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## Brain-driven entrepreneurship research: Expanded review and research agenda towards entrepreneurial enhancement

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# Working Paper

## **Brain-Driven Entrepreneurship Research: Expanded Review and Research Agenda Towards Entrepreneurial Enhancement**

Víctor Pérez Centeno

Working Paper 02/18

Institut für  
Mittelstandsforschung

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# **BRAIN-DRIVEN ENTREPRENEURSHIP RESEARCH: EXPANDED REVIEW AND RESEARCH AGENDA TOWARDS ENTREPRENEURIAL ENHANCEMENT<sup>1</sup>**

Víctor Pérez Centeno, University of Kobe  
15 April 2018

## **ABSTRACT**

The advent of significant advances in neuroscience has produced the capacity to examine the human brain at a profound level, yet the academic and practical value of existing evidence based on neuroscience techniques and methods within the field of entrepreneurship remains unexplored.

To address these issues, the author draws from entrepreneurship research and presents a brain-driven approach as a basis for future in-depth studies on the role of cognitive, affective, motivational and hormonal mechanisms in entrepreneurship theory and practice. To further articulate a research agenda, the author reviews the state of knowledge of existing evidence by content analysis of articles published until 2016. The analysed articles incorporate the use of a brain-driven research perspective in their studies. It is found that although neuroscience affords unique technological opportunities, few studies have thus far benefited from these advances, and among existing studies, only the topic of entrepreneurial decision-making has been partially covered.

Building on these observations, the author proposes a definition of brain-driven entrepreneurship research and a research agenda to advance the integration of neuroscience tools and technologies in entrepreneurship research.

**Keywords** Entrepreneurial neuroscience, neuro-entrepreneurship, entrepreneurial enhancement, cognition, brain-driven entrepreneurship, entrepreneurial enhancement

**JEL-Classification** L26, M13, O33

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<sup>1</sup> This is a draft chapter. The final version is available in the Handbook of Research Methodologies and Design in Neuroentrepreneurship Edited by Mellani Day, Mary C. Boardman and Norris F. Krueger edited by Mellani Day, Mary C. Boardman and Norris F. Krueger, published in 2017, Edward Elgar Publishing Ltd <http://doi.org/10.4337/9781785365041.00011>

# 1 INTRODUCTION

Heraclitus wrote ‘No man ever steps in the same river twice, for it's not the same river and he's not the same man’ in describing the unavoidable nature of change which is familiar to the field of entrepreneurship research and practice.

Over the last few decades, entrepreneurship research has been a focus of interest in society as well as in education and academic research (Landström, 2004).

At the risk of oversimplification, it can be argued that three different eras of entrepreneurship research can be identified, during which some specific disciplines dominated: initially, economics (1870-1940), followed by social sciences (1940-70), and after 1970 management studies (Lohrke & Landström, 2010).

The economics era focused on what happens in the market when the entrepreneur acts (Landström, 2007). That is to say, the ability of the entrepreneur to perceive opportunities for profit on the one hand and as the creator of instability and creative destruction on the other (Landström, 2004). Frank Knight, Joseph Schumpeter and Israel Kirzner fairly represent this era (Landström & Benner, 2010). As economics became formalised and mathematically oriented, it made it difficult to include the entrepreneur in the economic models (Hébert & Link, 2009).

The consequence was that classical, and early neoclassical economic theorists left the concept of entrepreneurship as a source of structural change within capitalist economies largely underdeveloped (Lohrke & Landström, 2010).

This development gave rise to the social sciences era, which, unlike the market focus of the economics era, nurtured a sociologist-psychologist orientation and explored the individual traits of the entrepreneur: who the entrepreneur is and why entrepreneurs act in certain ways (Landström, 2004). By 1940 some social scientists began to take an interest in entrepreneurship as an empirical phenomenon (Lohrke & Landström, 2010). By 1960 scholars from psychology also entered the field with interest in the entrepreneur as an individual, and their work started to investigate his/her traits and personality (Lohrke & Landström, 2010).

Between the 1960s and 1970s, some significant economic and political changes led to the emergence of the management studies era. It was a period of ‘creative destruction’, in which new technologies were gaining ground. Changes were taking place in the industrial structure and questions were being raised about the efficiency of large companies. Attitudes toward entrepreneurship and small businesses were merging, and there was an increasing political debate by politicians such as Ronald Reagan in the USA and Margaret Thatcher in the UK (Lohrke & Landström, 2010).

Entrepreneurship and industrial dynamics became a dominant theme in society, and many scholars from different areas of management moved into this promising field of research (Lohrke & Landström, 2010).

In contrast to the social era, which concentrated on the entrepreneur as an individual, the management era placed attention on entrepreneurship as a process, that is, how entrepreneurship develops. By the 1990s entrepreneurship research could be regarded as a strongly growing field with a high degree of fragmentation, where an emergent group of researchers was mainly anchored in management studies. Thus, it is perhaps not until the 1990s that we can start talking about entrepreneurship as a research field (Lohrke & Landström, 2010).

These three eras of entrepreneurial thinking have built a significant knowledge base on the phenomenon of entrepreneurship; nonetheless, there are research gaps, which cannot be addressed due to the methodological and technological limitations of existing approaches. Hence, a new era that has to do with the incorporation of neuroscientific technologies and methods, is beginning to resonate within the minds of several entrepreneurship scholars (Blair, 2010; de Holan, 2014; McMullen, Wood, & Palich, 2014; Nicolaou & Shane, 2014; Pérez, 2017; R. Smith, 2010).

The emergence of this new era makes sense because as de Holan (2014) asserts, many concepts within entrepreneurship research can be explained only very poorly with the instruments used now.

It is like trying to explain something that happens in the mind with tools that capture only very partially, and sometimes in a biased way, what the brain does (de Holan, 2014).

Work done on entrepreneurial cognition is the major intellectual driver towards this new era.

Research includes entrepreneurs' cognition<sup>2</sup> (R. K. Mitchell et al., 2002), knowledge (Shane, 2000), intuition (J. R. Mitchell, Friga, & Mitchell, 2005) and mindsets (Haynie, Shepherd, Mosakowski, & Earley, 2010), among many other phenomena taking place within the human mind (de Holan, 2014).

Nonetheless, instead of focusing on what entrepreneurs think, how they think, why they think the way they do and how they came to think that way, a majority of scholars are still assessing what entrepreneurs are or have (attributes), or what they do (behaviours) (de Holan, 2014).

This omission is surprising, given that the focus of entrepreneurship research lies in how entrepreneurs think and make decisions (de Holan, 2014). In this sense, de Holan (2014) highlights the relevance of neurosciences, arguing that we have not yet begun to explore what neuroscience can do for entrepreneurship, and we only know how little we know. As Nicolaou and Shane (2014) claim, this research gap should be eliminated, and the field must come to incorporate neuroscience theory and methods.

This study strives to accomplish that through a review and research agenda for entrepreneurship research from a neurosciences angle that builds upon existing research and knowledge of the entrepreneurial phenomenon through the lenses of neuroscience.

The review and research agenda are developed in three steps.

First, I build on extant work on entrepreneurship research undertaken using neurosciences and highlight the conceptualisation of a brain-driven approach to entrepreneurship research.

Second, I discuss the developments of entrepreneurship research that are relevant for understanding the relevance of using neurosciences in entrepreneurship research.

Thirdly, to better identify avenues for future entrepreneurship research, I assess the manner and extent to which entrepreneurship research leverages regarding conceptualising and uncovering the potential of using a brain-based approach. Through content analysis of existing articles incorporating a neuroscience method in their studies, I depict the current state of knowledge about a brain-driven research perspective. I show that for all its achievements, research has yet to leverage the full potential of applying such an approach to entrepreneurship research.

I build on these observations to formalise the research agenda. I suggest a definition of brain-driven entrepreneurship research and propose a series of strategies to address and expand this approach in more in-depth ways.

## **2 CONCEPTUALIZING BRAIN-DRIVEN ENTREPRENEURSHIP RESEARCH**

I start with grounding the analysis on the use of neurosciences in entrepreneurship research and discuss key conceptualisations advocated in that spectrum. Towards the end of the section, the advances in entrepreneurial cognition research are also discussed: those which I see as essential for understanding the roots of the use of neurosciences in the field of entrepreneurship.

### *2.1 Conceptualization of a brain-driven approach to entrepreneurship research*

The application of neurosciences to entrepreneurship research is new; thus, it is imperative to frame the scope of it within this study.

Just as new technologies are a primary source of innovation and opportunity in entrepreneurship (Drucker, 2014; Schumpeter, 1934), the same might also be said of science (Sanders, 2007).

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<sup>2</sup> Cognition focuses on the knowledge structures that people use to make assessments, judgements or decisions related to evaluating opportunities and creating growing ventures (R. K. Mitchell et al., 2002)

Neurosciences did not exist even 20 years ago, but thanks to technological advances it has become one of the fastest growing areas of the biological sciences, and a revolutionising force across social sciences that challenges disciplines ranging from economics to sociology and psychology (McMullen et al., 2014).

Taking into account that entrepreneurship draws on many of these disciplines, the field is unlikely to be immune to neuroscience's transformative impact (McMullen et al., 2014).

In simple terms, neuroscience entails the study of how the nervous system develops, its structure, and what it does (Nordqvist, 2014). It is an interdisciplinary science which liaises closely with other disciplines, such as mathematics, linguistics, engineering, computer science, chemistry, philosophy, psychology and medicine (Nordqvist, 2014).

In addition to the set of basic concepts (See Table 1), there are eight branches of neurosciences that are of special interest to the field of entrepreneurship: cognitive neurosciences, affective neurosciences, behavioural neurosciences, cultural neurosciences, computational neurosciences, neuroinformatics, systems neurosciences, and social neurosciences.

Nordqvist (2014) succinctly defines these branches: cognitive neurosciences study the higher cognitive functions that exist in humans and their underlying neural bases. Affective neuroscience examines how neurons behave about emotions. Behavioural neuroscience studies the biological bases of behaviour, while cultural neuroscience looks at how the brain, minds and genes shape beliefs, practices and cultural values over different periods. Computational neuroscience attempts to understand how brains compute, using computers to simulate and model brain function. Neuroinformatics integrates data across all areas of neuroscience to help understand the brain and treat diseases. Neuroinformatics involves acquiring data, sharing, publishing and storing information, analysis, modelling, and simulation. Systems neuroscience follows the pathways of data flow within the central nervous system to define the kinds of processing going on there and uses that information to explain behavioural functions. Social neuroscience is an interdisciplinary field dedicated to understanding how biological systems implement social processes and behaviour (Nordqvist, 2014).

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Table 1 around here  
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There are two fundamental elements, which when applied jointly, link the contribution of the above branches of neurosciences to entrepreneurship research: the experimental research paradigm and brain imaging technologies.

On the one hand, unlike entrepreneurship, where the usage of experimental methodologies has been limited (Patel & Fiet, 2010; Schade & Burmeister, 2009; Simmons, Hsu, Wieland, & Begelfer, 2016), neurosciences research is performed fundamentally through experimental design and the use of brain imaging technologies.

An experimental design implies the organisation of an experiment to allow effective testing of the research hypothesis; it is the way in which a scientist sets up the manipulations and measurements of an experiment (Huettel, Song, & McCarthy, 2009). An experiment is the controlled test of a hypothesis (Huettel et al., 2009).

Experiments entail pluses and minuses (Coolican, 2014); nonetheless, their use might prove to be more beneficial than detrimental to entrepreneurship research (Krueger & Welp, 2008; Schade & Burmeister, 2009; Shepherd, Williams, & Patzelt, 2015; Simmons et al., 2016).

Because much of the focus of entrepreneurship research is on the individual, experiments can be used to provide the most reliable and valid assessment of individual-level behaviour and processes (Patel & Fiet, 2010).

Thus, the successful application of a neuroscientific approach to the investigation of any entrepreneurship theme presupposes the elaboration of a well-designed experiment.



On the other hand, equally relevant is the technological element. The human mind has been studied for thousands of years, but the human brain has only been studied for about a century (Carter & Shieh, 2015). Only 150 years ago, the ability to study the nervous systems of humans was limited to direct observation and by examining the effects of brain damage in people and other organisms (Carter & Shieh, 2015). Technologies have developed at such a speed that modern neuroscientists now have hundreds of techniques that can be used to answer specific scientific questions (Carter & Shieh, 2015).

Technically known as whole-brain technologies, they can be either structural or functional. Structural techniques produce images of the anatomical architecture of the brain, whereas functional techniques produce images of the physiological processes that underscore neural activity (Carter & Shieh, 2015).

For instance, functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) are functional imaging techniques, and as such suitable to be applied to the field of entrepreneurship.

Although these technologies may enable a deeper study of the brain by facilitating higher spatial and temporal resolution (Carter & Shieh, 2015), there is a discussion about their relevance to the field. Some scholars argue that these technologies may advance the state of the art in entrepreneurship research (Blair, 2010; de Holan, 2014; Krueger & Welp, 2014), allowing a better understanding of how decision-making (R. Smith, 2010), cognition, emotion and behaviour (Krueger & Welp, 2008; Wargo, Baglini, & Nelson, 2010) are processed in the brain. Other experts are cautious about any collaboration between neuroscience and entrepreneurship (Beugré, 2010; Tracey & Schlupeck, 2014).

The articulated conjunction of these two elements: the experimental design and the use of brain imaging technologies, allows me to provide a working definition of a brain-driven approach to entrepreneurship research that may help to delineate it from other research streams.

Brain-driven entrepreneurship research refers to the study of any suitable topic of entrepreneurship, using both an experimental design in any of its forms and any existing or forthcoming brain-imaging technologies. In other words, this approach entails the combined use of experiments and brain-imaging technologies.

Defined as such, a brain-driven approach to entrepreneurship is different from neuro-entrepreneurship or entrepreneurial neuroscience in that the scope of these terms remains generic. For instance, neuro-entrepreneurship is tacitly referred as being located at the intersection of neurosciences, entrepreneurship/entrepreneurial cognition and experiments (Krueger & Welp, 2008). Other scholars describe it as a new field which has borrowed from work in neuroscience, neuropsychology and neuroeconomics to understand better and test how entrepreneurs think, behave and make decisions (Blair, 2010). It is also different to experimental entrepreneurship because such an approach implies the sole use of experiments to investigate entrepreneurial behaviour from the perspectives of economics, cognitive, social and developmental psychology, neuroscience, philosophy, evolutionary anthropology (Krueger & Welp, 2008).

A brain-driven approach to entrepreneurship entails the analysis of cognitive/affective/motivational/hormonal processes, which can be depicted in a single entrepreneur or team of entrepreneurs at a neural and behavioural level. These levels are also portrayed in Section 4.2.

The cognitive/affective/motivational/hormonal level concerns the internal mental processes reflected as neural substrates and behavioural responses. The neural level focuses on identifying the brain regions that are activated when entrepreneurs display a particular type of behaviour, and the behavioural level focuses on the entrepreneurs' responses to various stimuli. Figure 1 presents a summary of the key components of a brain-driven perspective to entrepreneurship research.

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Figure 1 around here  
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To understand the scope and contribution of a brain approach to entrepreneurship research, an understanding of the basic concepts highlighted in Table 1 is necessary.

Acknowledging these is necessary for consistent definitions when theorising about this approach. From now on, the term brain-driven entrepreneurship research is used as such or in its abbreviated form, BRE.

## 2.2 *From entrepreneurial cognition to brain-driven entrepreneurship research*

The possibility to investigate deeper knowledge structures within the arena of entrepreneurial cognition marks the genesis of scholarly interest in the use of neuroscientific tools (Krueger & Day, 2010).

Entrepreneurial cognition is an important perspective in entrepreneurship (R. K. Mitchell et al., 2007; R. K. Mitchell et al., 2002; R. K. Mitchell et al., 2004). The emerging interest to investigate entrepreneurial phenomena from a brain perspective lies in prior research carried out in this research stream (Krueger & Day, 2010). Entrepreneurial cognition is defined as ‘the knowledge structures that people use to make assessments, judgments or decisions involving opportunity evaluation and venture creation and growth’ (R. K. Mitchell et al., 2002, p. 1). In other words, entrepreneurial cognition deals with the question: ‘how do entrepreneurs think?’ (R. K. Mitchell et al., 2007).

While earlier approaches to entrepreneurial cognition focused on the psychological processes that underlie behaviour (Shaver & Scott, 1991), the area has broadened to focus on heuristic-based logic (Simon, Houghton, & Aquino, 2000), perceptual processes (Gaglio & Katz, 2001), expertise (R. K. Mitchell, Smith, Seawright, & Morse, 2000) and effectuation (Sarasvathy, 2001).

Omoredede et al. (2015) depict the evolution of entrepreneurial cognition research in three periods. The first period took off in the late 1980s and early 1990s with the highlighting of various components and content of entrepreneurial cognition, heading to a spectrum ranging from cognitive heuristics and biases in decision making to entrepreneurial perceptions and intentions (Cooper, Woo, & Dunkelberg, 1988).

The term entrepreneurial cognition, nonetheless, did not gain significant awareness until the mid-1990s (Omoredede, Thorgren, & Wincent, 2015). Scholars such as Palich and Bagby (1995) and Busenitz and Lau (1996) argued that cognition is a relevant factor that substantially affects individuals’ start-up intentions and capacity to exploit opportunities, even when high risk might be an evident distraction.

At the turn of the millennium, researchers focused even more on studying cognition (Baron, 1998; Busenitz & Barney, 1997; Howard-Jones, 2014; R. K. Mitchell et al., 2002). Baron (1998) added the concepts of counterfactual thinking, affect infusion, planning fallacy, self-justification and self-efficacy. Chen, Greene, and Crick (1998) applied the construct of entrepreneurial self-efficacy (ESE) to differentiate entrepreneurs from managers.

Simon et al. (2000) identified cognitive errors and biases such as the illusion of control, overconfidence, and believing in the law of small numbers.

Other scholars applied several existing constructs of cognitive reasoning by analysing and evaluating the cognitive approaches to creating new ventures, the risk involved, and decision-making as a means of furthering this field (Omoredede et al., 2015). Forbes (1999), Gaglio and Katz (2001) and Baron (2000) evaluated how entrepreneurial intentions are formed, the use of schemas and heuristics, the sense-making processes of scanning, interpretations and actions, entrepreneurial alertness; and counterfactual thinking.

Until the mid-2000s, cognition research focused on assessing if and why entrepreneurs differ from non-entrepreneurs and why some entrepreneurs are more successful than others (Omoredede et al., 2015).

Since the mid-2000s, scholarly interest has continued to examine previously explored contents, but a greater focus has emerged on entrepreneurial scripts and the impact of cognition on evaluating opportunities (Omorede et al., 2015). The self-efficacy concept has also gained more attention (Drnovsek, Wincent, & Cardon, 2010).

Similar to the study of self-efficacy, the study of scripts has expanded to examine how entrepreneurs think about creating their enterprises and growing their businesses (R. K. Mitchell et al., 2007; Simon et al., 2000; B. Smith, Mitchell, & Mitchell, 2009). Smith et al. (2009) used the concept of entrepreneurial scripts to differentiate expert entrepreneurs from novice entrepreneurs within and across countries in their commitment to constructing and initiating new business transactions.

Barbara Sahakian's team compared top managers with serial entrepreneurs on emotion-independent ('cold') cognition and emotion-dependent ('hot') cognition, discovering that entrepreneurs preferred and were better at hot cognitions (Lawrence, Clark, Labuzetta, Sahakian, & Vyakarnum, 2008).

Grichnik, Grichnik, Smeja, and Welp (2010) found that between and within subjects, experimenters could induce different cognitive states by envisioning either an economic venture or a social venture with significant cognitive consequences such as significant differences in fear of failure.

Sánchez, Carballo, and Gutiérrez (2011) concluded that studying scripts provides not only more information on individual entrepreneurs' behaviour but also helps the understanding of entrepreneurs functioning within a group.

More recent contributions on entrepreneurial cognition have shed light on the transition from static to dynamic cognitive research conceptualisations through some degree of emphasis on socially situated cognition (Randolph-Seng, Mitchell, & Mitchell, 2014).

Randolph-Seng, Mitchell, et al. (2014) argue that these new developments concentrate on four themes: theory, entrepreneurial affect, entrepreneurial neuroscience and entrepreneurial thought.

Carsrud and Brännback (2014) suggest a linkage-focused work connecting cognitive factors such as intentions and motivations to subsequent behaviours such as goal setting. Bird (2014) highlights the crucial role that entrepreneurial behaviour plays as a concrete outcome: one of cognition's most observable outcomes. Randolph-Seng, Williams, and Hayek (2014) integrate the research literature on non-conscious cognition with research in entrepreneurial intentions and intuition.

The interface of feeling with thinking is relevant, too. Foo, Murnieks, and Chan (2014) suggest that the affective/cognitive connection exists and exerts influence on both time and levels of analysis.

Denis A. Grégoire (2014) draws attention to different types of affective/cognitive forces in entrepreneurship, depending on their enduring versus episodic nature and their plane of influence.

Other scholars propose and test a culturally situated model that relates entrepreneurial emotions/passion and cognition/self-efficacy, exploring how these factors impact venture performance (Drnovsek, Slavec, & Cardon, 2014).

Likewise, the hardware that complements the software of human feeling/thinking takes on relevance. Baucus, Baucus, and Mitchell (2014) demonstrate how entrepreneurs' brains are physiologically the same as most people's but are different regarding their experiences and knowledge.

McMullen et al. (2014), explains the formation and successful implementation of opportunity beliefs and provides a new view that points to the theme of entrepreneurial neuroscience.

On entrepreneurial thought, Forbes (2014) proposes a new way of thinking about advances in large-scale codification processes (media, etc.) and network formation (markets and social structures), in part because such advanced symbol systems depend upon language as primary to idea transmission and understanding. Clarke and Cornelissen (2014) claim the formative role of language in shaping the ideas of entrepreneurs and their attempts to gain a broader understanding and recognition for a new venture from stakeholders and resource providers.

This account is not meant to present a detailed spectrum of research on entrepreneurial cognition for each period covered. Rather it presents some of the key findings on entrepreneurial cognition and unveils a concern about its methodological and technological limitations, which call for consideration of a brain-driven perspective to advance the frontiers of entrepreneurship research.

Some of these limitations are pointed out by Omorede et al. (2015), who argue that: ‘some of the cognition topics that are interesting to advance are methodologically challenging, because it is difficult for people to reflect on their own conscious processes. Studies of the brain and procedures such as brain scanning are, therefore, suggested as next step’ (p. 766). Baucus et al. (2014) contend that neuroscience renders the entrepreneur as human. Krueger (2014), referring to the use of neurosciences on entrepreneurial cognition research, states: ‘it is easy to see the possibilities for extending this model.’

(p. 3).

### 2.3 *Strengths and limitations*

There are optimistic and critical voices concerning the academic added value of a brain-driven perspective to entrepreneurship research.

The optimists argue that neurosciences methods, technologies and tools may contribute to entrepreneurship research in several ways (Nicolaou & Shane, 2014) from the new possibilities afforded by these new tools (de Holan, 2014).

The use of these technologies may help to understand how entrepreneurs think, a major part of what research on entrepreneurial cognition seeks to explain (R. K. Mitchell et al., 2007).

Neuroscience may complement aspects of the biological perspective on entrepreneurship (Nicolaou & Shane, 2014) and allow understanding of many facets of the practice of entrepreneurship and those who carry it out, by providing evidence that can be developed and taught in classrooms (de Holan, 2014).

Schade (2005) highlights the ability of neurosciences to focus closely on individual decisions.

Along the same direction, Krueger and Welp (2014) claim that neurosciences might be useful for a better understanding of entrepreneurs and entrepreneurship.

Instead of examining the verbalisation of thinking as a mechanism to see what is going on in the mind, neuroscientific tools allow the examination of the mind itself as it is doing something, as it is being done elsewhere (de Holan, 2014). For example, its tools enable analysis of what happens in the mind of a person who is looking at something he or she considers beautiful or ugly (Cela-Conde et al., 2004) without having to ask, and therefore avoiding the issues of confusion, desirability, or outright lies (de Holan, 2014).

de Holan (2014) contends that the research potential of neurosciences is vast, broad and not limited to the topics of behavioural decision theory, game theory, perceptions, emotions & affect.

Hoskisson, Covin, Volberda, and Johnson (2011) point out that these questions might be better approached from a neurological spectrum: what happens in the brain of an entrepreneur that allows him or her to recognise or construct an opportunity, be resourceful or do bricolage? Is the functioning of his or her brain superior to other people's, or pathologically biased and impervious to the rather slim odds of the success of new ventures? Is successful entrepreneurship related to a unique capacity to recognise an opportunity, or, as has recently been argued, the capacity to organise resources around that opportunity, or to ignore reality<sup>3</sup>? Is successful entrepreneurship related to a superior ability to reason, or is it more a capacity to seduce people, or both, or neither? And are these differences created? Can they be developed? Do entrepreneurs detect opportunities faster than other people? And if they do, are they more error-prone?

de Holan (2014) suggests that Hoskisson's questions can be better answered with neuroscientific tools than with most of the tools used now, and the answers produced may permanently change the way the entrepreneur is seen, the entrepreneurial process, and entrepreneurial management in general. If what is needed is more research on the micro antecedents of innovation and performance, one cannot afford to keep ignoring the foundational micro antecedents of any human decision and action: the brain (de Holan, 2014).

<sup>3</sup> Each involves different parts of the brain, different neuronal paths, and different skills, some of which are acquired (de Holan, 2014).

Entrepreneurship can use theories and techniques developed in the neurosciences to help better understand these phenomena, while neuroscientific research can exploit scientifically interesting phenomena in the field of entrepreneurship (Blair, 2010). Put simply, the application of neurosciences in entrepreneurship represents a unique opportunity to ask questions that could not be answered before, to test questions that could not even be thought to have been asked before, to test questions in a better way and to get better answers (Krueger & Welp, 2014).

On the other hand, the potential of neurosciences in entrepreneurship research is treated with some scepticism. McBride (2014) argues that studies linking questions of interest to techniques from cognitive science and neuroscience have been less than impressive, mixed, muddled, or only partially true.

Tracey (2014) claims that neuroimaging at present is incapable of shedding meaningful light on the questions that de Holan suggests it could answer.

The cognitive processes are so complex, and the uncertainties so great, that it is unclear, for example, as to whether opportunity recognition is rooted in particular cognitive functions that exist in a particular part of some brains, but not in others (Tracey & Schluppeck, 2014). Far less easy is to disentangle these functions from the broader social and cultural contexts in which individual entrepreneurs (and their brains) are embedded (Tracey & Schluppeck, 2014).

To suggest otherwise is to stretch the power of neuroimaging beyond the limits of credibility and may expose entrepreneurship research to ridicule (Tracey & Schluppeck, 2014).

Most neuroscientists do not believe that higher level cognitive functions can be localised to a small selection of brain areas: it is very likely that such functions involve a distributed pattern of neural activity across different areas of the brain (Tracey & Schluppeck, 2014).

Just because one part of the brain appears more active when a person performs a particular task does not necessarily imply that it is the part of the brain responsible for that task (Logothetis, 2008).

Tracey and Schluppeck (2014) claim that there is still debate in the literature on neuroscience about the extent to which fMRI reflects excitatory or inhibitory neural responses in any particular brain region.

Statistical correlation in neuroimaging data with performance in a task or behavioural traits does not imply that the identified areas play a causative role. As Wade (2006) notes, 'If a scan shows that a brain area 'lights up' when someone is doodling, that does not mean the area is a doodling centre!' (p. 23).

Coupled with the above mentioned technical and methodological limitations of neuroscience tools, another explanation why neuro-entrepreneurship is not gaining credibility is that it is built on and/or around a view of entrepreneurship which is not a theory (individual/opportunity nexus), and that view itself is built on very dubious ontological grounds (McBride, 2014).

As is the case with any methodology used to study a social phenomenon, both the tools that neuroscience uses and the way they are used are subject to limitations, biases, and boundary conditions (Eastman & Campbell, 2006; Vul, Harris, Winkielman, & Pashler, 2009).

Neuroscience is not a solution to all research questions; nevertheless, not using a powerful and available research methodology is not a very good idea (de Holan, 2014).

By highlighting the strengths and limitations of neuroscience in entrepreneurship research, I have attempted to create a coherent basis for this review, as well as for future brain-driven entrepreneurship research. I have outlined prior and latest findings on entrepreneurial cognition since it is the major driving force towards the use of neurosciences. Similarly, I have conceptualised the term brain driven entrepreneurship research to demarcate the boundaries of this new research stream. These three elements bolster the aims of this review.

### 3 METHODOLOGY OF THE REVIEW

To identify pathways of existing evidence I content analysed published entrepreneurship studies that applied a neuroscientific perspective as set out in Section 2.1, that is studies that combined an experimental design and the use of any neuroscience technology. The aim is to examine how this approach is depicted and what is known from its use in entrepreneurship. The methodology is guided by the procedure applied by Mainela, Puhakka, and Servais (2014). The following sections illustrate the methods I followed to select and analyse the articles.

#### 3.1 Identification of relevant literature

The articles were selected through a stepwise process, extensively following the protocol of Kitchenham (2004), which supports the aim of searching for relevant research, systematic and comprehensive. The selection procedure is partly similar to that followed by Denis A Grégoire, Corbett, and McMullen (2011) in their review of developing a conceptually sound research agenda for research on entrepreneurial cognition.

First, the totality of journals listed in the Social Sciences Citation Index (SSCI) was taken into account. Since 95.05% of peer-reviewed articles published in social sciences are published in English, I chose English as the search language.

Secondly, I crosschecked that listing with the ten most influential journals in entrepreneurship journals as ranked by Stewart and Cotton (2013).

Thirdly, I searched for journals related to the topic of the review outside the SSCI platform, and as a result included the Journal of Neuroscience and Neuroeconomics.

Fourthly, I identified the leading conferences linked to the theme of the review and added into the search the last five years of proceedings of the Babson College Entrepreneurship Research Conference, the Academy of Management Annual Meeting, the Annual Meeting of the Society for Neuroeconomics and the NeuroPsychoEconomics Conference.

Fifthly, I contacted scholars who had presented during the 2015 Academy of Management Panel Symposium on Neuro-entrepreneurship and asked for suggestions for eligible articles.

The protocol for identifying the literature is presented in Table 2.

The search took into account articles published until 2016. It was a deliberate choice made to maximise the identification of eligible articles.

The selection of the articles had two stages. The first stage was intentionally wide in scope: it consisted of the identification of eligible articles through a search on the whole SSCI database, the ten most relevant entrepreneurship journals as ranked by Stewart and Cotton (2013), Google Scholar, the proceedings of three major conferences and networking with related scholars. Since the topic of this review is new, I considered it appropriate not to limit the search to journals with a pre-determined ISI-impact factor.

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Table 2 around here  
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Then I searched the journals through the keywords ‘brain’, ‘neuro’, ‘neural’ AND entrepreneur\* to minimise subjective interpretation bias. These terms are sufficiently inclusive to capture the most substantial articles within the established conceptual boundaries and exclusive enough to discard less relevant articles. I also examined the citations of Krueger and Day (2010), de Holan (2014), Nicolaou and Shane (2014) and Tracey and Schluppeck (2014) as these articles focus specifically on the issue of neuro-entrepreneurship.

In the second stage, I directed my attention to the conceptual bases of the articles. As a brain-driven approach to entrepreneurship research refers to the study of any suitable topic of entrepreneurship



using both an experimental design and any brain-imaging technologies, the chosen articles applied this approach and used both ‘neurosciences/brain/neural’ and ‘entrepreneurship/entrepreneurial/entrepreneur’ in their titles, abstracts or keywords. I ensured that the articles incorporated concepts from both neurosciences and entrepreneurship theory by reviewing the theoretical section of the studies. I also excluded articles which did not use both experimental design and a brain-imaging technology, non-empirical articles, non-peer reviewed articles, non-published articles and commentaries providing overviews of the field.

Through this procedure, I identified two articles from two journals. I also identified eight non-empirical articles, five conference presentations and commentaries providing overviews of the field, but these were excluded because they did not fulfil the selection criteria set in the protocol for identifying relevant literature (See Table 2).

### 3.2 Coding procedure and analysis methods

In the analysis, I used the content analysis procedures typical of grounded theoretical analysis (Corbin & Strauss, 1990). Overall, the analytic procedure mainly follows the meta-narrative procedure presented by Greenhalgh, Robert, Macfarlane, Bate, and Kyriakidou (2004). I started with mapping the data with three types of coding: open coding, axial coding and selective coding (See Table 3).

In the open coding, I used data-driven (emic) and theory-led (etic) codes (Pike, 1967) to be able to study the articles from the inside (categories that emerge from data) and outside (categories derived by researchers based on prior research)(Mainela et al., 2014).

The articles were coded. I started with an examination of the research aims and theoretical frameworks of the studies to define the entrepreneurship phenomena of interest.

Through data-driven coding of the research questions, theoretical basis and the fields of contribution, I depicted the research focus and conceptual foundations of the studies.

I then recorded their definitions, if indicated, and how the studies approached the use of neurosciences.

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Table 3 around here  
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The conceptualisations presented in Table 1 worked as a frame of reference, but it was soon noticed that the articles focus exclusively on the issue of decision-making. I, therefore, took into account the decision-making literature on which they relied in their conceptual discussion and the latest findings on entrepreneurial decision-making and decision-making behaviours.

I examined each study more as a whole to assess it as a piece of research from the decision-making viewpoint rather than searching for certain variables or words. In this way, I aimed to unveil the specificities of a BER about decision-making that could influence the research agenda.

In the axial coding, I searched for similar conceptual bases and recorded unifying concepts. In the selective coding, the idea was to engineer a basis for defining research streams. Each research stream has a particular basic approach to conditions, actions, interactions and outcomes.

In the phase of appraisal, I evaluated the articles concerning their relevance to entrepreneurship research by their key results and contributions.

I then produced a narrative account of the conceptual foundations, key findings and contributions and a synthesis of the observations.

## 4 RESULTS OF THE REVIEW

The analysis unveils the early findings of a set of entrepreneurship studies carried out at a brain level. The study covered the totality of peer-reviewed eligible empirical articles published until 2016. A summary of the studies is presented in Table 4.

### 4.1 Findings and contributions using BER in entrepreneurship research

I illustrate what I know about the added value of a brain-driven perspective in entrepreneurship research through the empirical findings and the conceptual ideas put forward from five perspectives: theoretical, behavioural, neural, experimental and technological.

### 4.2 Decision-making efficiency over decision speed

Entrepreneurs' brains are physiologically the same as other persons' brains, but regarding experiences and knowledge, they are different (Baucus et al., 2014).

One of these differences has to do with how the entrepreneurial context of high uncertainty, ambiguity, time pressure, emotional intensity, and high risk affects decision-making (Baron, 2008; Busenitz & Barney, 1997; Mullins & Forlani, 2005). Applying different conceptual perspectives and methods, the studies focus on what is claimed to be substantial to entrepreneurs: finding what differentiates the decision-making ability of entrepreneurs from non-entrepreneurs (Stanton & M Welpé, 2010). More concretely, the studies address the issue of 'entrepreneurial decision-making' in a context of uncertainty from a brain level perspective.

Judgment and decision-making are well-established topics of interest in management, psychology, sociology, and political science, to name but a few (Gilovich & Griffin, 2010; Hastie, 2001). Within entrepreneurship, the topic of entrepreneurial decision-making is relevant as well (Baron & Ward, 2004; Shepherd et al., 2015).

A recent review categorizes six decision-making frameworks along the primary activities associated with entrepreneurship: opportunity assessment decisions, entrepreneurial entry decisions, decisions about exploiting opportunities, entrepreneurial exit decisions, heuristics and bias in the decision-making context, characteristics of the entrepreneurial decision maker, and environment as decision context (Shepherd et al., 2015).

The studies implicitly touch upon three dimensions of entrepreneurial decision-making: opportunity assessment decisions, decisions about exploiting opportunities (Laureiro-Martínez, Brusoni, Canessa, & Zollo, 2014) and characteristics of the entrepreneurial decision-maker (Ortiz-Terán et al., 2013).

Opportunity is at the core of entrepreneurship, so understanding how entrepreneurs arrive at decisions relating to opportunity recognition, evaluation and exploitation is critical to advancing our knowledge of the field as a whole (Shane, 2003; Shane & Venkataraman, 2000). At the same time, individuals are heterogeneous in their beliefs and desires, and these differences help explain why some choose to become entrepreneurs and why others choose managerial or other employment-related roles (Shepherd et al., 2015).

Laureiro-Martínez et al. (2014) examine the neurobiological mechanisms behind decision-making efficiency among entrepreneurs and managers. They operationalise decision-making efficiency as total payoff divided by response time. They highlight that the ability to make decisions quickly is vital to keep up with fast environmental changes, survival and market performance.

Ortiz-Terán et al. (2014) assess the relationship between neurophysiologic and personality characteristics in entrepreneurial decision-making. They mainly focus on how decision-making differs between founder entrepreneurs and non-founder entrepreneurs.

To put it simply, Laureiro-Martínez et al. (2014) evaluate decision-making regarding quality and time, whereas Ortiz-Terán et al. (2014) focus mainly on the reaction time also known as decision-making speed and the cognitive mechanisms behind it.



Reaction time is the time taken between the onset of a stimulus/event and the production of a behavioural response (e.g. a button press) (Bear, Connors, & Paradiso, 2007).

Laureiro-Martínez et al. (2014) conclude that entrepreneurs make more efficient decisions compared to managers. Their results suggest that expert decision-making success may be enhanced by the individual's ability to track evidence and in disengaging attention from current reassuring options, both mechanisms leading to more efficient decision-making.

The evidence obtained by Ortiz-Terán et al. (2014) indicates that founder entrepreneurs make faster decisions compared to non-founding entrepreneurs. In their view, founding entrepreneurs might be more oriented towards opportunity recognition and capture and eager to make more rapid decisions about which opportunities to pursue. However, they dedicate significant cognitive resources to decision closure and resolution of residual conflicts (Ortiz-Terán et al., 2013). Entrepreneurs have to invest more mental effort in this process, partly because they need to check the decisions they have just made (Baron & Ward, 2004).

The studies refer to a cognitive approach to entrepreneurial decision-making. The cognitive perspective is concerned with mental processes such as perceiving, remembering, reasoning, deciding and problem-solving, and it assumes that only by studying mental processes is it possible to fully understand what organisms do (Nolan-Hoeksema, Frederickson, Loftus, & Wagenaar, 2014). Cognitive biases influence entrepreneurial activity, and cognitive biases strongly influence entrepreneurial decision-making (Baron, 2004; Busenitz & Arthurs, 2007; Shaver & Scott, 1991).

To examine decision-making efficiency, Laureiro-Martínez et al. (2014) combine a cognitive and exploration-exploitation view. Ortiz-Terán et al. (2014) applied both a cognitive and personality trait approach to assess decision-making.

The studies use cognitive view, and further value could have been achieved by characterizing these studies within the context of existing approaches to entrepreneurial decision-making such as the two modes of entrepreneurial decision making: effectuation and causation (Maine, Soh, & Dos Santos, 2015), naturalistic decision-making (Gustafsson, 2006), the Stimulus-Organism-Response model to entrepreneurial decision-making (Michl, Welp, Spörrle, & Picot, 2009), and so on.

The interplay between the level of certainty (high, medium, low) and the elicited cognitive processes portrayed in the studies (intuitive cognition, heuristics, analysis) could have been aided, for instance, by the cognitive continuum theory (Hammond, 1988), or the factors influencing differential susceptibility to cognitive errors by entrepreneurs and others (Baron, 1998).

Baron (1998) confirms that due to the peculiar characteristics of their environment (notably high levels of uncertainty, novelty, emotions and time pressure) entrepreneurs are apt to demonstrate decision-making biases or heuristics. The list of these includes counterfactual thinking, affect infusion, attributional style, the planning fallacy and self-justification, and self-serving bias (Baron, 1998).

Since entrepreneurs are more liable than managers to use decision-making biases and heuristics (Busenitz & Barney, 1997), the studies could have profited from the particular assessment of a suitable heuristic within their design.

Entrepreneurial cognition-based concepts might be used to distinguish entrepreneurs from non-entrepreneurs (R. K. Mitchell, 1994), but they cannot be solely used to assess entrepreneurial decision-making. Emotions and motivations also play a key role in entrepreneurial decision-making (Michl et al., 2009; Reed, 2010). Evidence shows that the brain is easily fooled by emotional states, which prevent it from making fully rational decisions (Camerer, Loewenstein, & Prelec, 2005). Lawrence et al. (2008) found that successful entrepreneurs and managers share great ability at rational analysis ('cold' cognition), but entrepreneurs display a significant edge in analyses that engaged both rational and emotional thinking ('hot' cognition). Perhaps unsurprisingly, 'hot' and 'cold' cognition tend to occur in different areas of the brain's front lobes (Krueger & Welp, 2014).

Baron (1998, 2000, 2008) postulates that entrepreneurs will experience very intense emotions in their decisions, including the effect of positive and negative emotions. Positive emotions such as joy and happiness might lead entrepreneurs not to fully evaluate all possible outcome alternatives, which consequently results in hasty and premature decisions (Ardichvili, Cardozo, & Ray,

2003; Baron, 2004, 2008). Negative emotions such as anxiety and shame do not have an exactly opposing effect compared to positive emotions, but they are rather heterogeneous (Michl et al., 2009). Although some researchers still see emotions and cognitions as two independent but interacting phenomena, it is common sense that emotions and cognition cannot be studied separately from each other, and only an integrative view will lead to an understanding of their effects on entrepreneurial decision-making (Michl et al., 2009).

The consideration of emotions and motivations within the analysis of entrepreneurial decision-making from a brain perspective remains a task pending for future studies.

The studies denote an effort to assess the decision-making process through the theoretical articulation of a cognitive/exploitation-exploration view (Laureiro-Martínez et al., 2014) and cognitive/personality traits view (Ortiz-Terán et al., 2013), having in common a brain-level of analysis, never attempted before within the field. I consider these findings as the beginning of a deeper analysis of the phenomena of entrepreneurial decision-making while acknowledging the need for the consideration of the emotional and motivational component to entrepreneurial decision-making.

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Table 4 around here  
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### 4.3 Behavioural modulation

The cognitive perspective studies mental processes by focusing on specific behaviours but interprets them regarding underlying processes (Nolan-Hoeksema et al., 2014). Decision-making is one of these processes.

Just as in neurosciences, brain-driven research within entrepreneurship requires the use of experimental tasks to modulate behaviour. The identification or elaboration of a suitable task is the determinant in the efficient modulation of the behaviour under scrutiny.

A task is a test of cognition or behaviour that is administered to a subject to assess the ability of the individual to use his or her cognitive functions to adequately produce a correct outcome to the request of the task (Hart, 2015).

Behavioural analysis is a mandatory first step. Research in neurosciences comprises two steps: the first aims to assess the behavioural effects of interest, and only if these work out is a neuroimaging tool the applied to investigate the neural correlates of the studied phenomena (Palva, 2014). Avoiding the behavioural component may result in lack of credibility of the result (Palva, 2014). Hence, any brain-oriented research in entrepreneurship should subscribe to the fulfilment of this requirement.

The studies rightly undertake behavioural analysis first. They modulate the participant's decision-making via the application of two tasks: the basic Stroop reaction time task (Ortiz-Terán et al., 2013) and the 4-armed bandit task (Laureiro-Martínez et al., 2014).

The former consists of words about a variety of colours (blue, green, red) printed in colours different from that of the word itself (e.g., the word 'blue' is printed in green or red) on a computer screen (Ortiz-Terán et al., 2013). The latter is a classical task of exploitative/explorative decision-making (Daw, O'Doherty, Dayan, Seymour, & Dolan, 2006) which involves repeated choices among four different slot machines that lead to variable gains in successive trials, all having the same structure (Laureiro-Martínez et al., 2014).

Both tasks are adequate from the perspective of their sought research objectives since decisions within the spectrum of entrepreneurship are normally made under the constraints of limited time, knowledge, and computational capacity (Rieskamp & Hoffrage, 2008).

The Stroop task is one of the best-known paradigms in cognitive psychology (MacLeod, 2005). The explanation that reading words were much more practised than naming pictures or colours introduced the concept of ‘automaticity’ to psychology (Cattell, 1886).

The fact that the investigation of Ortiz-Terán et al. (2014) was the first that makes use of this task within the context of entrepreneurship led me to find existing evidence on the mechanisms that may cause it.

The accounts of what causes the interference produced during the Stroop task are various: degree of practice (Cattell, 1886), speed of processing (Dyer, 1973), competition between ongoing processing of the word and the colour dimensions at the same time (Logan, 1980), and build-up of practice for the word pathway being greater than that for the colour pathway (Cohen, Dunbar, & McClelland, 1990).

This variety of possible causal factors suggests that interpreting the results of Stroop experiments as evidence for a particular type of processing or a particular process is suspect (MacLeod, 2005).

The reasons behind the interference should be taken as a first step in attempting to explain how entrepreneurs react before an ambiguous stimulus.

The scientific measurement of the speed factor in decision-making nonetheless provides concrete scientific evidence that proves that founding entrepreneurs make faster decisions as compared to non-founding entrepreneurs. In doing so, it adds value to the topic of entrepreneurial decision-making.

Prior studies argued that entrepreneurs rely on heuristics in their decision-making more than managers (Deligonul, Hult, & Cavusgil, 2008), the founders of new firms must make quicker decisions than the managers of established firms (Shepherd et al., 2015), heuristics facilitate entrepreneurial decision-making (Busenitz & Barney, 1997), optimism, experience and overconfidence affect entrepreneurial decision-making (Shepherd et al., 2015), but none of them measured the moment in which decision making takes place or attempted to explain the neural mechanisms behind it.

Since every task is subject to improvement, it remains a natural next step to include the emotional aspect which can be assessed within the context of the Stroop task (McKenna & Sharma, 1995).

On the other hand, the 4-armed bandit task used by Laureiro-Martínez et al. (2014) is appropriate to modulate entrepreneurial decision-making, because entrepreneurs make decisions about where to explore in search of new opportunities, and how to exploit known opportunities (Bryant, 2014).

They also concentrate their enquiry on measuring performance, which has also been a subject of interest in cognitive neuroscience (Cohen, McClure, & Angela, 2007; Daw et al., 2006).

Similar to Ortiz-Terán et al. (2014), the investigation of Laureiro-Martínez et al. (2014) is the first of its kind to apply the 4-armed bandit task in the context of entrepreneurial exploration and exploitation.

The task used by Laureiro-Martínez (2014) is an adjusted version of the original bandit problem, which is a dynamic decision-making task that is simply described, well-suited to controlled laboratory study, and representative of a broad class of real-world problems (Steyvers, Lee, & Wagenmakers, 2009).

Some of the reasons for the suitability of this task to entrepreneurship are the following: bandit problems provide an interesting and useful task for the study of human capabilities in decision-making and problem-solving (Steyvers et al., 2009). They provide a challenging task, similar to many real-world problems, that is nevertheless simple to understand. They require people to search their environment in intelligent ways to make decisions, exploring uncertain alternatives and exploiting familiar ones (Steyvers et al., 2009). The ability to search effectively, striking the right balance between exploration and exploitation, is a basic requirement for successful decision-making (Gigerenzer & Todd, 1999). In other words, bandit problems shed light on how people make decisions in general and on how information is integrated into decisions in particular (Schulz, Konstantinidis, & Speekenbrink, 2015).

Armed-bandit tasks concentrate on the trade-off between exploration (trying out new things) and exploitation (maximising expected rewards) under uncertainty. Since these two aspects are fundamental to the entrepreneurial process and play a central role in the recognition and exploitation of opportunities (Shane & Venkataraman, 2000), it is an appropriate task to study entrepreneurial decision-making efficiency. The fact that bandit problems have a known optimal solution process also makes it possible to compare it with human decision-making (Steyvers et al., 2009).

The results obtained by Laureiro-Martinez (2015) are the first which assess decision-making efficiency based on data collected directly from entrepreneurs' brains and elaborate on the possible process taking place. They also confirm that entrepreneurs are quicker than managers and as equally effective as managers when faced with a simulated task of exploration and exploitation.

The depth of analysis and results achieved by Laurie's team is germane when taking into account that a growing body of research on exploration and exploitation study the phenomena from a narrow perspective, mostly within larger, well-established firms (Jansen, Simsek, & Cao, 2012; Stettner, S. Aharonson, & L Amburgey, 2014), SMEs to a lesser extent (Frigotto, Coller, & Collini, 2014), and entrepreneurial behaviour from an individual-level perspective (Kuckertz, Kohtamäki, & Droege gen. Körber, 2010; Voutsina, Mourmant, & Niederman, 2014).

In addition to the appropriateness of the task and the implied cognitive mechanisms trailing decision-making efficiency, the measures of the task could have been bettered had the emotional and personality trait aspect been considered, because performance in bandit problems also seems to have natural links to the personality traits that control risk behaviour. Too much exploration in solving a bandit problem could be regarded as a form of risk-seeking behaviour, while too much exploitation could be regarded as risk-averse behaviour (Steyvers et al., 2009).

Moreover, the analysis of individual differences in solving bandit problems, which is also said to be feasible and important (Steyvers et al., 2009), is also a relevant construct to entrepreneurship research, and hence remains a topic pending for a future study.

#### 4.4 *Experimental design*

A common complaint among brain imaging specialists is the misconception that you can simply place a human subject into a scanner, tell them to look at some stimulus, and then publish the results. Like any other technique, whole-brain imaging experiments must be carefully designed and interpreted, more than the non-specialist may sometimes appreciate (Carter & Shieh, 2015). A brain-driven approach to entrepreneurship requires the same level of accuracy.

Like any other experiment in neuroscience, experiments examine the effect of an independent variable on a dependent variable. The independent variable is the experimental variable that is intentionally manipulated by the researcher and is hypothesised to cause a change in the dependent variable (Carter & Shieh, 2015).

To test a hypothesis, a scientist designs an experiment (Huettel et al., 2009). Experiments, in a technical sense of the word, first manipulate some aspect of the world and then measure the outcome of that manipulation (Huettel et al., 2009).

An experiment can be defined as a controlled test of a hypothesis (Huettel et al., 2009). It is the most powerful way of doing this because it eliminates a lot of alternative explanations which can occur with other kinds of evidence and allow the investigation of alternative explanations of effects in extensions of the original experiment because experiments are easy to replicate (Coolican, 2014). Experiments can isolate cause and effect because the independent variable is controlled (Coolican, 2014) and can control many extraneous influences so that validity is high and alternative explanations of events are eliminated or weakened (Coolican, 2014).

In spite of the fact that experiments may address the internal validity problem of empirical research in entrepreneurship (de Holan, 2014), are effective for theory building (Colquitt, 2008) and facilitate the effective discrimination of the factors of interest from other factors which are often rapidly



changing (Krueger & Welp, 2014), experiments in entrepreneurship research are not the prevalent research method (Schade & Burmeister, 2009; Simmons et al., 2016).

The exploratory search performed on the SSCI database using the keyword *entrepreneur\* AND experimental* design from 2000 to date revealed that out of 996, only 13 articles had been produced using either an experimental (eight articles) or quasi-experimental design (five articles). The outcome of this search suggests that experiments in entrepreneurship research represent 3% of the papers produced.

The studies applied an experimental approach, which is said to be especially suited to empirically test hypotheses within the decision-making framework (Schade & Burmeister, 2009).

Though the studies differ regarding their design and measurement tool, a strict comparison among them is not feasible, but the assessment of the coherence of their experimental design is. A well-designed experiment shares three key characteristics: appropriateness of the independent variable, appropriateness of the dependent variable and testability of the hypothesis within the set designed test (Huettel et al., 2009).

In an experiment, the independent variable can be a stimulus, task, or even a difference in the subjects being tested, such as their age, gender, or disease state (Carter & Shieh, 2015).

Ortiz and Terán et al. (2014) measured Event-Related Potentials (ERPs), specifically N200<sup>4</sup>, P300<sup>5</sup> N450<sup>6</sup> generated by a Stroop task and complemented by the Temperament and Character Inventory revised<sup>7</sup>. They collected brain electrical activity using EEG. Laureiro-Martínez et al. (2014) measured BOLD signal intensity generated by a 4-armed bandit task. In their case, indirect brain activity data was gathered using fMRI.

The employed independent variables are suitable: Stroop task (Ortiz-Terán et al., 2013) and 4-armed bandit task (Laureiro-Martínez et al., 2014). The use of subject generated event boundaries seems appropriate, in that it provides a better estimate of how each subject performs as compared to having other people do the task for them (Huettel et al., 2009).

Because the participants do not know that they are going to respond to the tasks until after they have finished viewing them for the first time, no bias is introduced by the used independent variables (Huettel et al., 2009).

The chosen dependent variables: ERPs (Ortiz-Terán et al., 2013) and BOLD signal (Laureiro-Martínez et al., 2014), despite the inevitable pluses and minuses of EEG and fMRI, are appropriate. For instance, the pulse sequence used can provide good BOLD, and ERP contrast and thus can provide appropriate dependent measures (Huettel et al., 2009).

Lastly, the hypothesis predicts a straightforward relation between the independent and dependent variables: that change in BOLD signal and ERPs should preferentially occur at event boundaries compared to other time points. They are falsifiable, in that it is possible for there to be no significant BOLD or ERP differences associated with event boundaries (Huettel et al., 2009).

Based on the above, the studies appear to be well-designed and capable of answering the stated experimental questions.

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<sup>4</sup> N200 is associated with changing features in the stimulus environment and has been interpreted as an automatic filtering stage for selective attention towards novelty (Luck & Hillyard, 1994). Two specific cognitive processes (response selection and executive control), both related to response inhibition, have been identified in the N200 (Falkenstein, Hoormann, & Hohnsbein, 1999).

<sup>5</sup> P300 is a marker of memory in evaluation of environmental stimuli whenever an ongoing task requires identification of salient information (Donchin & Coles, 1988).

<sup>6</sup> Cognitive tasks that require detection of processing conflicts between competing response options (e.g. incongruent condition of the Stroop task) reliably elicit a N450 (Appelbaum, Meyerhoff, & Woldorff, 2009). The N450 is present following both stimulus and response conflict (West, Bowry, & McConville, 2004).

<sup>7</sup> (TCI) is an inventory for personality traits devised by Pelissolo et al. (2005). Ortiz-Terán et al. (2014) focused on the dimensions of novelty seeking, harm avoidance, reward dependence, persistence, and self-directedness.

#### 4.5 *Neurocognitive mechanisms of entrepreneurial decision-making*

Methods of social and psychological sciences can investigate the effects that changes in the environment and personality traits have on behaviour, and can, at most, infer the cognitive and emotional underpinnings (Polezzi, Guarneri, & Civali, 2012). However, to have a proper understanding of the complexity of the interaction going on during a decision process, it is fundamental also to investigate the mutual effects that changes in the environment, behaviour and neural underpinnings have on each other (Polezzi et al., 2012). For this reason, neuroscientific methods can lead to a better understanding of decision-making (Polezzi et al., 2012).

Aided by comprehensive experimental designs and standard neuroimaging technologies, the studies were successful in locating the brain regions concerned with decision-making and provided explanations on how the decision-making processes may take place in the brains of entrepreneurs.

Ortiz-Terán et al. (2014) found that founder entrepreneurs need less time to visualise stimuli before making a decision, a task undertaken mainly in the occipital area, which they claim that is due to greater attention to stimuli. Founder entrepreneurs show a longer time for post-evaluation, postulating that this might be due to a complex interaction between systems affecting memory, active searching, attention, complex computations, establishing comparisons, decision-making and checking of answers.

They also found that brain location about two cognitive processes can differentiate entrepreneurs: an early one linked with motor response initiation, mostly localised around supplementary motor areas, and a late one linked to integrative cognitive processes which serve to analyse and evaluate a given response, mainly in the anterior frontal regions.

Laureiro-Martínez et al. (2014) found that, compared with managers, entrepreneurs show higher decision-making efficiency and a stronger activation in regions of the frontopolar cortex (FPC). They confirm that exploitative choices recruit ventromedial prefrontal activations involved in reward anticipation (Tobler, O'Doherty, Dolan, & Schultz, 2007) and tracking the value of the current choice (Boorman, Behrens, Woolrich, & Rushworth, 2009; Kolling, Behrens, Mars, & Rushworth, 2012). Explorative choices engage the frontoparietal regions, alongside the dorsal sector of the anterior cingulate cortex (dACC) and locus coeruleus, associated with executive and attentional control (Boorman et al., 2009; Corbetta & Shulman, 2002).

They conclude that decision-making success might be enhanced by the individual's ability to track evidence in favour of constantly evolving alternative options, and in disengaging attention from current reassuring options, both mechanisms leading to more efficient decision-making. These same skills are likely to promote success in entrepreneurial endeavours that require adaptation to rapidly changing and unforgiving environmental circumstances.

These findings help to understand the decision-making process among entrepreneurs at a brain level because they add depth to the analysis of existing theories (Endres & Woods, 2006), processes (Gibcus & Hoesel, 2008; Schade & Burmeister, 2009; Vermeulen & Curseu, 2008) and models of entrepreneurial decision-making (Khefacha & Belkacem, 2015; Macchione S, Rocha M, & Bigio, 2013; Miao & Liu, 2010; Olayinka, Olusegun, Kellikume, & Kayode, 2015; Pech & Cameron, 2006; Vermeulen & Curseu, 2008).

Embedding their results within the three stages of the decision-making process: emergence of an idea, elaboration of an idea and implementation of the decision (Gibcus & Hoesel, 2008), or the six steps in the decision-making process: recognition, formulation, search, evaluation, choice and implementation, would have strengthened their explanatory power.

If the decision-making processes of entrepreneurs is influenced by the interplay between the attributes of the decision-maker and the specifics of the situation that he or she is facing, it may have been helpful to consider the entrepreneurial decision styles which are argued to be characterized by distinct cognitive decision content (Lucas, Vermeulen, & Curseu, 2008).

The analysis of the cognitive components in relation to decision-making could have been enhanced with the use of tools such as cognitive maps (Gómez, Moreno, Pazos, & Sierra-Alonso, 2000) and cognitive scripts, both viable ways of examining the cognitive structures of entrepreneurs and understanding the differences between entrepreneurs and managers (Brännback & Carsrud, 2009). The studies inform the neural correlates of entrepreneurial decision-making under an ambiguous task (Ortiz-Terán et al., 2013) and an exploratory-exploitative task (Laureiro-Martínez et al., 2014) and confirm their results with prior evidence found in neuroscience research. They conclude that entrepreneurs make faster decisions than non-entrepreneurs. The issue of time is relevant because a basic finding in cognitive science is a relation called the speed-accuracy trade-off: a decision-maker can increase accuracy at the cost of increasing decision time (Busemeyer, 2015). Decisions take time and the time taken to make a choice can change the decision (Busemeyer, 2015).

Furthermore, the studies also use for the first time EEG and fMRI technologies in the analysis of entrepreneurial decision-making and provide evidence that links decision-making with speed (Ortiz-Terán et al., 2013) and decision-making with efficiency (Laureiro-Martínez et al., 2014). The causal evidence achieved at experimental level by Ortiz-Terán et al. (2014) and Laureiro-Martínez et al. (2014) enhances theory building in a field which is dominated by retrospective, self-reporting and correlational research methods (Simmons et al., 2016).

For those who doubt the potential of a brain-level approach to entrepreneurship, these results may tell little, but for those who assess this evidence as the natural perfectible steps of an emerging research stream, this evidence may represent the opportunity to get involved.

Saying this is by no means an exaggeration considering that novel neuroscience techniques such as decoded fMRI neuro-feedback are capable of unconsciously eliminating fear memories and changing face attraction (Kawato & Koizumi, 2016), amongst others.

The speed of technological advances and research in neuroscience signals that the induction of entrepreneurial skills or mitigation of entrepreneurial performance inhibitors such as 'fear of failure' might be attempted in the future.

#### 4.6 EEG and fMRI

Humans have long been fascinated by a unique quality: how we think and behave (Hart, 2015).

More concretely entrepreneurship scholars are infatuated by discovering how entrepreneurs think differently from non-entrepreneurs (Busenitz & Barney, 1997; R. K. Mitchell, 1994; R. K. Mitchell et al., 2002) and other entrepreneurs (Baron, 2004, 2006; R. K. Mitchell et al., 2007).

Decisions, whether they are made consciously or unconsciously, rely heavily on neural processes that entail selection, inhibition, planning and other aspects of executive control (Purves et al., 2008). To understand the cognitive processing which underlies decision-making means to investigate different aspects that collectively can contribute to the final decision (Polezzi et al., 2012).

Several techniques allow neuroscientists the opportunity to study the neural basis of cognition, emotion, sensation and behaviour in humans (Carter & Shieh, 2015).

These methods are known as functional brain imaging techniques, and they are used to measure neural activity in the central nervous system without physically penetrating the skull (Carter & Shieh, 2015), that is, to determine which neural structures are active during certain mental operations (Carter & Shieh, 2015). These tools can show that information is represented in certain places within the brain without being consciously perceived (Carter & Shieh, 2015).

Palva (2014) contends that the neural correlates might be achieved if only there is prior confirmatory behavioural data.

The studies examine the neurocognitive decision-making mechanisms among entrepreneurs and non-entrepreneurs by making use of two brain imaging techniques: fMRI (Laureiro-Martínez et al., 2014) and EEG (Ortiz-Terán et al., 2013). Since fMRI or EEG training is outside of the scope of this review, those interested should consult additional resources for detailed information about fMRI



design and analysis (Buxton, 2009; Huettel et al., 2009; Jezzard, Matthews, & Smith, 2001) or EEG (Picton et al., 2000).

Both tools are appropriate to the studies since their use within neurosciences is known to monitor the evidence or preference accumulation process during decision-making (Busemeyer, 2015).

Within entrepreneurship, it is the first time these technologies have been applied to the study of decision-making.

EEG is a non-invasive technique that measures the gross electrical activity of the surface of the brain (Carter & Shieh, 2015). Though it is not truly a brain imaging technique since no meaningful images of the brain can be produced using this technique alone, it can be used to ascertain certain particular states of consciousness with a temporal resolution of milliseconds (Carter & Shieh, 2015).

A powerful application of EEG is in event-related potentials (ERPs). An ERP is a distinct, stereotyped waveform in the EEG that corresponds to a specific sensory, cognitive or motor event. For example, if a human subject abruptly hears an alarm, the perception of the sound may be represented as an ERP in the EEG waveform (Carter & Shieh, 2015).

An ERP waveform is an electrical signature of all the different cognitive components that contribute to the processing of that stimulus. Systematically varying certain aspects of the stimulus may lead to systematic variations in particular aspects of the ERP waveform. The assessment of waveform variations enables inferences to be drawn about the timing and independence of cognitive processes (Bear et al., 2007).

What is of interest in ERP data is the timing and the amplitude of the task (Bear et al., 2007).

Ortiz-Terán et al. (2013) employed ERPs to compute the reaction time among founding entrepreneurs and non-founding entrepreneurs. Aided by LORETA software, they also pursued identification of the brain locations generated by the Stroop task. Beyond the explanation of possible decision-making mechanisms, they are unable to disentangle the series of decision-making stages produced.

The application of a general method for dividing reaction times into different stages, such as the additive factors method (Sternberg, 1969), could help to single out the decision-making stages in a more comprehensive fashion.

On the other hand, fMRI is a tool to study the neural basis of cognition (Aldrich & Carter, 2004).

The main goal of fMRI is to detect the local variation of the BOLD signal in the brain and its potential correlation with a given task or action (Charron, Fuchs, & Oullier, 2008).

BOLD is a marker of neuronal metabolism based on the principle that neurons that are becoming more active require nutrients from the blood rapidly to support their energy requirements. As part of a process known as hemodynamic response, active neurons will extract oxygen quickly from the blood compared to inactive neurons, each of these displaying different magnetic properties. The variation in the magnetic signal can be detected using fMRI to obtain what is referred to as a BOLD signal (Hart, 2015).

One of the biggest limitations of this technique is that the signal represents an indirect measure of cerebral activity; however, it is a non-invasive, safe and relatively available technique (Polezzi et al., 2012).

Laureiro-Martínez et al. (2014) applied fMRI to assess decision-making efficiency and identify the neural correlates of exploration and exploitation among entrepreneurs and managers.

Their findings are important because, apart from indicating which areas in the brain light up under one condition or another, fMRI can provide access to processes that overt behaviour and self-reporting measures cannot. These results can lead to the identification of causal brain mechanisms that underlie important and complex phenomena (Norris, Coan, & Johnstone, 2007) such as entrepreneurial decision-making.

fMRI and EEG studies are also complementary, and combining information from them is a useful way to examine the spatial and temporal dynamics of brain processes (Babiloni et al., 2004; Dale et

al., 2000; Liebenthal et al., 2003). Each method has its strengths and limitations: the spatial resolution is in the range of millimetres with fMRI and the time resolution is in the range of milliseconds with EEG (Mulert et al., 2004).

It means that the integration of more techniques (fMRI, ERPs, etc.) and different kinds of data (behavioural and neurophysiological) can lead to more robust and reliable conclusions compared to those exclusively based on behavioural data (Polezzi et al., 2012).

The combined use of fMRI and EEG might also be beneficial to entrepreneurship research, but it is challenging to implement due to the significant amount of new knowledge required.

In short, these methods hold much promise (Foo et al., 2014). Brain-imaging is making real and important methodological progress, and it is no longer a field that can be characterised as being in its infancy. The practical consequence of all this is that contemporary researchers can no longer afford to be unaware of the methods and language of neuroimaging generally and fMRI in particular (Norris et al., 2007).

## 5 AGENDA FOR FUTURE DEVELOPMENT AND RESEARCH

The research agenda suggests paying increased attention to the added value of using a brain-driven approach to entrepreneurship research, particularly, but not only, to the facet of entrepreneurial decision-making.

I initiated this review by highlighting the three eras of entrepreneurial thinking and the emergence of a new era preceded mainly by research carried out on entrepreneurial cognition. I refer to this new era as the neurosciences era. It is argued that there is value in grounding entrepreneurship research in neuroscience (Baucus et al., 2014; de Holan, 2014). Neuroscience can be beneficial to entrepreneurship scholarship (Blair, 2010) both in developing an understanding of the many facets of the practice of entrepreneurship and those who carry it out (de Holan, 2014).

To encourage future research in this direction, I proposed the term ‘brain-driven entrepreneurship’ to fine-tune the scope of the contribution of this new era to the field of entrepreneurship. Bear in mind that currently the terms neuro-entrepreneurship (de Holan, 2014; Krueger & Day, 2010) and entrepreneurial neuroscience (Randolph-Seng, Mitchell, et al., 2014) are implicitly used to point out the generic use of neuroscience tools in entrepreneurship research.

I suggested the following definition: brain-driven entrepreneurship research refers to the study of any suitable topic of entrepreneurship using both an experimental design in any of its forms and any existing or forthcoming brain-imaging technologies.

I intended the definition to allow for the study of any topic of entrepreneurship among those highlighted in Section 5.1. This list is, however, not exhaustive.

The accelerated development of brain-imaging technologies in neuroscience has attracted the attention of scholars from various fields. Although relatively new for our field, these tools have been validated in other disciplines such as economics and marketing, and have shown great potential to help clarify questions such as how entrepreneurs perceive and act upon opportunities, how they perceive them, what areas of their brain are mobilised when they do so, and whether these differ from other, less entrepreneurial subjects (de Holan, 2014).

For instance, brain cortical activity analysis using these tools reveals that entrepreneurs process information in a different way than the control group and these differences have cognitive and behavioural consequences. Entrepreneurs act earlier in response to certain stimuli but process their action slowly than the controls, and they select a good opportunity faster than the controls and make fewer mistakes (de Holan, 2015).

While neuroscientific technologies hold much promise (Foo et al., 2014), they do have limitations: they rely on reverse inference, in which the engagement of a particular cognitive process is inferred from the activation of a particular brain region (Poldrack, 2006), and these technologies produce largely correlative measures of brain activity, making it difficult to examine the causal role of specific brain activations for a chosen behaviour (Glimcher, Camerer, Fehr, & Poldrack, 2009).

Also, research questions related to the interaction of environmental factors with individual characteristics to predict how people make decisions are difficult to operationalise with fMRI studies because only a small number of individuals, and consequently a small number of environments, are available (Foo et al., 2014).

Nonetheless, the advantages afforded by these tools, such as the possibility to pinpoint what happens in the brain when people make decisions and the precise neural analysis of the links between affective and cognitive processes (Foo et al., 2014), should not be neglected by entrepreneurship scholars, especially by those interested in cognitive, affective, and motivational issues of entrepreneurial behaviour.

The use of any of the technologies highlighted in this review is not straightforward, as indicated in Section 4.3. Their application requires the elaboration of a well-designed experiment and the existence of behavioural evidence. Any attempt to bypass this ‘golden rule’ of neurosciences will result in non-credible evidence (Palva, 2014).

Furthermore, the application of a brain perspective to entrepreneurship research should not be targeted as a pure individual enterprise - its multidisciplinary nature demands the collaboration of experts from at least three fields: entrepreneurship, psychology and neurosciences. Those interested in joining this camp will possibly need to upgrade their skills in experimental design, cognitive psychology, and, depending on the topic of research, in any of the neuroscience branches listed in Section 5.3

### *5.1 Broadening the scope of research streams*

Investigation into how entrepreneurs think has become one of the major targets of entrepreneurship research, but a thorough examination of this phenomenon entails methodological constraints (Omoredede et al., 2015) and technological opportunities (Foo et al., 2014; R. Smith, 2010; Wargo et al., 2010) that may be afforded by neurosciences. In fact, neurosciences may provide new ways to conceptualise and measure important facets of decision-making (R. Smith, 2010).

The studies reveal that entrepreneurship research at a brain level is scarce and limited to the topic of entrepreneurial decision-making speed between entrepreneurs and non-entrepreneurs (Ortiz-Terán et al., 2013) and decision-making efficiency (Laureiro-Martínez et al., 2014) among entrepreneurs and managers.

The used techniques and the achieved results might not be perfect, as is usual in any new and emerging approach, but the potential is there (Blair, 2010; de Holan, 2014; Nicolaou & Shane, 2014; R. Smith, 2010).

Neuroscientific tools facilitate a breadth of potential topics and research areas to be embraced (R. Smith, 2010). Entrepreneurial decision-making is just one of many possible themes feasible to be studied under the umbrella of a brain-focused approach. The potential of entrepreneurship research using neuroscientific technologies and tools is broader (Nicolaou & Shane, 2014) and not limited to the topics of behavioural decision theory, game theory, perceptions, emotions and affect (Krueger & Welpe, 2014).

In addition to more brain-driven research on traits, adaptation, expertise and mindset (McMullen et al., 2014), future research is highly encouraged, particularly from four perspectives: importing concepts and theories from other branches of neurosciences, as described in section 2.1; combining multiple levels of analysis; taking into consideration the mechanisms of each of the stages of the entrepreneurial process; and exploring the links between entrepreneurial mental processes and business sectors.

First, forthcoming studies should take into account the inputs from a wide range of neuroscience branches (affective, behavioural, cultural, computational, social, neuroinformatics, systems neuroscience). The incorporation of this knowledge may allow a profound level of analysis of cognitive, motivational, affective, and hormonal processes behind entrepreneurial decision-making in particular, and the entrepreneurial process in general. They may also complement research on

how hormonal (Nicolaou & Shane, 2014) and genetic differences influence the wiring, structure, and function of the brain (Toga & Thompson, 2005). Norqvist (2014) defines these branches in Section 2.1.

These topics may represent a completely new world for the majority of entrepreneurship scholars, and its progressive incorporation to the field will take some time. Questions of interest include, for example, how do entrepreneurs emotionally process decisions under situations of certainty and uncertainty?

What are the motivational mechanisms that are activated before, during and after decision-making? How do hormones impact upon entrepreneurs' decisions? How do all of these factors together affect decision-making among entrepreneurs? How does the leverage of these factors differ from non-entrepreneurs? Where in the brain do these phenomena take place?

Second, Low and MacMillan (1988) argue that entrepreneurship studies could and should be carried out at multiple levels of analysis and that these analyses complement each other. Entrepreneurship research can be performed at various levels: individual, team, firm, industry/population, regional and national level (Davidsson & Wiklund, 2001). The reasons for studying entrepreneurship on multiple levels of analysis lie in the characteristics of the entrepreneurial phenomenon itself (Low and MacMillan, 1988).

In addition to the need for more studies at the individual level, new investigations are required at the team level. For instance, the two major aims of entrepreneurial team research: how the interaction (Breugst, Patzelt, & Rathgeber, 2015) and composition of the team influence the team's and the venture's development (Knockaert, Ucbasaran, Wright, & Clarysse, 2011) might be explored at a brain-level. An exercise of this nature will need a well thought out experimental design and a smart combination of available brain imaging tools, but it is certainly feasible. Investigations at other levels: firm, industry/population, regional and national, might prove to be more challenging to implement. Interesting questions include, for example: how does cognition influence decision-making among entrepreneurial teams? How does affect impact upon decision-making among entrepreneurial teams in situations of uncertainty? How does motivation operate among entrepreneurial teams compared to managerial teams? How do these factors change regarding gender, age, level of education and culture? Which the brain regions are related to these factors?

Third, the entrepreneurial process is defined as a set of stages and events that follow one another. These stages are the idea or conception of the business, the event that triggers the operations and implementation and growth (Bygrave, 2009). The studies do not mention the stage to which participating entrepreneurs belong, but they specify that at the time of the study the entrepreneurs had created at least one company (Ortiz-Terán et al., 2013) and they had implemented their idea and were running their firms (Laureiro-Martínez et al., 2014). That means that participating entrepreneurs may belong to the stage of either implementation or growth.

Further studies should delve deeper into the mechanisms of decision-making that take place along the entrepreneurial process from a brain perspective. For instance, studies that examine entrepreneurial decision-making during the conception of the business or across the event that triggers the entrepreneurial action may provide new evidence on the interplay of decision-making as the entrepreneurial process evolves. The questions of interest include, for example: how do cognitive mechanisms of decision-making evolve across the stages of the entrepreneurial process? What is the interplay of affect and motivation during the conception of the business and the triggering of operations? How are these processes reflected in the brain? Which brain regions are involved?

Fourth, 'necessity' entrepreneurial activities are commonly observed to occur in the traditional (and informal) sectors, whereas 'opportunity' entrepreneurial activities occur in the modern sectors (Caliendo & Kritikos, 2010; Desai, 2011; Naudé, 2011).

The studies do not provide much information about the sectors in which entrepreneurs operate, which is a relevant issue since it may provide further evidence on their necessity/opportunity orientation and may imply different decision-making mechanisms. Future research should take this aspect into account to be able to elucidate the possible cognitive, affective, motivational and hormonal

similarities or differences during decision-making and their possible link to traditional or technology-oriented sectors. Questions of interest include, for instance: what are the cognitive and affective decision-making mechanisms of a necessity-entrepreneur compared to an opportunity entrepreneur? How does motivation impact on decision-making among necessity-entrepreneurs in contrast to opportunity-entrepreneurs? How does the brain represent these mechanisms? Which brain areas are linked to these processes?

## 5.2 *Enhancing the use of experimental designs*

One of the primary challenges for a researcher in entrepreneurship is to engage in more systematic, theory-driven efforts (Tan, Fischer, Mitchell, & Phan, 2009). But, despite the number of published papers related to the theory of entrepreneurship, no accepted theory of entrepreneurship has emerged (Bull & Willard, 1993). Rather than explaining and predicting a unique set of empirical phenomena, entrepreneurship has become a broad label under which a wide range of research is housed (Shane & Venkataraman, 2000).

Entrepreneurship as a field of research is in need of experimental methodologies to fully study key phenomena (Shane, 2003), but the field is dominated by retrospective, self-reporting and correlational research methods (Simmons et al., 2016).

These research methods do not usually allow researchers to establish causality because the variables are all measured concurrently. Therefore one cannot assume that one variable influences another as the result of a significant correlation (Simmons et al., 2016).

On the other hand, research streams within the field such as, but not only, entrepreneurial cognition are facing growing methodological constraints (Omoredede et al., 2015) and technological opportunities, which, if adopted, may enhance causality and thus theory-building.

Causality is relevant to theoretical contributions as testing causality can validate or reject relationships predicted by theory and answer the question of what triggers the dependent variable and perhaps even why (Simmons et al., 2016). An experiment enables the plausible establishment of causality and, if properly designed, can exclude alternative interpretations by direct and indirect control. Experiments thus address the internal validity problem of empirical research in entrepreneurship (Foo et al., 2014; Krueger & Welp, 2014). Gatewood, Shaver, and Gartner (1995) also advocate the use of experimental designs in entrepreneurship research to randomise the allocation of respondents to research conditions.

In addition to the advantages of experiments listed in Section 4.4, experiments are especially suited to investigate entrepreneurial decision-making due to an additional reason. In entrepreneurship, many objects and relations to be researched are dynamic or are embedded in a dynamic environment. These dynamics potentially threaten the reliability of ostensibly identified relationships in field studies. Only with experimental control might the factors of interest be discriminated from 'noise' (Schade, 2005).

Despite these advantages, experiments have barely penetrated entrepreneurship research (Patel & Fiet, 2010; Schade & Burmeister, 2009; Simmons et al., 2016).

I prove this with two sources of evidence: on a search of the SSCI database, I found that out of 996 articles only 13 articles have been produced using either an experimental (eight articles) or quasi-experimental (five articles) design. Experiments represent approximately 3% of papers produced within the field.

On a review of 29 entrepreneurship journals published over the period 2000-2015 (Simmons et al., 2016), 40 articles were found with single or multiple designs that employed experimental methods to explore diverse themes including entrepreneurial decision-making, emotions, intentions, opportunities, risk propensity and perception, team dynamics, education and methodological approaches. The majority of entrepreneurship studies that use experimental design focus on opportunity identification and entrepreneurial intentions.



A lack of use of experiments in entrepreneurship research is a critical issue, not only because it reduces the theory building possibilities for the field, but also because the methodological component that precedes the use of any neuroimaging technique (EEG, fMRI, etc.) is certainly the articulation of well-designed experimental design. Not even the most advanced brain imaging technology can replace the faults of poor experimental design.

Further experimental research is needed not only in entrepreneurial decision-making but also other research streams such as cognitions and emotions, social and human capital, business exits and failure, corporate venture logic and methods (Simmons et al., 2016). Particularly encouraged is the design of experiments that assess the role of cognition, motivation and emotions in entrepreneurial decision-making, as well as its neural correlates to assess the decision-making process among entrepreneurs at the level of cognitive units, cognitive domains and cognitive processing streams (Hart, 2015). It is the articulation of both elements: experimental designs and the use of brain imaging technologies that makes a brain-oriented approach to entrepreneurship promising.

I anticipate a challenging learning process especially for scholars unfamiliar with this approach but at the same time an opportunity to test causality and enhance theory-building within the field.

### 5.3 *Promoting the use of brain-assessment technologies*

We do not need to invent the wheel in entrepreneurship research as there are external concepts and theories in other fields that could be tested in the entrepreneurial context (Landström & Benner, 2010).

Brain-imaging is an important new addition to the toolbox of empirical researchers, as it provides new behavioural hypotheses and data that can evaluate current theories (Pushkarskaya, Smithson, Liu, & Joseph, 2010). It may also provide useful information about the timing and location of brain activation during performance of an enormous range of cognitive tasks. Such information (when combined with behavioural evidence) has proved of much value in increasing our understanding of human cognition (Eysenck, 2006).

The studies in this review promise to advance our understanding of many of the mysteries of entrepreneurial thinking in general and entrepreneurial decision-making in particular.

The studies show the first signs of the potential of EEG and fMRI to analyse the underpinnings of entrepreneurial decision-making. These technologies are capable of unveiling the neural correlates and shedding light on the cognitive and affective mechanisms taking place within the mind of the entrepreneur.

Nevertheless, besides EEG and fMRI, there are at least three other technologies that deserve consideration. These are magneto-encephalography (MEG), transcranial direct current stimulation (tDCS) and decoded neuro-feedback.

MEG involves using a superconducting quantum interference device (SQUID) to measure the magnetic fields produced by electrical activity. It has an excellent temporal resolution, and its spatial resolution can be reasonably good (Eysenck, 2006). In the same way as fMRI, MEG might be used to examine the neural correlates and the cognitive/affective mechanisms of any theme within the scope of entrepreneurial thinking.

tDCS stands for transcranial direct current stimulation (tDCS). It is a safe method for non-invasively (Nitsche & Paulus, 2011) modifying the behavior of neurons using weak electrical currents (usually 1-2mA) (Lewis, Thomson, Rosenfeld, & Fitzgerald, 2016) circulating between two scalp electrodes (i.e., an anode and a cathode) placed over the target cortical regions (Nitsche & Paulus, 2011).

tDCS might be useful for entrepreneurial research and practice because it modulates decision making (Ouellet et al., 2015) and allows studying the interplay of behaviour and a specific brain region based on the excitation or inhibition of neuronal activity.

Decoded neurofeedback is a technique that helps individuals learn how to self-regulate brain activity with the help of neurological feedback provided by sensory devices. Recent studies suggest that

neurofeedback is capable of extinguishing fear memories, changing facial preferences, etc. at a sub-conscious level (Kawato & Koizumi, 2016). The application of this method in entrepreneurship might be influential as well, for example giving the possibility to mitigate the fear of failure among novice entrepreneurs subconsciously.

The selection of the appropriate method depends on five factors: the type of phenomena to be investigated, the availability of theoretical/conceptual skills, the suitability of the chosen techniques, the availability of statistical skills, and the budget. EEG and tDCS are the most economical technologies, whereas the use of MEG, fMRI and decoded neurofeedback is rather expensive.

Despite the advantages that tools like fMRI may afford to entrepreneurship research, there is a deeper methodology known as neuronal recording (Rolls, 2014). At this level, it is possible to measure the full richness of the information being represented in a brain region by measuring the firing of its neurons. Neuronal recording can reveal fundamental evidence crucial for our understanding of how the brain operates but it is an invasive method which significantly limits its application (Rolls, 2014).

Neuroscience may generate new ways to conceptualise and measure important facets of decision-making, but it should not be forgotten that brain imaging techniques are susceptible to the interpretation problem that whatever causes the largest activation is interpreted as what is being encoded in a region (Rolls, 2014).

There is also a role to be played by qualitative research methodologies such as in-depth interviews, observational techniques, self-reflective action search (R. Smith, 2010), etc.

In addition to recommending the use of neuroscience tools coupled with field studies (Foo et al., 2014), future research should also aim to intensify the individual and combined use of electrophysiological methods such as EEG, functional brain imaging techniques such as fMRI, MEG, brain stimulation tools such as tDCS, and novel techniques such as decoded neurofeedback, as long as their use is preceded by a well-designed experiment and backed by behavioural evidence.

#### *5.4 Fostering the development of skills in psychology, neuroscience and brain imaging tools*

Entrepreneurship researchers have already borrowed concepts and theories from mainstream disciplines such as economics, psychology and sociology and adapted them to the study of entrepreneurship (Lohrke & Landström, 2010). This intellectual borrowing of concepts and theories from other fields has already produced several major benefits (Lohrke & Landström, 2010).

Certainly, undertaking research using a brain-driven approach may become a challenging journey for an entrepreneurship scholar familiar with traditional research methods, because the execution of such an approach requires the posing of new concepts and theories outside the walls of business schools.

Importing theories from other fields of research is often a necessary first step towards developing unique theories of one's own (Zahra, 2007).

The importing of concepts and theories on experimental design, brain-imaging techniques, cognitive psychology and neuroscience is necessary to the further development of the field, but access to these inputs is usually only available at faculties of psychology or medicine.

The literature shows that the use of experiments in entrepreneurship is very scarce (Simmons et al., 2016), and this review reveals that only two studies have been able to employ a brain-oriented approach, as mentioned in Section 3.1.

Three reasons may explain this: the topic is still new, its potential is unknown to the majority of entrepreneurship scholars and, most importantly to those who know it, the type of knowledge and research skills required to materialise it constitute a significant entry barrier.

For example, terms such as N200, P300 and N450, quite usual in EEG research, or concepts like the dopaminergic mesocorticolimbic system, quite common in neuroscience undergraduate courses, will possibly not be understood by an entrepreneurship scholar.



Therefore, investigators interested in embracing a brain-oriented research approach should focus on enhancing their knowledge of experimental design, neuroscience (cognitive, affective and social neuroscience) and brain-imaging technologies (data collection and analysis) to be able to start with this journey.

Entrepreneurship research from a brain perspective is a multidisciplinary enterprise, which requires the accumulation of expertise from various fields, but when borrowing theories from other disciplines, we need to contextualise the theories that we use (Zahra, 2007).

Imported theories and concepts from neurosciences must be adapted because imported theories from other disciplines have been developed to understand fundamentally different phenomena from entrepreneurship; therefore, a mismatch between theory and context can result in inconclusive or even incorrect findings (Lohrke & Landström, 2010).

### *5.5 Nurturing interdisciplinary and interfaculty collaborative research*

The studies reveal the high level of cooperation required among disciplines. An average of six scholars contributing from various fields such as economics, management, neurosciences, technology, psychiatry and business took part in the studies. It is not a lucky coincidence when taking into account the type and level of interdisciplinary knowledge required in each step of the research process.

It also reflects the fact that producing research within a brain-focused approach entails the collaboration of experts from at least three fields: entrepreneurship, psychology and; neurosciences.

Future efforts should encourage the establishment and formalisation of interdisciplinary teams, interfaculty teams, research groups and, ultimately, a research community.

The setting and formalisation of such initiatives are vital in that it will enhance the implementation of research projects, facilitate knowledge exchange among participating scholars and ensure the academic quality of resulting evidence.

Some steps in this direction have already been carried out with the organisation of two consecutive neuro-entrepreneurship symposia during 2014 and 2015 by the Academy of Management and the preparation of a MOOC course on brain-driven entrepreneurship. Nonetheless, to date, no other initiatives are known to have taken place at an international or university level.

## **6 FINAL REMARKS AND LIMITATIONS**

The studies suggest that entrepreneurship research applying a brain-driven perspective may help to unveil in-depth evidence that could be used to further the study and understanding of various entrepreneurial phenomena, not only entrepreneurial decision-making.

Future research needs to build on the progressive integration of neuroscience technologies, cognitive psychology and experimental design towards the research of numerous entrepreneurship themes that may potentially benefit from this approach. To further that aim I conducted the current review.

The review has some limitations which need to be acknowledged.

The keywords focused on peer-reviewed articles, whose title or abstract included the terms ‘brain’, ‘neuro’, ‘neural’ AND entrepreneur\*. These terms consider the keywords of the review and can be considered to maximise the finding of the articles within the scope of this revision. However, it is possible that some articles may not have included these terms in their titles and abstracts, and as a consequence have been omitted. The search for articles from the ten most influential journals in entrepreneurship journals as ranked by Stewart and Cotton (2013), from the proceedings of leading conferences linked to the theme of the review, and through scholars linked to the topic of the review, substantially minimises this risk.

Another limitation arises from the challenges of interpretive research concerning the structure of the results. I needed to assess, critically judge and reflect on the contribution of the studies. Other researchers might have come up with a different way of organising the results.

The lack of explicit definitions of related concepts such as ‘entrepreneurial neuroscience’ and ‘neuro-entrepreneurship’ required interpretive effort. I carried out two procedures to overcome subjective interpretation. I outlined the conceptualisation of brain-driven entrepreneurship research to establish a common basis for the review. Every article was also analysed based on five criteria: theoretical, behavioural, experimental, neurocognitive and technological.

The number of articles might appear to be few, but it should be noted that the quality of a review is not defined by the number of articles, but by a combination of a well-designed research question, the identification of relevant strengths and caveats, and the directions that need to be taken in going forward.

A review can be undertaken and published with no articles at all. As such, it is feasible to narratively describe the differences, potentially postulate why the differences exist, and how strategies can be applied in going forward to curtail the differences in the future design of studies on the topic (Nwaru, 2015).

A limited number of studies on a particular topic is a signal that data in that topic is scarce and a review could underline that more studies are required in that topic to appraise the evidence better and reach decisions on policy, practice and research (Nwaru, 2015).

Lastly, the studies are relatively recent, and they need a particular period to reveal their potential influence; therefore, through this review, it is only feasible to see trends rather than the latest developments (Kraus, Filser, O’Dwyer, & Shaw, 2014). Nonetheless, the encountered findings are sufficient to unveil the need for further studies on entrepreneurial decision-making from a brain-driven angle, the uniqueness of the data that can be obtained from this approach, and the need for its expansion into other topics within the domain of entrepreneurship research.

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## APPENDIX

Table 1. Basic Concepts

Conceptualizations	Determining Characteristics
Neurosciences	Known also as neural science, it studies how the nervous system develops, its structure, and what it does.
Cognitive neurosciences	Use evidence from behaviour and the brain to understand human cognition
Brain imaging	A branch of medical imaging that concentrates on the brain. It can be useful for the study of the brain, how it works, and how different activities affect the brain.
Cognitive psychology	Understands human cognition by using behavioural evidence.
Brain-driven entrepreneurship research	Combines the use of experiments and brain imaging technologies to explore entrepreneurial phenomena.
Entrepreneurial cognition	Aims to understand the knowledge structures that people use to make assessments, judgments, or decisions involving opportunity evaluation and new venture creation and growth.
Experimental entrepreneurship	Use of natural, economic and hypothetical experiments in entrepreneurship research.



Table 2. Protocol for identifying relevant literature

Criteria	Rationale
(1) Publication until 2016 (including in-press articles until April 2016)	Specific starting point not set to deliberately widen the identification of eligible articles.
(2) Publication as a full-length journal article or research note	Non-empirical articles, non-peer reviewed articles, non-published articles and commentaries providing overviews of the field were excluded.
(3) Publication in the field of entrepreneurship	<p>Searched the totality of journals listed in the Social Sciences Citation Index (SSCI) with an intentionally wide scope so that all possible articles were identified.</p> <p>Searched for the ten most influential entrepreneurship journals as ranked by Stewart and Cotton (2013).</p> <p>Searched for journals related to the topic of the review outside the SSCI platform</p> <p>Searched the proceedings of the Babson College Entrepreneurship Research Conference, Academy of Management Annual Meeting, Annual Meeting of the Society for Neuroeconomics and the NeuroPsychoEconomics conference (last five years).</p> <p>Contacted scholars who participated in the 2015 Academy of Management Symposium on neuro-entrepreneurship in search of possible articles.</p> <p>Searched journals through the keywords ‘brain’, ‘neuro’, ‘neural’ AND entrepreneur* to reduce subjective interpretation bias.</p> <p>Examined the citations of Krueger (2010, 2011), de Holan (2014), Nicolaou and Shane (2013), Tracey and Schlupeck (2014) to identify missed relevant works.</p>
(4) Keywords ‘brain/neuro/neural AND entrepreneur used’ in the title, abstract or keywords of the article	<p>Brain-driven entrepreneurship research was defined as the study of any suitable topic of entrepreneurship using both an experimental design in any of its forms and any of the existing or forthcoming brain-assessment technologies.</p> <p>Ensured that the articles explicitly used both experimental design and any of the available brain-imaging technologies</p>

Table 3. Analysis procedure

Phase	Task	Description
Mapping	Open coding	
	Emic, data-driven codes	Examining the articles from inside
	Etic, theory-led codes	Examining the articles from the outside
	Axial coding	Analysis of interrelationships
	Selective coding	Analysis of concepts
Appraisal	Evaluation	Evaluation of the articles about their validity and relevance
	Extraction and collation	Compilation and ordering of key results
Synthesis	Identification of research streams	Identification of common elements, concepts and results
	Narrative of each research stream	A narrative account of the elements and contribution

Table 4. Summary of studies

Key Items	Laureiro-Martínez et al. (2014)	Ortiz-Terán et al. (2014)
Research question	What are the neural bases of individual differences in decision-making efficiency?	What are the relationships between key neurophysiological and personality characteristics in entrepreneurial decision-making?
Definitions	Decision-making efficiency operationalised as total payoff divided by the response time	Decision-making is a common task that plays a pivotal role in translating perception into action and is affected by factors such as personality or attention. It consists of multiple operations, including multiple option evaluation, actions and outcome monitoring
Hypothesis	While engaged in a task requiring fast and efficient decision-making, individuals with experience in facing a broad range of pressing, heterogeneous decisions, compared with a group experienced in making more specialised choices, will show better performance	Decision-making is different both neurophysiologically and regarding reaction times in founder entrepreneurs when compared with non-entrepreneurs
Decision-making measure	Performance divided by the response time	Reaction time
Task	Exploitative/ Explorative decision-making	Decision-making speed
Other measures	4-armed bandit task	Stroop reaction time task
		Personality: Temperament and character inventory-revised
Data collection tool	fMRI	Electroencephalography (EEG)
Sample	24 entrepreneurs and 26 managers	25 founder entrepreneurs and 20 non-entrepreneurs (people who never created a company)
Statistics	SMP toolbox, Matlab v7.4, GLM, ANOVA	Nonparametric Mann-Whitney test, linear regression, ANOVA F-Tests, logistic regression analysis.
Main results	<p>The groups were comparable regarding pay-off</p> <p>Compared with managers, entrepreneurs get the same result in less time, showing higher decision-making efficiency and a stronger activation in the frontopolar cortex</p> <p>Neural signature of entrepreneurs found in the pre-frontal cortex</p> <p>Exploitation and exploration are linked with the activation of different brain areas</p> <p>Exploitative choices recruit ventromedial prefrontal activation</p> <p>Explorative choices engage the frontoparietal region, anterior cingulate cortex and locus coeruleus</p>	<p>Reaction times indicate that founder entrepreneurs make faster decisions than non-entrepreneurs, both behaviorally and physiologically</p> <p>The faster decision could be linked to the better capacity to selective visual attention, response selection and executive control. Unlike non-entrepreneurs, founder entrepreneurs' brains display activity in the supplementary motor areas (inferior parietal sulcus) and the orbitofrontal cortex.</p> <p>The novelty seeking parameter is prominent among founder entrepreneurs</p>

Figure 1. A Brain-driven approach to entrepreneurship research (BRE)

