Exploring the Potential and Limits of a Neuroscientific Approach to Entrepreneurship

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Abstract

We critically examine the potential that neuroscience holds for the future of entrepreneurship research and provide a framework for entrepreneurship researchers interested in pursuing this line of inquiry. Specifically, we propose four complementary mechanisms through which neuroscience can inform entrepreneurship theory and research. We conclude with a discussion of the limitations and ethical implications of a neuroscientific approach to entrepreneurship.

EXPLORING THE POTENTIAL AND LIMITS OF A NEUROSCIENTIFIC APPROACH TO ENTREPRENEURSHIP

Over the past 50 years academics have tried to understand the drivers of entrepreneurial activity. Researchers have identified a wide range of factors that influence the tendency to engage in entrepreneurship ranging from career experience (Shane and Khurana, 2003) to personality (Leutner et al., 2014) and sociocultural factors (Aldrich, 1999). Recently, academics have started investigating the role of biological factors in entrepreneurship. This biological perspective has focused on the role of genes, hormones, physiology and their interactions with the environment in explaining entrepreneurial behavior (Shane and Nicolaou, 2015). For example, studies have identified a genetic predisposition to both starting a business (Nicolaou, Shane, Cherkas, Hunkin and Spector, 2008a; Zhang et al., 2009) and to recognizing entrepreneurial opportunities (Nicolaou, Shane, Cherkas, and Spector, 2009). Research has also investigated the role of hormones, such as testosterone, in influencing entrepreneurship (White, Thornhill and Hampson, 2006; Greene, Han, Martin, Zhang, and Wittert, 2015; Bonte, Procher, and Urbig, 2015; Nicolaou, Patel and Wolfe, 2018). Finally, research has examined the role of neurodevelopmental conditions such as dyslexia and ADHD in positively influencing the likelihood of engaging in entrepreneurship (Logan, 2009; Thurik et al., 2016; Wiklund et al., 2016, 2017).

Neuroentrepreneurship is the latest addition to this biological perspective[1]. While there is a dearth of research employing a neuroscientific approach in entrepreneurship, researchers have suggested that neuroscience may improve our understanding of entrepreneurship (Krueger & Day, 2010; Stanton, Day & Welpe, 2010). For example, Stanton et al. (2010) explored how a neuroscientific study of the brain can further our understanding of how uncertainty is processed by an entrepreneur. Krueger and Day (2010) provided a review of entrepreneurial cognition studies and introduced neuroscientific ideas, arguing that the study of entrepreneurship through neuroscience could be beneficial to both fields. Recently, in a dialogue in the Journal of Management Inquiry, Martin de Holan (2014) and Nicolaou and Shane (2014) urged entrepreneurship scholars to consider and incorporate neuroscientific methods and techniques in entrepreneurship studies. As Martin de Holan (2014) argues “we cannot afford to keep ignoring the foundational microantecedent of any human decision and action: our brain” (p. 95).

Other scholars, however, have adopted a more critical stance on the role of neuroscience in entrepreneurship. For example, Tracey and Schluppeck (2014) questioned whether neuroentrepreneurship can be a new frontier in entrepreneurship research or whether it is more akin to “brain pornography”. They argue against applying neuroscientific methods and techniques to high-level cognitive functions such as entrepreneurial decision-making, emphasizing that neuroscience is incapable of understanding the cognitive processes that underlie entrepreneurship research as the processes are very complex and the uncertainties very large. Tracey and Schluppeck (2014) are also concerned that neuroimaging may lead to reductionist and deterministic accounts of complex entrepreneurial phenomena.

While we mostly side with the “neuroscience is useful” part of the debate, we stress that scholars need to exercise caution and manage expectations about what neuroscience can offer to the entrepreneurship field. In this respect, we propose a framework through which neuroscience research in entrepreneurship can be organized and identify a number of areas where neuroscience can help advance entrepreneurship theories and debates. While current research has provided an important first foray linking neuroscience and entrepreneurship, there is a need to bridge research conducted in the two fields and to examine *if* and *how* a neuroscience perspective can advance entrepreneurship concepts and theories. The value of neuroscience to entrepreneurship is still not clear, and it is critical not to set up unrealistic expectations as to its value. We, therefore, seek to critically examine whether neuroscience can help us improve our understanding of entrepreneurship and whether it can answer questions that cannot be answered using alternative methodologies.

We follow Shane and Venkataraman (2000) in defining entrepreneurship as the identification, evaluation and exploitation of opportunities (Shane, 2011). Entrepreneurship is not synonymous with organizational emergence – firm formation is merely one institutional arrangement through which entrepreneurship can occur (Shane, 2011) - and it includes corporate entrepreneurship. It therefore spans different social roles and practices. As a result, we move beyond the entrepreneur versus non-entrepreneur distinction and instead focus on the relationship between entrepreneurship (as a collection of activities including the identification, evaluation and exploitation of opportunities, typically under conditions of uncertainty) and neuroscience. As neuroscience has examined topics ranging from strategic thinking (Bhatt and Camerer, 2011), culture (Chiao, 2011), altruism (Preston and de Waal, 2011), evaluations (Cunningham and Zelazo, 2007) to social interactions (Eisenberger and Muscatell, 2013), we argue that neuroscience can also be used to understand the antecedents and nature of entrepreneurial activities including the identification, evaluation and exploitation of opportunities.

We caution scholars to be sensitive to the potentially different paradigmatic traditions that neuroscience and entrepreneurship scholars come from. Traditionally, the neuroscientific paradigm has been based on comparing two sets of images, belonging to different groups. For example, comparing men and women or adults and children. Both the images and the comparison groups can be seen as being based on what Searle (1995) calls brute facts (physical, observer-independent facts). However, if we extend this practice to entrepreneurship, caution is required when comparing neuroscientific images of those labelled entrepreneurs with those labelled non-entrepreneurs since these latter labels and grouping labels are based on social conventions or “social facts” (observer-relative facts).

While social facts may rest on brute facts via language and related social practices for assigning meaning, they are not reducible to brute facts. However, neuroscientific observations are epistemically brute - that is, brute for us and not brute per se (Vintiades and Mekios, 2018: 2) - but not ontologically brute (Barnes, 1994; Vintiades and Mekios, 2018). It is important to note that even in biology the function of an object is “never intrinsic to the physics of the phenomenon but [is] assigned from outside by conscious observers and users. Functions….are always observer relative” (Searle, 1995: 14). For example as Searle (1995) argues “it is because we take it for granted in biology…that there is value in survival….and continued existence….that we can discover that the function of the heart is to pump blood. If we thought the most important value in the world was to glorify God by making thumping noises, then the function of the heart would be to make a thumping noise, and the noisier heart would be the better heart” (Searle, 1995:15). We also emphasize that the brain is plastic and changes over time due to training, experience and learning (Herdener et al., 2011) and therefore associations between neuroscience and entrepreneurship can be bi-directional.

HOW NEUROSCIENCE CAN INFORM ENTREPRENEURSHIP RESEARCH

We propose a framework of how neuroscience can advance entrepreneurship theory and research, arguing that neuroscience can complement, inform and extend entrepreneurship research in four complementary ways. Our framework includes the following four mechanisms: (i) capturing hidden mental processes that cannot be investigated using other techniques; (ii) informing the discriminant and convergent validity of entrepreneurship constructs; (iii) examining the antecedents and temporal ordering of entrepreneurship variables; and, (iv) refining and adjudicating between different theoretical perspectives in a way that behavioral data cannot.

Within this framework, we provide examples and potential opportunities that arise in two ways so as to maintain both *diversity* and *focus*. First, we maintain diversity by examining a number of areas in cognition, affect and decision making in entrepreneurship, identify research gaps, and show how neuroscience research can help address these. There is extensive research in both neuroscience and entrepreneurship in these areas enabling us to bridge the structural hole between the two disciplines; these are also some of the most fascinating areas of investigation in entrepreneurship research (Baron, 2008; Cardon, Foo, Shepherd & Wiklund, 2012; Gregoire et al., 2011; Mitchell et al., 2002; Mitchell et al., 2007; Schade, 2010; Shepherd et al., 2015; Baldacchino, Ucbasaran, Cabantous & Lockett, 2015)[2].

Second, we maintain focus by taking one particular area of cognition, affect and decision making and examining how each of the four mechanisms can be applied in this area. By examining one particular topic along the four dimensions of our framework, we show how neuroscience can be used to address *different* research questions within the *same* research topic. We selected intuition - which refers to a way of 'processing information that is largely unconscious, associative, fast and contextually dependent' (Baldacchino et al., 2015: 212) (Table 1) - for the following reasons. First, intuition has been called 'the seed of any entrepreneurial action' (Dutta and Crossan, 2007: 40) and a recent systematic review of the literature indicates that it is a promising and up-and-coming area of research in entrepreneurship that warrants additional attention (Baldacchino et al., 2015). In fact, only 25 papers have been published in this area, half of which are after 2008 (Baldacchino et al., 2015). Second, it is an area we believe most entrepreneurship scholars can relate to. This is because "we experience feelings about what is or what is not the right decision, but the reasons that underlie these feelings escape us. We know but we cannot explain why. It seems as though we have an intuition or sixth sense that is beyond our own comprehension" (Baldacchino et al. (2015) citing Hogarth (2001)). Finally, it is an area where there has been considerable work in neuroscience (Lieberman, 2000) with the potential to advance entrepreneurship theory and research [3].

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CAPTURING HIDDEN MENTAL PROCESSES

Neuroscience can advance our understanding of entrepreneurship by capturing hidden mental processes that are not amenable to empirical investigation using alternative methodologies. Such hidden processes can be unconscious or automatic, are not open to introspection, and entrepreneurs may not even be aware of them. Moreover, entrepreneurs may be unwilling or unable to express their thoughts either verbally or behaviorally.

Spotlight on Intuition

Intuition is one area where neuroscience can advance entrepreneurship research by capturing such hidden mental processes. The broader body of work around entrepreneurial cognition is concerned with how entrepreneurs process and make sense of information (Mitchell et al., 2007: 2; Gregoire, Corbett & McMullen, 2011). It has been argued that humans process information in two distinct modes, or at two different levels (Dane & Pratt, 2007; Hodgkinson and Sadler-Smith, in press). The first process is characterized by non-conscious, automatic, inductive, holistic thought, which gives rise to intuitive processing. The second process is characterized by conscious, rational, logical, sequential, deductive and detailed reasoning, which results in analytical processing (Allinson, Chell & Hayes, 2000; Dutta & Thornhill, 2008).

The first of these modes – intuition - is increasingly believed to play a central role in entrepreneurship (Baldacchino et al., 2015) and is used by entrepreneurs to guide many of their key decisions including buy/sell decisions, choice of key stakeholders such as partners and investors, and selection of products for promotion and markets for entry (Mitchell, Friga & Mitchell, 2005).

Nevertheless, there is still a great deal to be learned about intuition, which is made difficult due to the non-conscious and affectively charged nature of intuitive processing as compared to analytical processing (Allinson et al., 2000; Dutta & Thornhill, 2008). Although individuals are aware of the outcomes of their intuition, the process of how they arrived at such decisions is not accessible to conscious scrutiny (Dane & Pratt, 2007). The intuitive sense of "knowing but without knowing why" (Hodgkinson, Sadler-Smith, Burke, Claxton & Sparrow, 2009: 279) therefore presents a challenge for traditional self-report methods.

Neuroscience has provided "evidence that human preferences, beliefs and behavior are influenced by sources that are outside the reach of conscious awareness, control, intention, and self-reflection" (Stanley, Phelps & Banaji, 2008: 164). For example, the caudate and putamen, comprising the basal ganglia, are important components of intuition (Lieberman, 2000) and implicit learning processes are the cognitive substrate of intuition (Lieberman, 2000). Other studies comparing intuitive versus non-intuitive judgments have shown that the medial orbito-frontal cortex, the lateral portion of the amygdala, anterior insula, and ventral occipito-temporal regions are involved (Volz and von Cramon, 2006).

We suggest that the application of neuroscience techniques to entrepreneurship can open up new avenues for our understanding of the use of intuition by entrepreneurs and investors alike. For example, neuroimaging investors during the investment decision-making process can enable us to understand how intuition influences their investment choices. By linking the investment choice to various brain areas and subsequently examining the neuroscience literature in relation to these areas to learn about their functionality may enable us to understand how a hidden mental process such as intuition influences this decision. For example, consider the close association between intuition and affect, with some scholars characterizing intuition as "affectively charged judgments" (Dane and Pratt, 2009: 40). Investigating whether intuition is localized in areas of the brain associated with affect can inform theory on the nature of intuition.

In imaging different parts of entrepreneurs' brains that relate to analytical or intuitive reasoning, neuroscience also holds the potential to address the debate as to whether these two modes of processing (i.e. intuitive/implicit versus analytical/explicit) constitute two opposite ends of the same bipolar construct (e.g., Allinson & Hayes, 1996; Hayes, Allinson, Hudson & Keasey, 2003), or whether they are two separate constructs altogether that operate independently, as argued by proponents of dual-process theory (e.g., Hodgkinson & Sadler-Smith, 2003a & 2003b). Neuroscientific evidence that these two constructs are localized in different parts of the brain could provide support for dual process theory. We return to this debate in the section on discriminant and convergent validity below. We next examine other areas in cognition, affect and decision making where neuroscientific techniques can be used to capture hidden mental processes.

Emotions

Entrepreneurial emotion is another area where neuroscience can advance entrepreneurship research by capturing hidden mental processes. Entrepreneurship generates substantial emotions because of time pressures, uncertainty, and the extent of personal consequences tied up in the fate of the firm (Baron, 2008; Cardon, Foo, Shepherd & Wiklund, 2012; Mueller, Wolfe & Syed, 2017). It is not surprising, therefore, that there is now an emerging body of work in the field of entrepreneurship that highlights the important role played by affect in entrepreneurial judgments and behaviors (see for example, Baron, 2008 and the special issue of Entrepreneurship Theory and Practice, 2012; Cardon, 2008; Cardon, et al., 2005, 2009; Drnovsek, Cardon, & Patel, 2016; Foo, Uy, & Baron, 2009; Mueller, Wolfe & Syed, (2017). Cardon et al. (2012: 3) go as far as to introduce the idea of "entrepreneurial emotions", which they define as "the affect, emotions, moods, and/or feelings—of individuals or a collective—that are antecedent to, concurrent with, and/or a consequence of the entrepreneurial process, meaning the recognition/creation, evaluation, reformulation, and/or the exploitation of a possible opportunity." The foundation for this definition is the emerging work suggesting connections between various emotions and various stages of the entrepreneurial process.

Researchers face methodological challenges when studying entrepreneurial emotions. As Cardon, Foo, Shepherd and Wiklund (2012: 5) point out: "It is somewhat limiting to ask people how they feel because they do not always know, and recall studies are especially problematic in this regard. In addition, many entrepreneurs are reluctant to admit to certain emotional experiences, such as fear or passion, so non-survey-based creative approaches are needed."

We see opportunities for scholars of emotion to draw on methods from neuroscience to address such challenges. Recent meta-analyses show that different emotions are associated with activity in different brain regions (Phan, Wager, Taylor and Liberzon, 2002; Vytal and Hamann, 2010). For example, fear is associated with activation of the amygdala; happiness activates the basal ganglia, emotional induction by visual stimuli engages the occipital cortex and the amygdala, and sadness engages the subcallosal cingulate (Phan et al., 2002). The discriminable neural correlates of different emotions implies that entrepreneurship scholars can better uncover the emotional experiences underlying many of the decisions entrepreneurs make by examining the brain areas activated by these emotions, although there are recognised limitations (discussed below) of using reverse inference to infer emotions from activation of brain regions (rather than vice-versa).

Relatedly, Hayton and Cholakova (2012) highlight the importance of considering cognition and emotions together. They point to work which shows that while affective and cognitive processes are associated with the arousal of different parts of the brain (e.g., Cohen, 2005; LeDoux, 2000), the two systems are closely connected. There is a growing body of evidence showing that while there are times when affect and cognition work together, affective processes can override cognitive processes resulting in what appears to be irrational behavior (Camerer et al., 2005; Cohen, 2005; Sanfey et al., 2003). As a result, neuroscience would suggest that any strong distinction between emotion and cognition is somewhat forced (Davidson, 2000) underscoring the need to jointly investigate emotion and cognition in entrepreneurship research.

To date, the emphasis has been on the influence of affect (and cognition) on early (e.g. opportunity identification and evaluation stages) (e.g. Foo, 2011; Hayton & Cholakova, 2012) and later (exit decisions) stages of the entrepreneurial process (Shepherd, 2003 & 2009). Aspects of the entrepreneurial process that lie between the two have been largely neglected. For example, what is the role of emotions when taking the plunge decision (i.e. the decision to exploit an opportunity that has been evaluated)? How do emotions affect partner selection, hiring decisions, or investment decisions (including the decision to grow the business)?

In this respect, neuroscience methods that are able to discriminate between brain activity evoked by different cognitions and emotions are being developed (Kassam, Markey, Cherkassky, Loewenstein and Just, 2013; Wang, Nie and Lu, 2014). Such methods can potentially inform whether or not decisions that were believed to be made from a purely rational point of view are associated with corresponding patterns of brain activity, or potentially allow inference from brain activity of what reactions an idea being pitched elicited in an investor. For example, while an investor's decision may be driven by altruistic behavior and emotions associated with the willingness to help others (Bygrave and Hunt, 2007), alternatively, it may be driven by monetary rewards related to the success of the venture and the low risk assigned to an entrepreneurial opportunity. In this respect, neuroscience can enable us to identify the mental processes underlying the investment decision; research has shown that altruism and emotional rewards from helping others are associated with the ventromedial prefrontal cortex (Rilling and Sanfey, 2011) while anticipation of monetary rewards elicits activation in the nucleus accumbens (Knutson, Adams, Fong, and Hommer, 2001). Although scholars should be careful not to fall into the trap of reverse inference, neuroscience research on the functionality of these areas can guide us in the formulation of hypotheses that can be tested further. A brain scan may even show brain activity of which the participant is not consciously aware (Haynes and Rees, 2006). This subconscious activity could even be a predictor of response, well-before the individual starts assessing the stimulus consciously.

Insight

Recognizing entrepreneurial opportunities is a major part of the entrepreneurial journey (Shane and Venkataraman, 2000) and researchers have been trying to understand the factors influencing opportunity recognition (Shane, 2003). Some entrepreneurial opportunities "spring from a flash of genius" (Drucker, 2002: 96) and are recognized by a sudden surge of creative insight (Hills, Shrader and Lumpkin, 1999). However, we know little about the role of insight in the recognition of entrepreneurial opportunities, despite its importance.

In this respect, neuroscientists have investigated the neural correlates of insight – the "aha moment", defined as "any sudden comprehension, realization, or problem solution that involves a reorganization of the elements of a person's mental representation of a stimulus, situation, or event to yield a nonobvious or nondominant interpretation" (Kounios and Beeman, 2014: 74). Research using both EEG and fMRI in separate experiments found that the moment of insight was associated with increased activity in the right hemisphere anterior superior temporal gyrus (fMRI study) and a burst of high frequency (gamma-band) activity in the same area (EEG study) (Jung-Beeman et al., 2004). As Jung-Beeman et al (2004: 500) argue, this area is "associated with making connections across distantly related information during comprehension".

Researchers have also attempted to enhance insight using transcranial direct current stimulation (tDCS) techniques with encouraging results (Chi and Snyder, 2011; 2012). Such stimulation techniques for insight enhancement may also prove useful in stimulating insights associated with the recognition of entrepreneurial opportunities. As Kounios and Beeman (2014) argue, “the advent of brain stimulation techniques now affords the opportunity to treat brain activity as an independent variable rather than a dependent one” (Kounios and Beeman, 2014: 86). More broadly, neuroimaging can potentially reveal the hidden mental processes underlying the role of insight in opportunity recognition. By examining the functionality of these neural correlates – for example, they may be involved in connecting distantly related sources of information (Jung-Beeman et al., 2004) – we can formulate plausible hypotheses about the process through which insight leads to the generation of entrepreneurial opportunities.

Implicit attitudes

Neuroscience can also enable us to comprehend the implicit attitudes of entrepreneurs and investors alike. Neuroscience research has shown that implicit attitudes, which automatically influence behavior without our awareness, work in a very different way than explicit attitudes that refer to conscious thoughts and beliefs (Stanley et al., 2008; Greenwald & Banaji, 1995). Recent efforts to elucidate the neural basis of implicit attitudes have identified a number of brain regions, including the amygdala, dorsolateral PFC, and ACC, whose activity reflects the automatic expression, recognition, and cognitive regulation of implicit attitudes (Stanley et al., 2008).

Entrepreneurs may have implicit, non-conscious biases that they are not aware of and would not explicitly admit to. For example, while some entrepreneurs may purport to have high growth ambitions, implicit attitudes surrounding the desire for control and autonomy may interfere with decisions relating to investment in growth. Investors are also characterized by implicit attitudes and beliefs, often claiming that their investment decisions are guided by implicit beliefs about the potential success of a venture (Brooks, Huang, Kearney, Murray, 2014). As implicit and explicit attitudes towards situations and outcomes can diverge (e.g. Phelps, O'Connor, Cunningham, Funayama, Gatenby, Gore, & Banaji, 2000) it is essential to understand if and how implicit attitudes shape entrepreneurial decisions. Neuroscience research can enable us to understand the workings of these implicit attitudes (e.g. Cunningham et al., 2004; Green et al., 2007; Becker et al., 2011). These non-conscious beliefs and thoughts may be as important as explicit attitudes in explaining entrepreneurial evaluations, behaviors and outcomes.

In sum, we see opportunities for a neuroscience approach to capture hidden mental processes and contribute to our growing understanding of the role of intuition, emotions, insights, and implicit attitudes in the entrepreneurial process. Further, there is very limited evidence on the relationships between some of these hidden processes. For example, what is the nature of the relationship between intuition and insight? Similarly, how do emotions interact with other emotions? Finally, what is the connection between intuition and implicit attitudes?

DISCRIMINANT AND CONVERGENT VALIDITY

Neuroscience can help in the validation of entrepreneurship constructs and theories. By relating latent mental constructs with neural activity, brain-imaging techniques can provide evidence for, or against, the convergent and discriminant validity of latent entrepreneurship measures. For example, in psychology, Willingham and Dunn (2003: 4) argue that imaging data "can add to confidence that the construct is well described and that the construct is indeed fundamental to social processing… The data allowing such confidence would be consistent involvement of the relevant brain areas supporting the construct across a wide range of tasks and absence of involvement when the construct is predicted not to be involved in a task." Moreover, localization of two apparently similar constructs in different regions of the brain would suggest that they may be different constructs (Powell, 2011; Willingham & Dunn, 2003). For example, Amodio and Devine (2006) explain how two constructs in implicit race bias, stereotyping and prejudice, which often appear as a single behavioral process, have distinct neural substrates. Similarly, Dovidio, Pearson and Orr (2008) argued that while behavioral research shows that racism and sexism draw from common cognitive foundations, neuroscience research shows that they activate different neural pathways. The neuroscientific approach can therefore enhance and refine our understanding of key constructs and be equally helpful to entrepreneurship scholars in this regard.

Spotlight on intuition and cognitive style

To illustrate this point, we refer to entrepreneurship research that has examined how cognitive style is associated with the tendency to engage in entrepreneurial activity (Allinson et al., 2000; Kickul, Gundry, Barbosa & Whitcanack, 2009). Cognitive style is often viewed as a bipolar construct assessed on the basis of analytic or intuitive dimensions. As discussed earlier, however, researchers do not agree on the uni-dimensionality or bi-dimensionality of this construct (Allinson et al., 2000; Brigham, Castro & Shepherd, 2007; Hodgkinson & Sadler-Smith, 2003a & 2003b; Ornstein, 1977). Neuroscientific evidence showing the extent to which intuitive-cognitive style is associated with activity in the same, or different, part of the brain vis-à-vis an analytic-cognitive style would help resolve the debate surrounding the separability of these two cognitive dimensions.

A systematic review of the literature on intuition in entrepreneurship has shown that 15 out of 17 studies have relied on self-reported measures with most studies relying on interviews, surveys or other cognitive style instruments (Baldacchino et al., 2015). In addition, only three studies attempted to measure the actual use of intuition (Dimov, 2007; Gustafsson, 2006; Baldacchino, 2013). By supplementing self-reported measures with brain data that provide more direct and objective measurements, neuroscience research can help in the validation of latent entrepreneurship constructs.

Implicit bias

Neuroscience may also shed light on the discriminant validity of sex and race discrimination, which negatively affect many entrepreneurs. Research suggests that female-owned businesses may be discriminated against when they try to sell to other businesses compared to male-owned firms (Bates, 2002). Discrimination also affects minority entrepreneurs (Blanchard, Zhao and Yinger, 2008; Bahn et al., 2016). However, we know very little about the underpinnings of implicit bias in entrepreneurship. Do sexism and racism have common foundations? Interestingly, neuroscience work has shown that sex and race discrimination are associated with different neural structures (Cosmides et al., 2003; Dovidio et al., 2008), which may also help us understand the drivers of implicit bias towards women and minority entrepreneurs. This can further research on how investors and prospective entrepreneurs encode sex and race in entrepreneurship.

Over-optimism vs. overconfidence

Similarly, entrepreneurship scholars frequently fail to distinguish between over-optimism and overconfidence in entrepreneurs (Cooper, Woo & Dunkelberg, 1988; Forbes, 2005; Ilieva, Brudermann and Drakulevski, 2018; Herz, Schunk & Zehnder, 2013; Salamouris, 2013; Verheul & Carree, 2007). The prevailing wisdom is that both of these constructs are associated with a greater likelihood of engaging in entrepreneurial activity. Evidence that these two constructs are localized in different parts of the brain would provide support for the discriminant validity of these two measures, and would enable scholars to obtain additional insights on the psychological foundations and workings of overconfidence and over-optimism in entrepreneurship.

ANTECEDENTS AND TEMPORAL ORDERING OF ENTREPRENEURSHIP VARIABLES

Neuroscience can shed light on the antecedents as well as temporal ordering of entrepreneurship constructs based on the timing of the brain activations associated with these constructs, and in doing so provide useful insights into the study of mediating relationships.

In this respect, fMRI has a high spatial but only a reasonable temporal resolution so it is not as useful for studying the temporal ordering of entrepreneurship variables as other techniques. Simultaneous fMRI and EEG is useful in this respect as it combines the high temporal resolution of the EEG with the high spatial resolution of the fMRI (Huettel, Song & McCarthy, 2009; Hermann and Debener, 2008; Hopfinger et al., 2005; Debener et al., 2006; Ritter and Villringer, 2006). Specifically, simultaneous EEG and fMRI recordings provide important advantages, with the EEG capturing neuronal electric activity with millisecond precision and fMRI enabling localization with high spatial precision (Debener et al., 2006). Both first-order constructs (where cognitive psychologists are more interested) and second-order constructs (where social psychologists are often interested) can be localized although there may be constructs that due to their complexity are unlocalizable (cf. Willingham & Dunn, 2003: 667). But as Willingham and Lloyd (2007: 146) argue: "This limitation does not diminish the importance of neuroscientific data at other levels of analysis, but it does serve as a reminder that there are important behavioral effects that cannot be directly informed by neuroscientific data".

Spotlight on Intuition

Neuroscience can shed light on the antecedents of an entrepreneurship construct and its use. For example, while many scholars hold that intuition is experientially derived (Hodgkinson, Langan-Fox & Sadler-Smith, 2008; Matzer, Bailom & Moordian, 2007; Miller & Ireland, 2005; Sinclair & Ashkanasy, 2005), others believe individuals may possess intuition which relies less on the knowledge base of the individual and more on their creative capacity to recognize gaps and to identify possibilities (Crossan, Lane & White, 1999). Neuroscience techniques could show different types of brain activity that would provide valuable evidence on the antecedents of intuition by examining the activations in selected neural regions that precede intuition. The debate might also be usefully informed by closer scrutiny of the role of experience in shaping cognition which we turn to next.

The role of experience in cognition

Entrepreneurial experience is one area where brain data can help identify the antecedents and temporal ordering of entrepreneurship constructs. The debate surrounding the influence of experience on cognitive processes is a key debate in entrepreneurship. Prior entrepreneurial experience has a strong positive effect on subsequent opportunity recognition (e.g. Baron & Ensley, 2006; Gruber, MacMillan & Thompson, 2012 & 2013; Ucbasaran, Westhead & Wright, 2009). Although explanations for this connection have been presented in the literature (e.g. pattern recognition, heuristics, prototypes), we still have limited knowledge of the cognitive processes that mediate the relationship between prior experience and opportunity recognition. Indeed, Gregoire, Barr and Shepherd (2010) call for future scholars to investigate whether individuals with different levels and kinds of entrepreneurial experience use different cognitive processes in their efforts to identify opportunities, and with what consequences.

Neuroscience techniques can help us in this respect by ascertaining whether the brains of serial entrepreneurs process information differently than the brains of novice entrepreneurs. Although it is not always a straightforward mapping from mental process to brain activity (or *vice versa*), neuroscience can tell us whether different parts of the brain are involved in processing information in different groups or whether the same parts of the brain process information differently in different groups. Such empirical insights may help us better understand how experience in business ventures increases the likelihood of identifying additional and more innovative entrepreneurial opportunities, as well as enabling us to compare the decision-making biases and heuristics of serial and novice entrepreneurs. As Shepherd (2015: 22) argues, additional research is needed that details “the types of heuristics used, how these are formed and triggered”.

Despite the advantages prior entrepreneurial experience affords entrepreneurs with respect to opportunity identification, an enduring puzzle is why there is an absence of consistent evidence showing that the ventures of experienced entrepreneurs outperform their novice counterparts (Ucbasaran et al., 2013). In some respects, the absence of a clear link between prior entrepreneurial experience and venture success is not surprising; entrepreneurs’ experiences are varied (e.g. by outcome - success or failure - and industry), as are their emotional and cognitive responses to their experiences (see: Ucbasaran et al., 2013 for a review of entrepreneurs’ responses to failure experiences). Thus, the key question is not whether entrepreneurial experience yields benefits, but rather when and how this experience can yield benefits to entrepreneurs in their subsequent ventures.

Neuroscience experiments aiming to study the effects of training on neuroplasticity[4] (Draganski, Gaser, Busch, Schuierer, Bogdahn & May, 2004), may help address when and how an entrepreneur’s experience yields benefits. If, as the entrepreneurship literature suggests, entrepreneurial experience is beneficial to entrepreneurs in their subsequent ventures, it may be reasonable to expect to see the effects of neuroplasticity in well-designed experiments revolving around the entrepreneurial process (i.e. opportunity recognition, idea generation, risk taking).

Neuroscience experiments could involve comparing the brain activity of serial versus novice entrepreneurs when dealing with a common given task (such as an investment decision). Such experiments can also help assess how entrepreneurial experience influences cognitive characteristics such as overconfidence, for example, when entrepreneurs are deciding whether to participate in a venture or not. Insights from these experiments would help advance research in entrepreneurship by helping to pinpoint more clearly differences in the ordering of cognitive processes that derive primarily from experience and identify the mediators in the relationship between experience and opportunity recognition[5].

Biosocial perspective

Neuroscience can also inform the recent literature on a biosocial perspective in entrepreneurship by uncovering the mediators – mental processes - of the genetic predisposition to entrepreneurship (Nicolaou, Shane, Cherkas, Hunkin & Spector, 2008a; White, Thornhill & Hampson, 2007, Zhang et al., 2009). Utilizing a traditional twin methodology with samples of identical (monozygotic) and non-identical (dizygotic) twins scholars have attempted to disentangle genetic from environmental influences in entrepreneurship (Nicolaou et al., 2008a; Shane et al., 2010; Zhang et al., 2009). These studies have yielded heritability estimates of around 40 percent for both the propensity to become an entrepreneur and the propensity to recognize opportunities, and have been replicated in three countries, UK, US and Singapore. Evidence of a genetic predisposition to entrepreneurial activity has also been identified using samples of adoptees (Lindquist, Sol & Van Praag, 2015).

Other related studies have examined the role of hormones in entrepreneurship. For example, White, Thornhill and Hampson (2006) found that genetically influenced testosterone levels were higher among people with start-up experience. Similarly, Bonte et al. (2015) found that prenatal testosterone was associated with entrepreneurial intent.

Neuroscience research can contribute to the biosocial perspective by examining how the genetic predisposition to entrepreneurship may be mediated by our brains. As humans are unlikely to have entrepreneurship specific genes, neuroscience techniques can potentially help entrepreneurship scholars uncover the mediators – mental processes - through which some of the genetic influence in entrepreneurship is manifested (Shane et al., 2010). Neuroscientific techniques can help identify endophenotypes, or intermediate observable characteristics, in the relationship between genes and entrepreneurial behavior. These endophenotypes might be more easily amenable to genetic analysis than entrepreneurial behavior *per se* (Plomin, DeFries, Knopik & Neiderhiser, 2013; Gottesman & Gould, 2003).

In addition, the study of the role of neurotransmitters[6] in the human brain, such as dopamine and serotonin, opens up a link with molecular genetics studies in entrepreneurship. For example, entrepreneurship research has suggested that a particular variant of the dopamine receptor (DRD3) gene may be associated with entrepreneurship (Nicolaou et al., 2011). In addition, sensation seeking, which is associated with dopamine, has been found to mediate part of the genetic predisposition to entrepreneurship (Nicolaou et al., 2008b). Neuroscience can further uncover how dopamine and other neurotransmitters are involved in entrepreneurial behavior (see also: Savitz, Solms, & Ramesar, 2006).

REFINING AND ADJUDICATING BETWEEN DIFFERENT THEORETICAL PERSPECTIVES

Finally, neuroscience can advance entrepreneurship research by helping scholars refine and adjudicate between different theoretical perspectives in a way that behavioral data cannot (Dovidio et al., 2008).

Spotlight on Intuition

Neuroscience can help address a debate in entrepreneurship regarding the definition and conceptualization of intuition (Baldacchino et al., 2015). Most studies have adopted a “universal” definition of intuition and argue that entrepreneurial intuition accords with most definitions in the psychology and management literatures (e.g. Dimov, 2007; Baron and Henry, 2010; Baldacchino, 2013). Others, however, have argued that there are specific types of intuition and view entrepreneurial intuition as nested within the domain of entrepreneurship and inherently linked to opportunity identification (e.g. Mitchell et al., 2005). As Baldacchino et al (2015:224) argue, "To what extent is intuition different when it is used in the process of entrepreneurial opportunity identification?" Neuroscience work can help us empirically verify whether entrepreneurial intuition is a different concept from general intuition and adjudicate between these views. In this respect, research has shown that the caudate and putamen, components of the basal ganglia, are associated with intuition (Lieberman et al., 2000). Functionalism would imply that if there are identical neuroanatomical bases between entrepreneurial intuition and general intuition there must be a conceptual overlap between the two concepts.

Creativity

Neuroscience can help us refine entrepreneurship theories on creativity. Creativity is the production of novel and useful ideas (Amabile, 1996). Novel and useful ideas are the lifeblood of entrepreneurship since entrepreneurs must generate valuable ideas for new goods or services that will appeal to some identifiable market and then figure out how to bring them to fruition (Ward, 2004). Since the seminal work of Schumpeter (1934), who proposed that entrepreneurs are more creative than others, a number of studies have examined the relationship between creativity and the tendency to engage in entrepreneurship (Weinberger, Wach, Stephan, & Wegge, 2018). For example, Fraboni and Saltstone (1990) showed that firm founders had a higher imagination score on the 16-factor personality scale than second-generation entrepreneurs who ran companies founded by their parents, while Baron and Tang (2011) found that creativity was positively associated with firm level innovation in a sample of entrepreneurs. The problem with these comparative studies, however, is that they provide little information about the creative process in itself, and leave many important questions unanswered. For example, what happens in one's brain that leads to a creative idea? What differentiates a "creative brain" from another one? What does a brain "in the process of creation" look like? Answers to these questions may help us better understand why and how creativity affects the tendency to engage in entrepreneurial activity.

Neuroscience provides several insights into the different neural structures and processes that might be associated with the creative process. For example, white matter[7] integrity has been related to creativity (Takeuchi et al., 2010). Specifically, Takeuchi et al. (2010) showed that the integrity of white matter tracts in the corpus callosum (the largest white matter structure in the brain and connects the left and right hemispheres) and the frontal lobe is positively correlated with individual creativity. The results are congruent with the idea that creativity is associated with higher intra- and inter-hemispheric coherence (Jausovec, 2000). In addition, the results are also congruent with the idea that creativity is supported by diverse high-level cognitive functions, particularly those of the frontal lobe (Folley & Park, 2005; Howard-Jones et al., 2005). Empirical testing could demonstrate if such results also hold for entrepreneurs.

In addition, Moore et al. (2009) demonstrated that a higher divergent-thinking score (most creativity tests are effectively tests for divergent thinking [Kim, 2006]) is associated with a smaller corpus callosum size compared to total white matter volume. One possible explanation for this finding is that a reduced size leads to a more efficient brain organization. Based on the above, we conjecture that one could predict a smaller corpus callosum size in ratio to total white matter volume in entrepreneurs compared to non-entrepreneurs, due to the established links between creativity and entrepreneurship.

In addition, some people may perceive entrepreneurial realities differently than others due to differences in functional connectivity within certain networks of their brain. For example, in a very interesting paper Beaty et al. (2018) found that creativity was associated with a pattern of functional brain connectivity consisting of frontal and parietal regions within default, salience, and executive brain systems. Because a creative mind is important in the perception of entrepreneurial realities, a similar functional connectivity pattern may also be associated with an increased likelihood of recognizing entrepreneurial opportunities.

In summary, the discussion above suggests that for entrepreneurs, as compared to non-entrepreneurs, the white matter is more likely to create more and better connections – particularly around the corpus callosum and the frontal lobe; and the size of the corpus callosum in ratio to white matter volume is likely to be smaller. After identifying the neural correlates of entrepreneurial creativity we can examine what is known about the function of these areas in the neuroscience literature and use this knowledge to help us improve theories about the process of creativity. For example, if creativity activates brain areas mostly associated with emotion this might inform theories about this construct in a different way than if it were associated with brain areas mostly related to cognitive processes; in this case, it would suggest that emotion needs to be an important component in theories of entrepreneurial creativity. Relatedly, if theory on the creativity process is inconsistent with the functionality of its neural correlates this may question and constrain current theory.

Evaluation of entrepreneurial opportunities

We know very little about how evaluations and decisions related to entrepreneurial opportunities change over time within individuals (Shepherd, 2015). There is research comparing novice and habitual entrepreneurs (Ucbasaran, Westhead and Wright, 2006) but limited work on the same individuals over time. It would be important to see how these evaluations are influenced by new knowledge. Experimental studies could scan individuals at different points in time with new knowledge and information being provided between the different scanning times to see how individuals assess opportunities by examining changes in the neural correlates across different evaluations over time. These changes in different brain areas may enable scholars to characterize how the acquisition of additional information generates changes in the way entrepreneurial opportunities are evaluated. For example, if the new information activates areas of the brain associated with reward anticipation this would suggest a different way through which learning influences entrepreneurial decisions (Knutson et a., 2001; Delgado et al., 2005) than if it were associated with brain areas associated with emotional factors (Dalgleish, 2004). Learning and experience may also change brain structure and structural connectivity over time in specific ways that can be identified with MRI scanning.

Decision making during interactions

Neuroscience can also help research on the interactions between investors and entrepreneurs. It is possible to scan multiple subjects while they are interacting with each other using multiple scanners, a technique often known as “hyperscan fMRI”. Such “hyperscanning” involves individuals interacting in a controlled setting while their brains are being scanned (Montague et al., 2002) For example, King-Casas et al (2005) examined the neural correlates of the expression and repayment of trust in a multi-round social interaction between 48 pairs of subjects and found that reciprocity by an investor predicted changes in trust by the trustee. Similarly, interactions between venture capital and business angel investors and entrepreneurs can also be examined via such hyperscanning techniques. These can help improve our understanding of the discussions and negotiations between investors and entrepreneurs. Much of the brain activity that occurs during an interaction may not correlate with any detectable behavior (Montague et al., 2002: 1160). This can include important information about the interaction that is taking place that is impossible to identify through any other mechanism. This can spawn new approaches to understanding social interactions and exchanges between investors and entrepreneurs that would otherwise be impossible to decipher.

A related research area where hyperscanning can help is the study of interactions within entrepreneurial teams. As many new ventures are started by teams, entrepreneurial teams have been the subject of a thriving research agenda over the past three decades (Aldrich et al., 2002; Kamm et al., 1990; Birley and Stockley, 2000; Cooper and Daily, 1997). We still know very little about issues of trust and reciprocity in entrepreneurial teams – hyperscanning may enable us to better comprehend the decision-making process in start-up teams.

DISCUSSION

In this paper we have critically examined the potential that neuroscience holds for the future of entrepreneurship research and provided a roadmap for entrepreneurship researchers interested in pursuing this line of inquiry. We proposed four complementary mechanisms through which neuroscience can potentially enhance entrepreneurship research. These include capturing hidden mental processes that cannot be investigated using other techniques; informing the discriminant and convergent validity of entrepreneurship constructs; examining the antecedents and temporal ordering of entrepreneurship variables; and, refining, constraining and adjudicating between different theoretical perspectives. Within this framework, we discuss potential opportunities that arise in cognition, affect and decision making that would be amenable to a neuroscientific investigation. We also examine how each of the four mechanisms can be applied in one particular area of cognition, affect and decision making: (entrepreneurial) intuition, one of the most promising and up-and-coming areas of entrepreneurship research (Baldacchino et al., 2015).

Our review shows that many topics of interest to entrepreneurship scholars in the areas of cognition, affect and decision making have already been studied by neuroscientists. We suggest that bringing together entrepreneurship and neuroscience can be beneficial to both fields. A link between the two disciplines is therefore not only possible, but appears to hold promise as it may lead to a new wealth of knowledge and insights, such as those generated by the addition of neuroscience to research in economics, law, political science, and many other fields. For neuroscientists, entrepreneurship scholars can generate new research questions whilst also offering a theoretically interesting context for study characterized by uncertainty, novelty, time pressure and heightened emotions.

We must stress, however, that brains are not all there is to behavior. Brains are located in bodies and bodies are located in environments that comprise other people and other objects. To predict or understand the determinants of behavior, knowing what happens in the brain is important; but behavior is also contingent on other physical systems such as the body, other people and the environment. This is an important baseline against which to discuss how much a neuroscientific approach can actually advance entrepreneurship theory and research.

While we think that neuroscience holds promise for scholars of entrepreneurship, we feel that it is critical to emphasize the problems and limitations of a neuroscience perspective in entrepreneurship. First, neuroscience methods have significant limitations with respect to the experimental conditions, which raise issues of ecological validity. The experimental set up in neuroscience experiments is often artificial and restrictive (e.g. limited movement, participants wear earplugs due to the noise from the scanner, heightened anxiety of participants etc.) and the results may only be valid in the idealized experimental setting. There are also issues of cost and training while the recording equipment may be constraining with direct implications for the manipulation and measurements of variables (Amodio & Ratner, 2013). These limitations with respect to the experimental conditions would need to be assessed in terms of the potential of neuroscience methods to significantly enhance our understanding of entrepreneurship.

Second, it is essential to keep in mind what can and cannot be concluded from neuroimaging experiments (Aguirre, 2012). Localization studies (seeking to identify which regions of the brain are activated by a particular process) cannot conclude on their own whether a particular region is necessary for a particular task (Aguirre, 2012). Interventional studies (involving knowing a particular area of the brain is involved in a cognitive process, but trying to identify what parameters mediate that area's participation in that cognitive process), due to their complexity, can lead to mistaken conclusions fairly easily such as correlating things that are in fact independent. Reverse inference studies that reason "backwards from the presence of brain activation to the engagement of a particular cognitive function" (Poldrack, 2006: 59) have the same problem as interventional studies (Aguirre, 2012). Poldrack (2006 & 2008) made a case for use of reverse inference studies using fMRI, based on certain specific conditions, but with a lot of caution; reverse inference can be useful when used as a reasonable guess to design further imaging studies, but it cannot be used to draw strong and reliable conclusions about the localisation of cognitive processes.

Third, there is a debate pertaining to what scientific progress in neuroscience could mean for humanity, and the associated *ethical* issues it raises. To quote Thomas Fuchs (2006: 600), this progress "*raises ethical problems whose importance is likely to surpass even the implications of modern genetics*". While giving a full review on *neuroethics* – a term coined by journalist William Safire in 2001 (Farah, 2012) – is beyond the scope of this paper, we believe it is important for entrepreneurship scholars looking to incorporate neuroscience research tools in their research to be aware of this debate. Moreover, researchers "should be sensitive to the social consequences neuroscientific information may have once it enters the public sphere… As science penetrates the public sphere, it enters a dense network of cultural meanings and worldviews and is understood through the prism they provide" (O'Connor, Rees & Joffe, 2012: 220).

Moreover, neuroscience is not a panacea and the validity of neuroscience studies has been criticized. For example, Button et al. (2013) argue that the average power of neuroscience studies is low with an overestimation of effect size and low reproducibility. In addition, there are issues of reverse inference that scholars need to be aware of (Poldrack, 2006), even though recent work has argued that reverse inference is not a fallacy per se (Hutzler, 2014). As Hutzler (2014: 1061) argues, "the predictive power of reverse inference can even be "decisive"—dependent on the cognitive process of interest, the specific brain region activated, and the task-setting used". Finally, it is vital not to over-claim the importance of a neuroscientific perspective in entrepreneurship as entrepreneurship is a social process and neuroscience can only partially help understand the drivers of entrepreneurship.

It is important to emphasize again that any associations in neuroentrepreneurship should **not** be taken as immutable facts. Different areas of gray and white matter can (and do) change over time, due to environmental factors, or through training/learning; this is a process that occurs naturally throughout our lives and is referred to as *brain plasticity* (or neuroplasticity). The changes in the brain are of a physiological nature as they reflect structural changes – e.g. at the synaptic level. Results from research on brain plasticity report the physiological and anatomical effects that training and / or learning can have on the brain. For example, musical training can lead to functional plasticity in the hippocampus (Herdener et al. 2010); juggling training affects gray matter volume in the mid-temporal area and the left posterior intraparietal sulcus (Draganski et al. 2004); basketball training increases striatum volume (Park et al. 2011); and learning a second language leads to white matter structural changes in adults (Schlegel et al., 2012). The neuroscience perspective is also compatible with social constructionism where the socially constructed understandings of reality can lead to the establishment of new neuronal pathways, or modifications of existing neuronal pathways.

Overall, we have tried to take a balanced view of the role of neuroscience in entrepreneurship. We believe that neuroscience has the potential to advance our understanding of entrepreneurship – but the limitations, and the ethical and moral implications should be taken extremely seriously.

[1] Although different from research on genetics, hormones, and physiology, neuroscience has similar epistemological foundations. As a result, neuroscience is embedded in the broader biological perspective in entrepreneurship (Shane and Nicolaou, 2015). There have also been attempts to bridge research in these fields (e.g. Caspi and Moffitt, 2006).

2 As our framework is not conditional on the inclusion of specific dependent variables, we are selective in our discussion of the specific examples. Those discussed should be seen as examples of the mechanisms we propose rather than as a comprehensive discussion of all the dependent variables in cognition, affect and decision making that would be amenable to a neuroscientific investigation.

[3] In an online appendix we review the neuroscience literature on cognition, affect and decision making, and provide an overview of the two main techniques that can be used in neuroscientific studies of entrepreneurship - functional Magnetic Resonance Imaging (fMRI) and electroencephalography (EEG). We also examine the methodological challenges of conducting an fMRI study in entrepreneurship.

[4] Neuroplasticity refers to the ability of the brain to reorganize by creating new neural pathways.

[5] In addition, supplementing self-report data with brain data may also reduce common method biases that often plague entrepreneurship research. In particular, utilizing brain data can minimize potential sources of bias such as social desirability, consistency motif, and common scale formats (Podsakoff, MacKenzie, Lee & Podsakoff, 2003).

[6] A chemical used by neurons to send signals to other neurons in the brain.

[7] Macroscopically the brain is composed of white and gray matter. The white matter represents the long distance axonal connections between neurons in different cortical areas.

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Table 1: Neuroscience opportunities for research on intuition in entrepreneurship

Mechanism	**Example**
1. Hidden mental processes.	Neuroscience can capture the hidden mental process underlying the non-conscious and affectively charges nature of intuition (e.g. better understand the 'gut feelings' of investors).
2. Informing discriminant and convergent validity.	Do intuitive versus analytical processing constitute two opposite ends of the same bipolar construct or are they two separate constructs that operate independently?
3. Examining antecedents and/or temporal ordering.	Are the antecedents of intuition experiential or based on individuals' creative capacities?
4. Refining, constraining and adjudicating between different theoretical perspectives.	Is intuition used in entrepreneurship different from mainstream conceptualizations of intuition in the broader management literature?