural outcomes.

Waegeman *et al.* (2014) also investigated an individual's self-control abilities, because postponing reward is associated with 'personal success in life and positive outcomes in academic domains' Waegeman *et al.* (2014, p. 66). Waegeman *et al.* (2014, p. 65) found that 'choosing for the delayed option activated a network including the inferior frontal gyrus, lateral and ventrolateral prefrontal cortices, and the lateral orbitofrontal cortex'. Conversely, they also found that 'individuals who behave more impulsively show more activation in the medial prefrontal cortex (anterior cingulate cortex, medial frontal gyrus), and no correlated activity with the inferior frontal gyrus' Waegeman *et al.* (2014, p. 65). The differences between Waegeman *et al.*'s (2014) findings and those of Weber and Huettel (2008) indicate how much future research is needed to understand the biology of the brain and its association with decision-making. Nevertheless, it is possible to state that discounting future losses and gains occurs asymmetrically in the brain (Xu *et al.* 2009). Xu *et al.* (2009, p. 65) 'speculate that this may provide a neural basis for the phenomenon that future losses are discounted less steeply than future gains.' Knutson *et al.*'s (2008a) results, from a financial standpoint, imply that anticipatory affect may alter the perception of rewards. These findings may lead to methods of determining when persuasive appeals should and should not work.

Other fields, such as innovation and technology, are also studying what may mediate decision-making processes in relation to prospective decision-making. Laureiro-Martinez *et al.* (2014), for example, explored efficient decision-making in managers and entrepreneurs through a gambling task. They found that entrepreneurs were able to get comparable total payoffs, but in less time than managers; in other words, there are individual differences between the two groups. Laureiro-Martinez *et al.* (2014, p. 8) summarize their research findings by arguing that ‘we found a group-specific neural signature of entrepreneurs’ higher decision-making efficiency in the FPC, a key region for explorative choice’. This finding suggests that entrepreneurs are able to ‘track evidence to decide when to disengage from exploitation and explore novel alternatives’ (Laureiro-Martinez *et al.* 2014, p. 8). It is unknown at this stage what drives this effect, genetic predisposition or individual experience.

Taken together, this literature provides insights into decision-making processes at two different levels. Firstly, affective and social factors drive different types of financial decision-making across different cortical mechanisms. Secondly, that the same neural mechanisms are involved in the processes of immediate decision-making responses as well as decisions that are delayed until a future time points. Organizational cognitive neuroscience research within this general area has already provided advances in understanding of key economic decision situation, and challenged the long-held premises of much economic decision theory.

Neuroscientific studies of decision-making within a marketing context

While economic decisions were among the first to receive attention in an OCN context, Plassmann *et al.* (2008) noted early on in the evolution of OCN that – despite the importance and pervasiveness of marketing – almost nothing was known about the neural mechanisms of individual decision-making within marketing exchange. This was surprising given that noted scholars in the field have argued that it should be self-evident that a deeper understanding of the physiological and biological processes that guide human sociality should prove helpful to marketing practitioners and scholars (Saad and Vongas 2009). Further, recent experiential models suggest that brands may also evoke emotions as well as visceral responses during encoding, retrieval and evaluation (Esch *et al.* 2012). Schaefer and Rotte (2007) term this ‘hot reasoning’. A physiological account of these factors may help scientists to decompose the components that go into market-based decisions and facilitate new theorizing about decision-making.

As in the previous section, there are two lines of investigation within this area that are defined by an OCN approach; examination of hormonal testosterone levels and neuroimaging (Table 3). Saad and Vongas (2009) found that testosterone levels rose in men when driving a sports car, but dropped when driving a family vehicle. Saad and Vongas (2009) suggest that, for men, being able to afford a car that few others can purchase triggers an endocrinological response similar to being in a competition. Importantly, they discarded the affect of fast driving, as the men in the study had agreed to obey the speed limits in their signed consent forms. Saad and Vongas (2009) argue that greater attention on hormonal research will have several benefits within the marketing context, especially in potentially conflictual interactions, such as customer service, where male clients could feel disrespected. Saad and Vongas (2009, p. 89) are aware that because their ‘work constitutes the first set of studies to demonstrate the relationship between conspicuous consumption and physiological changes in men’, it may invite future critique, as all scientific research should. To this end, Saad and Vongas (2009) report at length their method and limitations to enable readers to make informed decisions regarding the future use of their findings.

Verbeke *et al.* (2014) continue down the path set out by Saad and Vongas (2009), by exploring the role of attachment styles in regulating the effects of dopamine on the behaviour of salespersons. They find that ‘the avoidant attachment style has a positive effect on CO [customer orientation] for sales representatives carrying only DRD2 A2 alleles, but no effect occur for sales representatives with at least one DRD2 A1 allele’ (Verbeke *et al.* 2014, p. 10). In other words, avoidant attachment styles may be beneficial in certain situations such as ‘goal-directed, motivational, and reward-related behavior’ (Verbeke *et al.* 2014, p. 10). In more detail, ‘the tension occurring between the need to keep a certain amount of distance between self and customer, and the drive to seek new opportunities leads to a greater application of skills meeting (mutual) needs and greater chance of success’ (Verbeke *et al.* 2014, p. 10). Verbeke *et al.* (2014, p.11) acknowledge that

Table 3. Empirical articles from 2007 to the end of 2014 for the marketing cluster

Number	Methodology	Theoretical contribution	Authors (date)
2	Hormones, e.g. testosterone and dopamine	Effect of conspicuous consumption on men's testosterone levels	Saad and Vongas (2009)
		Role of attachment styles in regulating the effects of dopamine on the behaviour of salespersons	Verbeke *et al.* (2014)
9	Neuroimaging	Exploring ad-elicited emotional arousal and memory for the ad using fMRI	Bakalash and Riemer (2013)
		Using declarative information or experienced emotions to evaluate brands	Esch *et al.* (2012)
		Trade-off aversion	Hedgcock and Rao (2009)
		Neural predictors of purchases	Knutson *et al.* (2007)
		Neural mechanisms of social influence	Mason *et al.* (2009)
		Neural correlates of customer loyalty	Plassmann *et al.* (2007)
		Neural representations of experienced pleasantness	Plassmann *et al.* (2008)
		Role of the ventromedial prefrontal cortex in the assessment of brands	Santos *et al.* (2011)
		Favourite brands as cultural objects modulate reward circuit	Schaefer and Rotte (2007)
1	EEG	Predicting purchase decision: the role of hemispheric asymmetry over the frontal cortex	Ravaja *et al.* (2013)
1	Steady state topography	The power of social television: can social media build viewer engagement?	Pynta *et al.* (2014)

their study is a small step in understanding the consequences of deeper, unconscious biological processes in organizational decision-making, but potentially 'can provide more valid and fair criteria for management than reliance only on background information, interviews, and psychological tests' in hiring and training.

Despite the promise of hormone-centric research, the majority of empirical studies within the marketing cluster of OCN employ neuroimaging technologies in an attempt to identify the neural substrates that are associated with market-related decisions. Similar to the literature revealed within the economic cluster, the literature in the marketing cluster has explored the role of past, current and future time periods on decision-making. Take Plassmann *et al.* (2007), who focused on the role of emotion and the mediating effect of current and past time experiences. They argue that a company should concentrate both on the technical requirements of a product or price, and encourage customers to create affective bonds to the company or its brands. In particular, Bakalash and Riemer (2013) point out that socio-cognitive emotional memory process has been a neglected area for research. Their study reveals 'greater amygdala activation in memorable (vs unmemorable) ads, reinforcing the association between ad-elicited emotional arousal and memory for the ad.' (Bakalash and Riemer 2013, p. 275). Schaefer and Rotte (2007) report a modulation of reward-related cortical networks (e.g. ventral tegmentum, ventral striatum) when viewing favourite brands. The engendered activation in the ventral striatal regions reflected a function of observers' favourite brands being previously associated with positive traits, which in turn acted as a social reinforcer. Ravaja *et al.* (2013) go further. Their results 'showed that relatively greater left frontal activation (i.e., higher approach motivation) during the predecision period predicted an affirmative purchase decision' (Ravaja *et al.* 2013, p. 1). The result was stronger for products that are branded at a national level because they are perceived to be higher quality than brands with private labels, since they are thought to be lower in quality. The result was also stronger for products below a normal price, therefore avoiding excessive prices and averting a perceived loss (as predicted by prospect theory). Ravaja *et al.*'s (2013) study is interesting from a methodology perspective within the marketing cluster, because it used electroencephalographic (EEG) asymmetry to predict purchase decisions.

Furthermore, Mason *et al.* (2009) suggest that the impact of social influence is detectable even when the participant does not intend or has been asked not to consider the value of the target item. The ventro-medial prefrontal cortex responds to socially tagged symbols, while activity in the caudate is due to popular (but not socially contextualized) symbols. The difference in activity was found after only a short training duration, involving abstract symbols tagged by the opinions of strangers, leading the researchers to speculate about the potential high impact of their findings when applied to more familiar contexts. One such context was studied by Pynta *et al.* (2014), who focused on second-screen usage (sharing viewing between the television and internet-enabled devices), finding that such usage 'can significantly enhance neural indicators of viewer engagement in the television program.' (Pynta *et al.* 2014, p. 71). Neural activity was innovatively measured by a custom-designed electrode cap and a steady-state topography (SST) methodology, which continuously tracks rapid changes in brain function. The implication of the study is that by encouraging social engagement, broadcasters can increase viewer loyalty and brand recognition of items within programme content.

Hedgcock and Rao (2009) in an fMRI study investigate how observers process trade-off choices that are difficult for them. They confirm that the introduction of a third, tie-breaking option provides the decision-maker with an opportunity to employ a simple decision rule (pick the fuel-efficient car) rather than engaging in an evaluation of two (un)attractive options. As a consequence, any negative emotion generated during the decision is minimized. Santos *et al.* (2011) support the notion that the ventromedial prefrontal cortex may be unimportant in the decision stage concerning brand preference. When they dissected the subjects' responses and isolated the decision-making period from the moment after the response, they found that, especially for positive brands, the ventromedial prefrontal cortex was indeed more active after the choice than during the decision process.

The literature reveals that this cluster also contains studies that have used neuroimaging to locate possible mechanisms in the brain related to prospective decision-making. Knutson *et al.* (2007) suggest that decisions to purchase may involve anticipated gain and loss, rather than just gain. Their study provides initial evidence that specific patterns of brain activity can actually predict purchasing decisions. Prior to the purchase decision, a preference triggers the nucleus accumbens (a structure that forms part of the ventral striatum), while excessive prices can activate the insula and deactivate the medial prefrontal cortex. The brain seems to frame a preference as an anticipatory combination of preference and price considerations. It would seem that this study is the closest yet to identifying the neural signature of purchase behaviour – although the utility of such results to actual marketers would require further explication.

Neuroscientific studies of decision-making within organizations

Interestingly, while both the preceding clusters showed a clear pattern of methodological focus – with hormonal and neuroimaging approaches being dominant – the literature in the organizational decision-making cluster reveals more experimentation. The plurality of techniques being used suggests that the study of organizational hierarchy is a fertile research area (Table 4). In the introduction, we defined OCN as a multidisciplinary approach in terms of both theory and method, so that the study of brain systems also incorporates the use of prior knowledge of brain systems to develop new hypotheses about organizationally relevant issues (Senior *et al.* 2011).

Wong *et al.* (2011) acknowledge that the links between psychological characteristics and leadership success have been well established, but argue that research has yet to identify innate personal traits that are related to leadership success and that predict organizational performance. Zyphur *et al.* (2009) used salivary testosterone to assess the effect of testosterone–status mismatch. They found that testosterone did not predict status in the group, but the greater the mismatch between testosterone and status, that is to say a high testosterone level and low status, the worse the collective efficacy of the group. Similarly to Saad and Vongas (2009), whose work was discussed in the marketing section, Zyphur *et al.* (2009, p. 70) recognize that 'The study of the biological underpinnings of behavior is in its nascent stages in the field of management'. Nevertheless, they argue that the relationship between hormones and organizational behaviour is an important topic, because 'Hormones provide a slower means of control over the functioning of biological processes compared to the nervous system' (Zyphur *et al.*, 2009, p. 70). Like Saad and Vongas (2009), Zyphur *et al.* (2009) acknowledge the rationale for and the limitations of their study – allowing readers to make an informed judgement as to the value of their findings at this stage.

Table 4. Empirical articles from 2007 to the end of 2014 for the organizational behaviour cluster

Number	Methodology	Theoretical contribution	Authors (date)
1	Hormones, e.g. testosterone	Testosterone–status mismatch lowers collective efficacy in groups	Zyphur *et al.* (2009)
3	Neuroimaging	Examination of the neural substrates activated in memories of experiences with resonant and dissonant leaders	Boyatzis *et al.* (2012)
		Neural bases of key competencies of EI	Krueger *et al.* (2009)
		Using brain-based measures to compose teams	Woolley *et al.* (2007)
5	EEG	Differentiating transformational and non-transformational leaders on the basis of neurological imaging	Balthazard *et al.* (2012)
		Psychological and neurological bases of leader self-complexity and effects on adaptive decision-making	Hannah *et al*. (2013)
		Using NeuroIS to understand information processing biases in virtual teams	Minas *et al.* (2014)
		Neuroscientific implications of psychological capital	Peterson *et al.* (2008)
		Leadership and neuroscience	Waldman *et al.* (2011)
2	Facial morphology	Testing a biosocial contingency model of leadership in intergroup relations using masculine and feminine faces	Spisak *et al.* (2012)
		CEOs' facial structure predicts their firms' financial performance	Wong *et al.* (2011
1	Fluctuating asymmetry	Developmental stability and leadership effectiveness	Senior *et al.* (2012)

There is, as might be expected, a group of empirical studies using neuroimaging methods to locate decision-making processes in the brain related to past and current time (although the group is comparatively small in this cluster). Boyatzis *et al.* (2012) used fMRI to examine the neural substrates activated in memories of experiences with resonant and dissonant leaders. Resonant leaders produces a positive emotional and interpersonal tone in their interactions with colleagues. Dissonant leaders have the opposite effect. Boyatzis *et al*. (2012) revealed that recalling past experiences with resonant leaders activated neural areas associated with the mirror neuron system, default mode or social network, and positive affect (for example, the bilateral insula). In contrast, they showed that recalling past experiences with dissonant leaders activated regions associated with the mirror neuron system related to avoidance, narrowed attention, decreased compassion and negative emotions (for instance, the right anterior cingulate cortex).

Woolley *et al.* (2007) explore novel team decision-making processes related to current time. They examine the ways in which the cortical systems within each individual member of a particular team operate synchronously with other team members, because this will yield information about how to build effective teams. Consistent with current understanding, they found that when individuals with the appropriate capabilities are present for the task, collaboration is not needed and, if it does occur, it does not improve performance. Woolley *et al.* (2007) extend this understanding by revealing that, when individuals are assigned roles that are inconsistent with their capabilities, team members collaborate despite the fact that they do not know their own or their colleagues measured abilities. Teams missing capabilities required for task success perform less well, despite the more they collaborate, because collaboration cannot generate the missing expertise. Linked to team processes, Krueger *et al.* (2009) revealed that key competencies underlying emotional intelligence (EI) are mediated in part by distinct sectors within the ventro-medial prefrontal cortex. Damage to the dorsolateral prefrontal cortex diminishes experiential EI, hindering the perception and integration of emotional information used to guide decision-making in real time.

There is also a small group of empirical studies using EEG methods. Minas *et al.* (2014), like Woolley *et al.* (2007), explored novel team decision-making processes, but used an EEG approach (to assess cognition) in combination with psychophysiological measures (EDA [skin conductance] and EMG [activation of the facial corrugator muscle], to assess emotion). Minas *et al.* (2014) focused on decision-making in virtual teams using collaboration technology, because they often make poor decisions. They found that 'information that challenges an individual's prediscussion decision preference is processed similarly to irrelevant information, while information that supports an individual's prediscussion decision preference is processed more thoroughly' (Minas *et al.* 2014, p.

50). This study confirms the role of confirmation bias during online team decision-making and clarifies the cognitive processes underlying confirmation bias. In contrast, Hannah *et al.* (2013) investigated the relationship of self-complexity on decision-making for 103 military leaders and found that the psychological and neurological markers of leader self-complexity were positively associated with levels of adaptive decision-making (although this may be the same sample as their work referred to in Balthazard *et al.* 2012). Balthazard *et al.* (2012) differentiate transformational and non-transformational leaders on the basis of their EEG trace in both civilian and military leaders. Focusing on transformational leadership, their findings point to the role of various frontal brain areas, including those associated with executive functions (such as planning and foresight), the effective handling of emotions (managing one's own and others), and the right frontal region (largely responsible for adding meaning to verbal communication, such as irony).

Balthazard *et al.* (2012), Peterson *et al.* (2008) and Waldman *et al.* (2011) acknowledge that the applicability of such knowledge to management practitioners is not immediately apparent; nevertheless, they argue that one possible benefit of their research is seeing more ecologically sound approaches to the assessment of leadership. Balthazard *et al.* (2012) argue that neuroscientific assessments are void of the types of biases (e.g. information processing biases and leniency error) that limit the impact of psychometric approaches, such as surveys, although as we have noted, they suffer from their own potential biases. Neuroscientific assessment, or the biological sources of leader behaviour, might ultimately be used to help facilitate the selection and placement of leaders in organizations. However, such methods would have to come with appropriate caveats and ethical safeguards.

The view that organizational behaviour is a social exchange has also seen scholars examine a number of social psychological questions with a plurality of approaches. One such group of studies examined the effects of facial characteristics and subsequent decision-making. The study of facial characteristics and their effects on social outcomes within the immediate social group has been active research area since the time of Galton (Bulmer 2003). However, the advent of OCN allows scholars to make inferences back to the biological systems that underpin such decision-making and, ultimately, how such biological systems affect behaviours in the workplace.

Take, for example, the small cluster of empirical studies that study facial measures and their relationship to the attributes of status: who gets promoted, in what context and to what effect? An evolutionary perspective provides a deeper understanding of the biological aspects of leadership and generates many novel hypotheses about how markers such as the human face affect leadership emergence and effectiveness (Spisak *et al.* 2012). Spisak *et al.* (2012) found that followers prefer leaders whose facial cues match the situational context, for example, in intergroup relations, masculine-faced leaders are expected to behave competitively and feminine-faced leaders cooperatively, reinforced with a consistent leadership message. Wong *et al.* (2011) identified leaders' facial structure as a specific physical trait that correlates with organizational performance, for instance, firms whose male CEOs have wider faces relative to their facial height achieve superior financial performance. From a top team development perspective, decision-making dynamics moderate this effect. The relationship between a CEO's facial measurements and the firm's financial performance is stronger in teams with a rigid decision-making style that see issues in black and white.

Other innovative methods include using developmental stability, the degree to which we can withstand environmental or genetic stressors during development. Fluctuating asymmetry (FA) concerns the extent to which the right and left sides of the body are asymmetrical and is one way to measure developmental stability. Senior *et al.* (2012) carried out two studies that examined both the predictive value of leader FA with leadership behaviours and its role in subsequently facilitating group performance. The first study revealed that individuals with a more asymmetrical morphology scored higher on the transformational dimensions of leadership psychometrics. Perhaps more interesting is the finding revealed in their second study, which showed a positive relationship between FA, self-reported well-being and task satisfaction, including a positive correlation between the leader's FA score and subsequent performance of the individual group members.

The contribution of OCN research so far and future research directions

Organizational cognitive neuroscience is at a crossroads in its theoretical development. Healey and Hodgkinson (2014, p. 766) succinctly capture this division:

> At one extreme, advocates such as Becker *et al.* (2011) are calling for a new, biologically rooted, subfield that aims to map neural mechanisms as the prime causes of organizational behaviour (see also Lee *et al.* 2012; Senior *et al.* 2011). At the other extreme, scholars are warning that applying neuroscience to MOS [management and organization studies] is a dangerous distraction (Lindebaum 2013; McLagan 2013).

Like Healey and Hodgkinson (2014), Foxall (2014) highlights the need for further resolution of conceptual problems in OCN. In order critically to reassess OCN research, it is important to review holistically current empirical research related to OCN, and its methodological limitations, which has been the purpose of this article.

The systematic review results presented above indicate that OCN is in the exploratory phase of its emergence and diffusion. This emergent phase may be the reason why the review yielded a comparatively small number (40) of empirical articles (as opposed to commentaries and general review articles) published between 2007 and the end of 2014. However, there are a number of interesting insights that can be drawn from the review, which will be of help in understanding the contribution of OCN research from 2007 to 2014, and hopefully beyond. First, even this number of empirical OCN articles in the time-frame of interest was greater than the total amount of similar empirical work between 1980 and 2006 (and presumably from all years prior to 1980). The mid-2000s marked a watershed in the evolution of OCN approaches to management and organizational research questions. Furthermore, a comparison of the pre-2007 period of empirical work with the 2007-onwards period of empirical work shows that the three-cluster pattern solidified post-2007. In particular, pre-2007, there were small numbers of isolated papers on topics such as strategy and finance, along with the more numerous papers on marketing, economics and organizational psychology. However, post-2007, the field consolidated into the evident three-cluster pattern described here, with proportionately fewer papers outside these clusters observed.

It is heartening to see emerging strength in depth across a number of key management and organizational fields with regard to OCN. The diffusion of OCN concepts is particularly interesting in that there is a strong consistency between the economics and marketing clusters. This may result from neuroeconomics and neuromarketing being more developed fields of research, coinciding with the explosion in the visibility and viability of neuroimaging methods, with management and organizational behaviour emerging later. Within marketing there exist well-established practice-led organizations, which establish their credibility from the availability of basic science research, and which are seemingly lacking in more general management and leadership areas at present. However, the early adoption of neuroscience into economics and marketing may have resulted in an overemphasis on neuroimaging and neuroendocrinology, which may lead researchers to exclude potentially useful methodologies. The marketing cluster is beginning to change, adopting other techniques (EEG and SST).

The organizational behaviour cluster is similar to economics and marketing in that there also exists research measuring the effect of testosterone levels on behaviour (one article) and adopting neuroimaging methods (three articles). However, there is experimental work using a greater variety of research methods – EEG (five articles), facial morphology (two articles) and fluctuating physical asymmetry (one article). Perhaps the reason for this is that organizational behaviour researchers took longer to assimilate neuroscientific approaches, and the growth in this field of work is more influenced by the methodological agnosticism advocated by OCN papers (Senior *et al.* 2011).

During the short life of the field, the contribution of OCN research has been important, most particularly because it begins to reveal the nature of human sociability in the context of management and organization studies (Saad and Vongas 2009). Certainly, Dulebohn *et al.* (2009) argue that fMRI methods collect objective biological data that are less susceptible to the biases of self-report data. However, all the methods associated with OCN are important, given that there is as yet scant literature in the fields of biological economics, marketing, organizational behaviour and the other fields of management and organization studies. Such knowledge helps academics and practitioners to understand the biological mechanisms that mediate choice in decision-making, and to decompose the components that go into decisions. The biological mechanisms may be physical traits (Wong *et al.* 2011) and neural mechanisms (Plassmann *et al.* 2008). While it remains early days, it is likely that OCN research will help to build models that better predict choice and decisions. However, it is vital to avoid overstretching our inferential claims from early research.

A recurring theme within the economics and marketing clusters is the capacity of neuroimaging to co-locate the cortical substrates that mediate decision-making processes within the brain, and to unpack such processes over time. Dimoka (2010) concludes that the greatest potential of fMRI is to justify theoretical propositions such as the distinction and relationship between trust and distrust. Another illustrative example from economics is by Dulebohn *et al.* (2009), who support the notion that procedural justice and distributive justice are independent constructs, while recognizing that, as forms of justice, they are closely related nomologically. Marketing studies differ from the economics work, in that marketing work explores the role of past, current and future time in decision-making. Knutson *et al.* (2007), for example, suggest that decisions to purchase may involve distinct dimensions related to anticipated gain and loss, not just gain, providing evidence that specific patterns of brain activation predict purchasing – the brain frames preference as a potential benefit and price as a potential cost.

Interestingly, it can be seen that the economics, marketing and organizational behaviour clusters are contributing to the system one and system two cognitive functioning debates regarding judgement in managerial decision-making (Kahneman 2003). System one thinking refers to our intuitive system, which is typically fast, automatic, effortless, implicit and emotional. By contrast, system two refers to reasoning that is slower, conscious, effortful, explicit and logical. From our review (whether or not system one and two thinking is referred to specifically), a common theme of OCN work is an exploration of the boundary between self-determination (free will) and predetermination (determinism). Much prior work on decision-making has focused on a rational foundation for human decisions, followed by the incorporation of Kahneman's intuitive system one mode. However, OCN research has joined more established fields of neuroscience in uncovering the limits of human freedom to act, and there is growing understanding of how our evolutionary past influences our choices and actions today. Ironically, as Pinker (2003) suggests, understanding these limits to our self-determination actually enhances our freedom to act in real terms.

The present review uncovered many papers that are explorations of human self-determination within a management or organizational context. Within economics, Tabibnia *et al.* (2008) address temporal separation and the process of resolving conflict between fairness and financial interests. They provide evidence that fair offers led to higher happiness ratings and the tendency to accept unfair proposals involved emotion regulation, which has been implicated in negative affect. Within marketing, there are a range of studies exploring the role of emotion in decision-making, for example, how individuals can respond positively to popular symbols (Mason *et al.* 2009), or how increasing price can increase subjective reports of pleasantness (Plassmann *et al.* 2008) and decreasing price can predict an affirmative purchase decision (Ravaja *et al.* 2013).

The organizational behaviour cluster investigates themes similar to those of the economics and marketing clusters, for example, emotions and decision-making are explored through the memories of experiences with resonant and dissonant leaders (Boyatzis *et al.* 2012). Nevertheless, because of the greater variety of research methods adopted within the organizational behaviour cluster, many other themes relating to our evolutionary past (and consequent self-determination) are explored too. Using neuroimaging methods, Woolley *et al.* (2007) innovatively examined the ways in which the brain systems in different team members' function synchronously, yielding potential insight into how to compose effective teams. On the basis of EEG, Balthazard *et al.* (2012) differentiate transformational and non-transformational leaders, while Senior *et al.* (2012) also examined this issue by measuring leader FA. Leaders' facial structure as a specific physical trait is correlated when followers expect masculine- and feminine-faced leaders (Spisak *et al.* 2012) and organizational performance (Wong *et al.* 2011). Balthazard *et al.* (2012) acknowledge that the applicability of OCN knowledge is not immediately apparent, but optimistically argue that neurologically based assessments are void of the types of biases associated with psychometric approaches.

Given the early stage of OCN as a field of research, there are ample fruitful avenues for future work that are suggested from the systematic review of existing research, though it is important that the various fields do not fragment. Instead, scientific progress is much better facilitated by (at this point) following the suggested research directions advocated by the authors of each empirical study presented in this systematic review. By adopting this approach, existing streams of research will benefit from additional data collection and analysis.

In order best to consolidate the OCN field, we argue that more basic science research is needed within and beyond the three clusters of economics, marketing and organizational behaviour. This review has revealed that, while there is clearly significant interest, there remains less empirical research. The difficulty of empirical collaboration in the OCN space is likely to have been an indicator of such scarcity, and it is heartening to see empirical work continuing to emerge even in the face of such difficulties. However, the current situation reveals that the other fields of management and organization studies offer significant new terrain for OCN discoveries. Powell (2011), for example, examines the potential contributions of brain research to strategic management research and practice, and appraises the prospects for collaborations between neuroscientists and strategic management scholars by posing four key questions that can be used to evaluate whether an empirical research program is worthwhile:

(1) Does it address a core problem in strategic management research or practice?
(2) Does it raise compelling new questions for neuroscientists?
(3) Has it been neglected in other fields and is it likely to remain neglected?
(4) Will neural evidence add to our understanding and, if so, how (through construct validation, theory testing or informing strategy practice)?

If these questions are passed, OCN knowledge has the potential to help academics and practitioners to understand the biological components of decision-making, the mechanisms that link the components, and the outcomes of the decisions. It is hoped that OCN research will ultimately help to build models that better predict choice and inform policy and strategic management frameworks.

Based on our review, we also call for far more variety in the research methods that are used. For the most part, there is a concentration on the two modalities of measuring the effect of hormone levels on behaviour and neuroimaging. However, the organizational behaviour cluster indicates that far more methodological diversity is possible. Senior *et al.* (2011) discuss the various techniques that could be used in OCN, and include the relative advantages and disadvantages of each, which could prove a useful starting point to researchers.

In addition, there is a need to explore translational activities – how OCN research findings could be ethically applied to the actual management of organizations. Practice-based organizations are already active in providing professional support to neuromarketers and neuromarketing scientists, but far more is needed here to avoid at best useless, and at worst actively harmful, practical applications of OCN research. This is important, since the application of OCN to practice continues apace. For example, Powell (2011) highlights that neuromarketing consultants already use brain scans to evaluate consumers' cognitive and emotional responses to product features, packaging and promotional campaigns. Beyond neuromarketing, he also highlights that lawyers use brain scans to show the mental capacities of defendants, and jury consultants use neural evidence to predict punishment and retribution in jury decisions (Powell 2011; Rippon and Senior 2010; Senior 2008).

Management and organizational development is perhaps an even more contested issue as far as the application of OCN is concerned. Balthazard *et al.* (2012) acknowledge that the applicability of OCN knowledge is not immediately apparent here, but also propose the possibility of a neurologically based assessment of leader behaviour. From an ethical perspective, Lindebaum and Zundel (2013) discuss reductionism or neuroscientific approaches that identify and analyse basic mechanisms that are assumed to give rise to higher order organizational phenomena, for instance, the way in which inspirational leaders are identified and developed. We concur with them that the challenges of reductionism need to be overcome if the possibility of advancing leadership studies is to be realized.

Concluding remarks

Organizational cognitive neuroscience is a brave new world of research opportunities, as the frontier of human neuroscience is crossed in the context of management and organizations. The range of activities associated with this new research world has been captured in a model of co-production in OCN, which is used to reveal the many interdisciplinary intersections between society, organizations and the brain (Butler 2014). In this paper, we have focused on empirical studies to review systematically the current state of the art in OCN research. We accept, however, that there are methodological debates and issues associated with OCN (Hedgcock and Rao 2009), which require researchers to be cognizant of the limitations of inferences they can draw.

We have identified three OCN clusters (economics, marketing and organizational behaviour), which have already made substantial theoretical contributions to management and organizations. Neuroimaging has the capacity to co-locate the cortical substrates that mediate decision-making processes within the brain, and to relate the processes to time. All three clusters are already providing insights into the specific boundaries surrounding the human freedom to act. Clarifying the more precise role of emotions and their regulation in forming a judgement in managerial decision-making in different contexts has been a recurring theme. The organizational behaviour cluster, probably because of the plural methods that have been adopted, has also been able to explore how team members function synchronously, and the links between physical traits and leadership. With this knowledge, we can compensate for the limits to our decision-making and enhance our self-determination to influence how we work. Knowing that there is much research still to be done, we have highlighted further emerging research themes, in addition to the themes suggested by the authors of the articles that we have reviewed.

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