The Entrepreneurial State of Mind: A Neuroscientific Perspective

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THE ENTREPRENEURIAL STATE OF MIND: A NEUROSCIENTIFIC PERSPECTIVE

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I dedicate this thesis to my wonderful colleagues at the Entrepreneurship Institute who took this lonely PhD student in as one of their own. You brought light and life to this topic.

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Over the last 4 years, I have had to tell myself time and time again *"if doing a PhD was easy, then everyone would do one"*. Without a doubt, that sentiment is so true. I've had to pick myself up from the pits of rejection, dust myself off and persevere on so many occasions. However, there are a few things that have been my driving force forward.

First is my passion for neuroscience and using it to understand the really hard stuff in life. For as long as I can remember, I have been fascinated by and analysed people's behaviour. Neuroscience provides me with a scientific template to describe what I was naturally inclined to notice. But it was when I was studying for my Master's that I discovered my love for cognitive neuroscience, a discipline I always describe to people as 'working out how people think and relating this to processes in the brain'. In my future career, this will be my main motivation, to take these insights from neuroscience and help people understand their own brains better. After all, I've used the science behind creativity to produce this thesis. Most importantly, I have understood the necessity of downtime and time away from problems to enable the creative state required to write what you are reading today. I think a huge gap in our society is understanding the way we behave at work (despite it being what we spend most of our time doing and looking for fulfilment from). So, let's change that.

The second, and most important driving force, is the people who have helped me along the way. Despite the lonely endeavour of undertaking a PhD, I have never really been alone during this process.

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COVID-19 IMPACT STATEMENT

The first two empirical chapters of this PhD, Chaper 3 and Chapter 4 were based upon data collected online from the *Entrepreneurial Brain Challenge*, therefore I was able to continue with collect the data and begin analysis throughout lockdown. However, the MRI portion of this thesis was heavily impacted by COVID-19, as all but essential scanning was halted. Whilst I managed to perform a between-subject MRI study presented in Chapter 5. We had also originally aimed to perform a within-subject MRI study on a subset of participants from the first MRI testing, in order to test the longitudinal changes in neurocognition that may result from experience. However, this aim was not achieved.

STATEMENT OF PERSONAL CONTRIBUTION

I contributed to this entire thesis. I initially scoped out and narrowed down the focus of the research. I then curated the design, piloting, set-up and collection of all empirical work presented, performed all the analyses, interpreted the findings and produced all figures. I wrote this thesis in its entirety. [1]

1 In places within this thesis, I use "our" and "we" when referring to empirical work performed as part of a research team and "I" when asserting my own opinions and viewpoints.

ABSTRACT

In many ways, entrepreneurial thinking represents the most unique aspect of human intelligence and thinking: the ability to innovate. Entrepreneurs create and drive forward new ideas despite the inevitable uncertainty. Yet evidence behind how this can be trained and the neuroscience behind this thinking is poorly understood. There are many theoretical and opinion pieces on neuroentrepreneurship, but the empirical research is falling behind. The adoption of neuroscience into this field requires a shift in the entrepreneurship research model (Nicolaou and Shane 2014).

This thesis intersects entrepreneurship theories and cognitive neuroscience, employing comprehensive and novel methods to understand entrepreneurial thinking.

In Chapter 1, the theoretical context of entrepreneurship cognition is introduced, emphasizing the shift from studies of traits to the malleable aspects of cognition, and the challenges with current methodology in the field. The chapter sets the stage for integrating cognitive neuroscience into entrepreneurship research to uncover the neural substrates of entrepreneurial cognition.

Chapter 2 identifies critical themes connecting neuroscience and entrepreneurship, including impulsivity, risk-taking, decision-making efficiency, emotional judgments, and creativity. The chapter highlights empirical research employing cognitive neuroscience methods to study entrepreneurship.

Chapter 3 defines competencies relevant to entrepreneurship, moving beyond stereotypes. Expert entrepreneurs excel in disruptive thinking and resource management, contributing fresh insights for entrepreneurship practice and training.

In Chapter 4, the neurocognitive attributes of entrepreneurs are evaluated. Exploratory approaches reveal a unique neurocognitive profile, marked by greater long-term memory and lower verbal reasoning abilities. Entrepreneurs exhibit distinct personality traits, such as lower conscientiousness and higher openness.

Chapter 5 reports findings from an MRI study. Although no behavioural differences are observed, fMRI analysis reveals context-dependent neurocognitive patterns in entrepreneurs. They exhibit cognitive ease in unfamiliar scenarios, emphasizing the role of context and task dynamics and suggest practice-based differences in the brain.

These chapters collectively contribute to integrating neuroscience into entrepreneurship research. I provide a fresh perspective on understanding entrepreneurs' neurocognition as a state which all individuals can engage, opposed to some special formula only entrepreneurs posses.

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ACC	anterior cingulate cortex. 24, 64, 67, 69, 303
ADHD	Attention Deficit Hyperactivity Disorder. 115, 117, 141, 144
AUT	Alternative Uses Task / Unusual Uses Task. 314
BOLD	blood oxygen level dependent. 16, 59, 60, 62
DMN	default mode network. 21, 24, 26, 64, 67, 139, 248–250, 273–276, 278, 303, 307, 310, 316–319
dmPFC	dorsomedial prefrontal cortex . 23, 276, 278, 300, 301, 312, 315
EEG	electroencephalogram. 57, 69, 100, 111, 115, 116, 118, 120, 128, 134, 136, 137, 244
FC	functional connectivity. 360, 366
fMRI	functional magnetic resonance imaging. 16, 56, 57, 59, 60, 62, 64, 66, 69–71, 76, 111, 120–122, 124, 125, 127, 128, 130, 131, 136–139, 142, 215, 250
IFG	inferior frontal gyrus. 23, 24, 274, 276, 278, 300, 301, 304, 312, 315, 317, 350
MDN	multiple demand network. 21, 24, 27, 64, 65, 248, 273, 274, 276, 278, 302, 304, 305, 309, 312, 317, 318, 320

MFG	middle frontal gyrus. 24–26, 270, 304–308, 310, 314, 316–319, 324, 350, 353
MRI	magnetic resonance imaging. 100
MTG	medial temporal gyrus. 274
PET	positron emission tomography. 58, 100
PFC	prefrontal cortex . 312
ROIs	regions of interest. 312, 315
RSN	resting state network. 320
RSNs	resting state networks. 27, 305, 336, 366
SMA	supplementary motor area. 64, 67
TFC	temporal fusiform cortex. 23, 293, 299–301, 315
TFG	temporal fusiform gyrus. 276, 278

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CHAPTER 1: GENERAL INTRODUCTION

> Success depends on intuition, on seeing what afterwards proves true but cannot be established at the moment.
>
> Joseph A. Shumpter

Entrepreneurship, a term woven into the fabric of our modern day, is everywhere. From the start-up culture driven by the likes of Zuckerberg and Musk to autobiographical books such as The Lean Startup and the multitude of podcasts detailing entrepreneurs' success stories (Reis 2011). The media is awash with suggestions of the *entrepreneur formula*. Even from the academic perspective, there is no clear-cut consensus, with different disciplines and sub-disciplines of sociology, business management, economics and psychology offering their different takes on entrepreneurship. Meanwhile, governments around the world believe that entrepreneurship is the key driver for economic development, and are keen to monitor and nurture it in the next generation (Hill et al. 2023; Bacigalupo et al. 2016).

This interest in entrepreneurship is no new endeavour, dating back to the 19th century. Economists such as Jean-Baptiste Say saw entrepreneurship as shifting resources from an area of lower to higher "productivity and yield' (Say 1836). Jump to the 20th century, and Joseph Schumpeter, among other economists, redefined entrepreneurship as a definition that largely informs our modern-day understanding

(Schumpeter 1943; Kirzner 1973; Knight 1921). In the 1930s, he shifted the focus to individual entrepreneurs, those who could take an idea (invention), and turn it into something new and useful (innovation) (Schumpeter 1943). That is, when the concept of entrepreneurship as a source of creative disruption emerged, new ideas were disrupted and displaced. Schumpeter's poster child for entrepreneurship was Henry Ford, who famously introduced the assembly line to car manufacturing, slashing production time from 13 hours to just an hour and 33 minutes by bringing the car to the workers on conveyor belts. The key principle here is that without entrepreneurs as the agent for change, innovation would simply not happen.

Fast forward to today, and innovation has become more complex and fast-paced, aided by technology and now by artificial intelligence. This may not always be as visible as the dramatic shifts in manufacturing that defined the 19th century, but the behaviour and thinking remain the same, in that creating new ideas and innovations boosts productivity. Figure 1.1 shows the waves of innovation over the last century, with each wave becoming shorter as innovation accelerates. Think of ChatGPT, a natural-language processing tool, that was made available to all less than a year ago and that has the potential to be the most disruptive technology of the century. A myriad of entrepreneurs have already begun to lean into this advancement in AI, such as the so-called *Prompt Artists* (Giuggioli and Pellegrini 2023). Moreover, theories of entrepreneurship are becoming more nuanced, better describing how entrepreneurs reason, form judgements and imagine concepts never previously seen before (Sarasvathy 2001). Yet, a fundamental question persists: What distinguishes entrepreneurs, those who imagine, create and implement new ideas, from those who do not? How and why do they think in this way when others do not? (R. K. Mitchell, L. W. Busenitz et al. 2007). While research on entrepreneurial cognition has theorized what is different about how entrepreneurs think, there is a lack of empirical understanding about

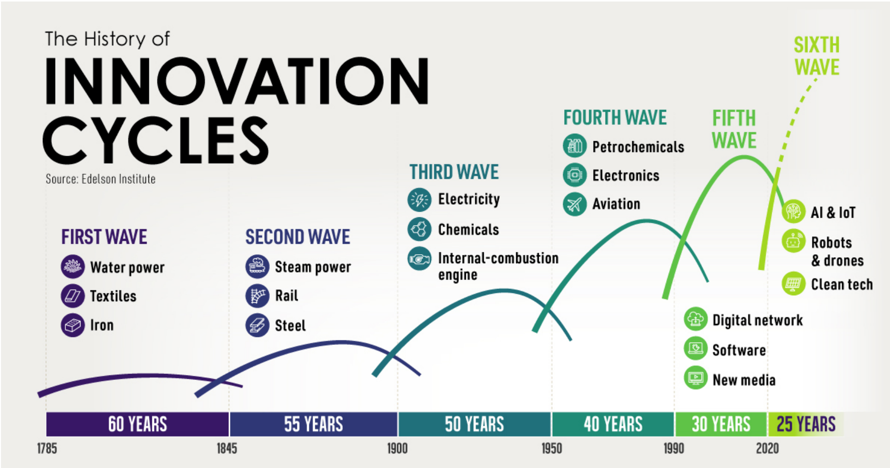

Figure 1.1: The History of Innovation Cycles from Visual Capitalist, based on Shumpter's view of creative destruction Neufeld and Ma (2021).

what might be driving these different thoughts and actions in the brain, and whether we can encourage or train entrepreneurship.

It is within this context that neuroscience enters the stage, offering a lens through which we can delve into the distinctive entrepreneurial cognitive processes and their underlying neurological underpinnings, striving to uncover the "how" and "why" of entrepreneurial thinking; how it is produced in the brain and why there are differences in how people think, make decisions or approach problems. Eventually, this strand of research will give us the means to ask the question: Can entrepreneurial thinking be trained? Neuroscience equips us to explore the intricacies of entrepreneurial thought patterns and the neural mechanisms that set entrepreneurs apart in their pursuit of innovation and creativity. By focusing on the brain, the organ that creates human cognition, we can contribute, complement, and challenge the classic view of *what defines an entrepreneur*.

In this chapter, I provide a concise introduction to the primary domains underpinning this thesis, starting with the *why*, emphasising the reason to study entrepreneurs as the means to better understand and thus better train and educate such thinking, in section 1.1. I then set up the theoretical position of this thesis in section 1.2. I discuss the shift from organisational to individual views of entrepreneurs, the shift from static traits to malleable cognition, and the current challenges and gaps in the field of entrepreneurial cognition which this thesis addresses. I introduce the necessary cognitive neuroscience background in section 1.3 and demonstrate the convergence of neuroscience and entrepreneurship in section 1.4. In section 1.5, I provide the necessary definitions for this thesis, defining the *entrepreneur* grouping and defining a new term *entrepreneurial neurocognition*. Towards the conclusion of this chapter, in section 1.6, I describe the unique contribution this thesis makes to the field. This overview remains largely theoretical, as we delve into a detailed literature review of where neuroscience and entrepreneurship intersect practically in Chapter 2. The purpose of this chapter is to establish this research territory and demonstrate the gaps in entrepreneurship research that the neuroscience methodology will address.

1.1 THE WHY: CAN ENTREPRENEURSHIP BE TAUGHT?

Before diving into research, it is crucial for any researcher to pause and reflect: Why am I pursuing this topic, and what approach am I taking? The core aim of this research is to offer fresh insights into how entrepreneurship may be taught. I am aiming to explore whether there are distinct differences in the way entrepreneurs think and act, and if so, what these differences entail—are they innate traits or skills that can be developed? This line of inquiry is essential because current methods for training entrepreneurs lack clarity on which aspects of entrepreneurial thinking are inherent to individuals and which can be nurtured through the right environment and interventions. The approach I adopt sits at the intersection of entrepreneurship theory, neuroscience methodology, and entrepreneurial education practice. By doing so, I aim to develop a thesis that not only generates fresh insights and knowledge, but also offers new alternative methodologies to studying entrepreneurs' mind and actionable recommendations for both practitioners and educators in the field.

Beyond the perspectives of business schools and economics teaching, approaches to nurturing entrepreneurship include entrepreneurial education literature, practice-based training, and accelerators. Academic entrepreneurship teaching from business schools has been criticised as often being too conservative, with a focus on business functionality rather than on enhancing creativity and flexibility. Scholars call instead for approaches that prioritize competency and mindset development (Pittaway and Cope 2007). Notably, neuroscience has been recognised as a valuable tool for offering different perspectives on innovation and creativity in entrepreneurship (A. Penaluna and K. Penaluna 2021).

Competencies encompass specific skills, knowledge, and characteristics/attitudes that contribute to effective performance and behaviour in a given role or situation (C. Dictionary n.d.). Entrepreneurial competencies, as defined by Mitchelmore and Rowley (1995), comprise underlying characteristics such as specific knowledge, motives, traits, self-images, social roles, and skills that lead to venture creation, survival, and growth. Importantly, these competencies can be acquired, making it necessary to identify specific entrepreneurial competencies for training and educational purposes (Mitchelmore and Rowley 2010). Government-level research aims to inform educational curricula regarding which competencies are essential for entrepreneurship. For instance, Entrecomp (2016) and Entrecomp in Action (2018), produced by the European Commission, present such competencies frameworks (Bacigalupo et al. 2016; McCallum et al. 2018). As shown in figure 1.2, this conceptual model shows 15 different competencies, contained under the 3 main competence areas of ideas and opportunities, resources, and into action. The progression shows how this framework

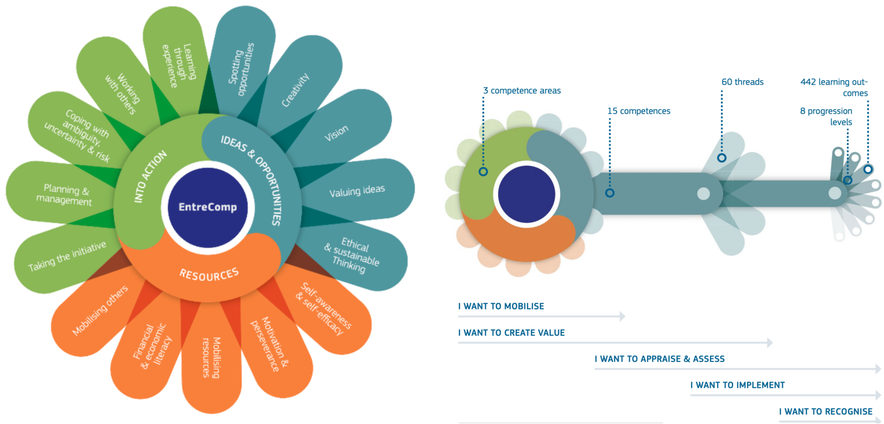

Figure 1.2: The 15 competencies in the EntreComp conceptual model from McCallum et al. (2018).

is implemented in practice, the complexity of which is demonstrated by the possible 442 learning outcomes for assessment.

When it comes to teaching entrepreneurship, traditional educational pedagogy primarily emphasises knowledge components of competencies, due to its ease of instruction and evaluation through standard assessments and exams (Komarkova, Conrads and Collado 2015). Knowledge is often referred to as the "hard skills" of entrepreneurship. Hard skills are defined as skills related to technical aspects of a job and frequently require the acquisition of knowledge ((Rainsbury et al. 2002) in Hendarman and Cantner (2018)). In entrepreneurship, this often relates to knowledge about marketing, technical, financial, legal, and tax (Chioda et al. 2021). Conversely, skills and attitudes necessary for entrepreneurship are commonly termed "soft skills" or "the entrepreneurial mindset", encompassing interpersonal, human, people and behavioural skills (Hendarman and Cantner 2018). Examples of these include creativity/innovation, teamwork, recognising opportunities and thinking critically (Robinson and Stubberud 2014). These competencies are the key in the historical theories of entrepreneurship (Schumpeter 1943), yet despite a long-standing consensus that such soft-skills are critical to entrepreneurship, they are arguably much more challenging to measure using objective criteria. Furthermore, beyond these assessment-related challenges, traditional teaching methods, such as lectures, do not by nature cultivate specific attitudes or skills, such as creativity and teamwork. Experiential pedagogy and learning-by-doing practices have a more substantial impact, as students learn to solve problems in real-life entrepreneurial settings (Nabi et al. 2017). This prompts the question: what truly constitutes essential entrepreneurial competencies, and how can individuals acquire and develop these?

Prior attempts have been made to distinguish between competencies that are inherent to individuals across cultures and those that can be taught or shaped by the environment, categorising competencies as either stable or dynamic (Leiba-O'Sullivan 1999). One empirical study focused on a prominent entrepreneurship program, the Student Mini-Company (SMC) program, and its impact on the development of entrepreneurial skills in college students (Oosterbeek, Van Praag and Ijsselstein 2010). During the SMC program, groups of students established, operated and dissolved small-sized businesses over the course of a school year. The program's objectives included building self-confidence, fostering pro-activity and creativity, and improving teamwork. Before and after the program, participants self-reported on seven "traits" related to the need for achievement, autonomy, power, social orientation, self-efficacy, endurance, and risk-taking propensity, as well as on three "skills" encompassing market awareness, creativity, and flexibility. The authors hypothesised that the traits investigated were stable and thus not expected to change, whereas the skills could be learned and enhanced through program participation. Surprisingly, the study found no significant impact on entrepreneurial skills resulting from the program. To add further complexity, some of the traits considered "stable" showed changes over the course of the program, suggesting that attempts to isolate stable and dynamic traits may not be the best approach to research entrepreneurial competencies. In this thesis, I argue that we should isolate the aspects of an individual's knowledge, traits, and skills that collectively form a competency.

There is limited empirical evidence to definitively identify which entrepreneurial competencies are intrinsic to individuals and which develop over time, primarily due to the absence of objective measurements for these skills and characteristics. This underscores the need for approaches that combine various methods to enable us to gain a better understanding of the factors contributing to entrepreneurship through a multilevel approach. For instance, in the case of creativity (one of the EntreComp competencies), we can explore the traits, attitudes, knowledge, and skills that enable and motivate individuals to create new opportunities. Consider for example the diagram in Figure 1.3, which illustrates Amabile (1998)'s framework for creativity, dividing skill/competency into three domains:

1. Expertise: Domain-relevant knowledge.
2. Thinking Skills: Cognitive and personality profiles conducive to innovative thinking.
3. Motivation: Attitude toward the task, with intrinsic motivation being more crucial than extrinsic motivation.

As Amabile (2011) suggests, creativity reaches its peak when an intrinsically motivated individual possesses high domain expertise and strong creative thinking skills, while working in an environment that supports creativity. This demonstrates how a combination of factors leads to the competency of creativity, emphasising the importance of environments that foster specific competencies. Consequently, research would benefit from adopting interdisciplinary approaches to understanding entrepreneurial competencies across all levels of analysis. This would help to expand our knowledge of the "soft skills" and mindset of entrepreneurs, providing insights into how to encour-

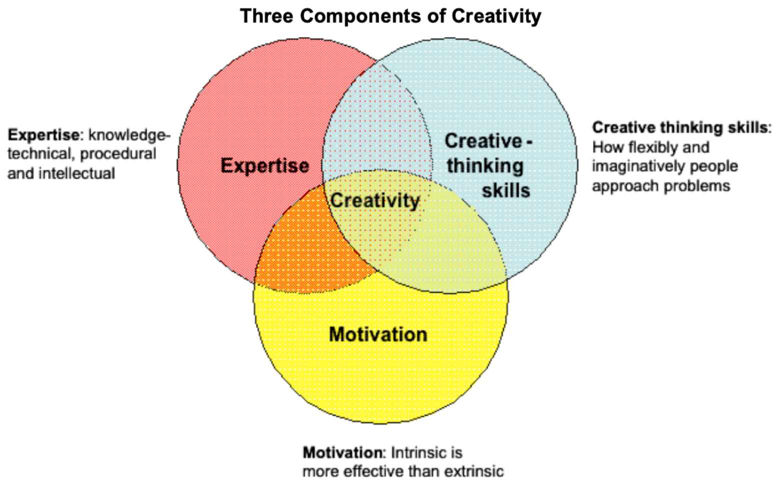

Figure 1.3: The three components of creativity (1) Expertise; (2) Creative Thinking Skills and (3) Motivation, from Adams (2005) and inspired by Amabile (1998).

age entrepreneurial competencies based on an individual's prior traits, cognitive skills, and motivations, along with the existing traditional approaches which aim to build one's knowledge.

1.2 A BACKGROUND TO ENTREPRENEURSHIP RESEARCH AND THE THEORETICAL POSITION OF THIS THESIS

1.2.1 *Theory: Who is the entrepreneur?*

Theories of entrepreneurship from Schumpeter (1943)'s era, including his theory of creative destruction, were also defined by the different perspectives on entrepreneurship offered by Kirzner (1973) and (Knight 1921). All theories emphasise the crucial role of the individual entrepreneurial agent, the environment in which they operate, and the role they play within it. Schumpeterian theory focuses on entrepreneurship as an innovation, bringing forward new ideas to replace the old. Kirzner (1973) attributes the role of the entrepreneur to an individual who is most alert to and acts upon opportunity, bringing in the importance of context and environment. Knight (1921)'s theory underscores entrepreneurs as those most willing to bear uncertainty, and to navigate such environments, risk and make decisions that others do not. In practice, entrepreneurs are likely to exhibit a combination of these behaviours. They may be alert to opportunities (Kirznerian), and innovate (Schumpeterian), while simultaneously bearing uncertainty (Knightian). Therefore, these theories do not necessarily contest each other but can be seen as the core facets of the complex phenomenon of entrepreneurship.

The focus on opportunity recognition has prevailed in the entrepreneurship literature across decades, which has resulted in a focus on the social and market factors that *present* opportunities to individuals, with Kirzner (1973) originally suggesting that entrepreneurs have an ability to notice opportunity without looking. For example, the promise of entrepreneurship research was laid out in Shane and Venkataraman (2000). Drawing upon multiple perspectives of entrepreneurship to establish a framework for the field, they define the scholarly field of entrepreneurship as an *examination of how, by whom, and with what effects opportunities to create future goods and services are discovered, evaluated, and exploited*. Three sets of research questions were posed:

1. Why, when and how do opportunities for the creation of goods and services come into existence?

2. Why, when and how do some people and not others discover and exploit these opportunities?

3. Why, when and how different actions are used to exploit opportunities?

However, accounts of opportunity recognition as the seed to entrepreneurship have been criticised as being too static and passive (Lumpkin, Hills and Shrader 2004), as these theories hold an assumption that opportunities simply exist in the environment waiting to be noticed - as demonstrated in the statements above portraying *how do opportunities... come into existence*. Instead an alternative approach suggests that opportunities arise out of the knowledge and experiences of individuals, placing the entrepreneurial individual as an active agent. According to this perspective, whilst an entrepreneur may *find* opportunity, this is thought to be through their prior knowledge and importantly, also through the judgements they make (Randerson, Degeorge and Fayolle 2016; Suddaby, Bruton and Si 2015), bringing entrepreneurial judgements and decision-making processes to the forefront of research. According to Penrose (2009), the process of entrepreneurial discovery arises from imaginative thinking, demanding a blend of creativity and knowledge. The exercise of judgment and imaginative exploration, crucial for creating value, doesn't happen in a vacuum; it requires specific knowledge and distinctive experiences (González-Cruz and Devece 2018). This means that unique internal resources (knowledge, frameworks, capabilities) allow the entrepreneur to perceive and make judgements on the opportunities that others are not noticing.

In line with this view of internal resources, much of the academic literature in management sciences and entrepreneurship has been influenced by the Resource-Based Theory (RBT) model, which proposes that internal factors to a firm, such as resources and capabilities, determine its profits to a greater extent than industry/external factors (Wernerfelt 1984). Yet whilst entrepreneurship is considered a key component of RBT, the original theory failed to look specifically at the individual entrepreneur and thus integrate the core components of innovation, creativity and entrepreneurial action. In an influential paper by Alvarez and L. W. Busenitz (2001), the authors define the distinctive domain of entrepreneurship within RBT, stating that *entrepreneurial opportunities exist primarily because different agents have different beliefs about the relative value of resources when they are converted from inputs to outputs*. They position that a resource not yet considered is the cognitive capability of the entrepreneur that allows them to see the value in other resources to hand, and thus turn this value into innovation. Building on the work of L. W. Busenitz and Barney (1997) and on the emergence of cognitive approaches, the resource based theory of entrepreneurs aims to discover the unique mindset or orientation that gives them a competitive advantage.

Research on entrepreneurial cognition has since gained momentum, with a myriad of research areas exploring the process of entrepreneurial thinking (Denis A. Grégoire, Corbett and Mcmullen 2011). Research in entrepreneurial cognition works off the premise that every action is influenced by mental processes — *by the cognitive mechanisms through which we acquire information, enter it into storage, transform it, and use it to accomplish a wide range of tasks (e.g., making decisions, solving problems)* (Sternberg 1984; Robert A Baron 2004). The cognitive perspective can answer many of the *why* questions in the entrepreneurship field; (1) Why do some persons but not others choose to become entrepreneurs? (2) Why do some persons but not others recognise opportunities for new products or services that can be profitably exploited? (3) Why are some entrepreneurs so much more successful than others? (Robert A Baron 2004). All questions position this cognition or unique way of thinking as a unique resource that entrepreneurs possess that other do not.

Overall, in essence, contemporary entrepreneurship research has shifted from a focus on external factors presenting opportunities to a more nuanced exploration of how individuals, through their cognitive processes, judgments, and decisions, actively contribute to the creation of value as an entrepreneurial process. Instead of solely asking where opportunities come from, there is a growing interest in understanding who the entrepreneur is, how entrepreneurs think and how this plays out in their action. The emphasis on cognitive processes raises questions about the potential for developing and enhancing entrepreneurial thinking skills and asking newer questions more rooted in process-theories such as: How does entrepreneurial thinking develop? This line of inquiry not only contributes to the theoretical understanding of entrepreneurship, but also has practical implications for fostering an entrepreneurial mindset and capability.

1.2.2 *The Trait Approach: Why Some and Not Others?*

The question of *why some and not others* naturally leads many scholars to explore the characteristics and traits of entrepreneurs. Trait research can elucidate which behaviours are important in entrepreneurship, yet, on its own, it is limited in offering any understanding of how entrepreneurial behaviour and cognition are developed and used. For many decades, the trait approach to entrepreneurship has been popular among many psychologists in the field, researching the association between personality traits and successful entrepreneurship. Researchers have assessed the Big-5 personality macro-traits (Brandstätter 2011; Zhao and Seibert 2006; Zhao, Seibert and Lumpkin 2010), as well as more micro-traits such as self-efficacy, autonomy, locus of control, risk attitude, optimism, and more (Cuesta et al. 2018; S. P. Kerr, W. R. Kerr, Xu et al. 2018).

Since the 1980s, personality models such as the five-factor model (FFM), or Big-5, have been the most widely used and validated models of personality. The Big-5 has been used to assess macro-traits such as extraversion (E), openness to experience (O), neuroticism (N), conscientiousness (C), and agreeableness (A), including in entrepreneurs (Goldberg 1990). It has been used to predict a wide variety of performance outcomes, including in sports, jobs, and leadership (Allen, Greenlees and Jones 2013; Judge and Bono 2000; Barrick and Mount 1991). The five-factor structure has also been shown to remain consistent across different cultures (McCrae et al. 1998) and shows good test-retest reliability, even with short versions of the questionnaire (Gosling, Rentfrow and Swann Jr 2003). A review of five meta-analyses showed differences between entrepreneurs and managers (higher C, O, E, and lower N, A), correlations with entrepreneurial intention (higher C, O, E, and lower N), and entrepreneurial performance (higher C, O, E, and lower N) (Brandstätter 2011). However, the authors noted a large amount of heterogeneity in the data of such meta-analyses, therefore it is important to consider that there may not be a single *type* of entrepreneur and the nature of the samples studied should be taken into careful consideration when extrapolating the results to entrepreneurship in general (Zhao and Seibert 2006). While a meta-analysis may reveal broad characteristics associated with entrepreneurship, the trait approach to entrepreneurship does not account for inter-individual differences and is unable to predict situation-specific behaviours.

Therefore, a new branch of personality research devised models bridging the Big-5 with specific entrepreneurial traits such as risk-taking, self-efficacy, innovativeness and internal locus of control (S. P. Kerr, W. R. Kerr, Xu et al. 2018). For example, Cuesta et al. (2018) created and validated the Battery for the Assessment of the Enterprising Personality (BEPE), in which they defined 8 specific entrepreneurial personality dimensions; self-efficacy, autonomy, innovativeness, internal locus of control, achievement motivation, optimism, stress-tolerance and risk-taking. Conversely, the Measure for Entrepreneurial Talent (META) uses only 4 dimensions, yet is the most widely used and validated scale for measuring entrepreneurial ability in domains such as; entrepreneurial creativity, opportunism, proactivity and vision (Leutner et al. 2014). The strength of these models is that these dimensions relate directly to entrepreneurial behaviours. However, the static nature of defining these as traits still assumes that people act the same regardless of context and they do not account for the extent to which behaviour may develop over time. It is important future research in entrepreneurship dissociates between these domains.

The pragmatic and theoretical challenges in defining who the entrepreneur *is* as a stable characteristic led many scholars to shift towards a cognitive approach and to ask instead *How does an entrepreneur think?* and *What does an entrepreneur do?*, thus taking a more dynamic view of entrepreneurship. The aptly named "“Who Is an Entrepreneur?” Is the Wrong Question" by (Gartner 1988) argues that approaches to understanding the traits or characteristics of entrepreneurs should be replaced with an approach that seeks to understand cognition and behaviour given situational contexts, such as uncertainty and opportunity. Therefore, a shift in focus began to study *what the entrepreneur does*, rather than *who the entrepreneur is*. Shane and Venkataraman (2000) state 20% to 50% of the population are thought to engage in entrepreneurial behaviour. This is important to the definition of entrepreneurship, as, rather than viewing entrepreneurship as a certain characteristic that only some individuals have, it should also be explored as to how certain people think and act in given entrepreneurial situations.

1.2.3 *Entrepreneurial Cognition: How do Entrepreneurs Think?*

Entrepreneurial cognition is defined as *the knowledge structures that people use to make assessments, judgments, or decisions involving opportunity evaluation, venture creation, and growth* (R. K. Mitchell, L. Busenitz et al. 2002). Robert A Baron (1998) and Gartner (1988) were amongst the first scholars who criticised the trait approach to entrepreneurship and wanted to explore not who entrepreneurs are, but instead how they think (L. W. Busenitz and Barney 1997; R. K. Mitchell, L. Busenitz et al. 2002). Whilst initially the criticism of the trait approach moved the academic field away from the study of the individual entrepreneur completely, with many scholars aiming for a more holistic view of the dynamic context in which entrepreneurial thinking emerged, Katz and Shepherd (2003) notes how cognition research catalysed *a new generation of individual-level studies of entrepreneurial processes* which included more rigorous empirical approaches. Amongst this was a special issue by Gartner et al. (1994) who encouraged for more research in the individual and social/psychological processes involved in entrepreneurial activity.

The cognitive approach was positioned by scholars such as Denis A. Grégoire, Corbett and Mcmullen (2011) as the means to truly disentangle what the *difference* is in entrepreneurs, noting that this can be done in two ways; either we may see what the differences are in the cognitive resources of an individual that predate entrepreneurial actions (e.g. the dispositions, cognitive skills, knowledge of an individual) or we may study the differences in the *live* cognitive experience of individuals (e.g. how they process information in the moment, due to interactions with context and environment). This distinction in two types of entrepreneurial cognition is also echoed in a question prevalent in cognitive science and management sciences: does cognition exists *in the mind* or, as is increasingly accepted across disciplines, is cognition embodied in interactions between the brain, body and world? This thesis sits within the theoretical realm of entrepreneurial cognition and will provide empirical work to debate amongst these two positions - is entrepreneurial cognition an intrinsic resource, or is it the result of interaction of the mind, body and environment?

Importantly, there are three aspects that characterise cognitive research (Denis A. Grégoire, Corbett and Mcmullen 2011):

- Mentalism: the study of mental representations, meaning the study of the *mind*. Research in this area currently looks at cognitive maps, knowledge structures, perceptions, scripts and schema of entrepreneurs. It is within this context that the cognitive resources of the entrepreneur can be studied. This aims to uncover the *black box* of the entrepreneurial mind – the hidden processes behind the observable actions.

- Process orientation: the process orientation considers the complex interactions between why, when and how entrepreneurial cognition comes into play, as a sum of the mind and environment. It looks into how this develops, based on the information processing model described later in section 1.3.2 by Neisser (1967) and the computational perspective of cognition, popularised in cognitive neuroscience. This view empathises the importance of agent-context interaction.

- Levels of analysis: cognitive research in the field of entrepreneurship and organisations does not exists only at the level of the individual. Instead, cognition in entrepreneurship may be studied from groups, organisations and society as a whole. Research in this realm looks into the collective cognitions that develop amongst many people.

As it stands, the first two aspects of entrepreneurial cognition form the strongest base and theoretical positions of work in the neuroscience of entrepreneurship, as means to study the mental states and processes of entrepreneurs, in how the brain interacts with the context and environment. In particular contemporary theories which integrate mentalism and process orientations at the individual level are of most relevance.

Research on individuals' entrepreneurial cognition has explored how entrepreneurs deal with risk and uncertainty, with a focus on the bias heuristics and overconfidence of entrepreneurs and their effectual logic (Sarasvathy 2001; L. W. Busenitz and Barney 1997). Another body of work looks at the information processing expertise of entrepreneurs in their ability to spot opportunities and recognise patterns (J. B. Smith, J. R. Mitchell and R. K. Mitchell 2009; Robert A Baron and Ensley 2006). More recently, there has been interest in cognitive adaptability and cognitive flexibility (Dheer and Lenartowicz 2019; Wang et al. 2020). One example of a pivotal theoretical milestone in understanding entrepreneurial behaviour with this approach was Sarasvathy (2001)'s theory of effectuation, a process cognition-based theory of entrepreneurship. This theory explains the process that entrepreneurs use to create ventures and gain popularity and is of practical relevance to how entrepreneurs think, plan, and make decisions. Effectuation involves starting with what one has (resources, abilities, and expertise) and then creating opportunities and outcomes based on these (Sarasvathy 2001). This is contrasted to a more traditional predictive approach termed causation, which can be described as an *analytical* approach to planning; drawing on an illustrative analogy of a chef in a kitchen (Sarasvathy 2001) brought the theory to life in her landmark paper. Imagining a chef who is given one of 2 possible instructions:

1. A chef using causation logic would decide to cook a given recipe, with the list of ingredients and instructions. They would then go out to gather the resources needed. This wouldn't leave much room for new recipes or creative combinations of ingredients.

2. A chef using effectuation logic would instead begin by looking at what ingredients and resources are available, then set about creating a new meal. While they may have a vision in mind for the dish they are creating, this meal could adapt and change along the way.

This analogy can be likened to the process of entrepreneurship, effectual logic may be more suited where there is no 'recipe' to follow and a higher degree of uncertainty. Effectuation presented a pragmatic shift in the way entrepreneurship was understood. Until this theory, much of the research focused on the discovery and exploitation of opportunities (Kirzner 1973). This theory brought forward the original ideas from Schumpeter (1943) and Knight (1921): 1) ideas are constructed by entrepreneurs and 2) entrepreneurs navigate uncertainty to exploit such ideas. This supports the position argued in section 1.2.1, that opportunities are not passively noticed, but it is the approach, judgements and decisions of the entrepreneurial agent that allow opportunity to be actioned, resources utilised and thus value created. The theory of effectuation takes the view away from the entrepreneurial agent as a rational being, following causal logic. Instead, it better describes how something never imagined before could come into existence, with a focus on the imagination, thought processes and cognition involved in uncertain contexts (Alvarez and Barney 2005; Read, Song and Smit 2009).

Effectuation incorporates an approach to judgement and decision-making where little predictions can be made, as the agent tackles completely uncertain grounds. Integral to this theory is the notion that the consequence of one's actions are unknown, which is core to innovation. Whilst traditionally entrepreneurship could be seen as means to optimize, effectuation places entrepreneurship and imagination in the same realm. An effectual approach to thinking is, as quoted by Denis A Grégoire and Cherchem (2020) "Given an uncertain world, what could I do with the means, resources, and capabilities I have or could readily mobilize?". The answer to such a question can only come from our imagination and ability to *create* or design an answer, therefore bringing an assumption forward that human imagination in the brain and thus creativity are key to effectual logic and thus entrepreneurial thinking. This theoretical position is therefore the basis for the empirical work in this thesis - which explores the capability of individual entrepreneurs to create and invent new possibilities never imagined before, given the current materials and resources they have access to (mentalism), the context they are within (process-orientation) and the corresponding neural correlates of such innovative thinking. The empirical work within this thesis will then be positioned to uncover what cognitive resources are required at different stages during the entrepreneurial process, and ultimately if they can be trained.

1.2.4 *Challenges with Entrepreneurial Cognition and the Gap this Thesis Addresses*

Despite a promising shift in research trajectory towards entrepreneurial cognition, major challenges exist. First, the field of entrepreneurial cognition is broad and disjointed, confusing to a new scholar and to an interdisciplinary approach which tries to uncover what underlies innovation in the entrepreneur's brain.

Notable reviews of entrepreneurial cognition summarise and highlight very different areas of work, from learning, cognitive misfit, regretful thinking, perseverance, decision-control in risk, signal detection frameworks, expert scripts, heuristics and systematic thinking (Katz and Shepherd 2003), to situated cognition, fear, affective dynamics, intuition, opportunity evaluation, team cognition, bricolage and effectuation (Denis A Grégoire, Cornelissen et al. 2015). Likely due to the vast possibilities that an entrepreneur's mind may explore, there is often no consensus nor summarized themes for which to base future work upon. Instead, the research focuses on specific and niche mental states or context-dependent processes of the entrepreneur's mind. This in the past has led to to some errors in theoretical accounts that were found later on to not be true. For example, Katz and Shepherd (2003) notes sporadic use of cognition work and an error in theoretical accounts of entrepreneurs as risk-takers, developing from the economic literature. When checked empirically, this was found not to be true, as Brockhaus Sr (1980) showed entrepreneurs to be only moderately risky.

Moreover, while the theoretical development of how an entrepreneur thinks continues to expand and support real-world views of entrepreneurs, empirical evidence of such cognitive models lags behind the current methodology (Perry, Chandler and Markova 2012; Denis A. Grégoire, Corbett and Mcmullen 2011). The limited current empirical work shows a link between effectuation principles, behaviour, and firm performance (Read, Song and Smit 2009), with no measures of how entrepreneurs make decisions. In an attempt to understand this cognition, researchers have asked participants to think aloud during experimental conditions (Read, Dew et al. 2009). However, it is debatable whether we actually measure cognition by asking someone to think aloud. A whole part of the puzzle is missed in the unconscious processing, memories, and biases of the individual that allow value creation. Cognition itself refers to how the brain processes, sorts, organizes and uses information (Neisser 1967). Empirical evidence for cognitive theories in entrepreneurship exists only in the behavioural or verbal measures and success metrics of firms rather than of the individual (see Table 2 in (Perry, Chandler and Markova 2012), showing the empirical evidence in effectuation mostly comes from verbal analysis e.g. speaking aloud). Therefore the gap in the theoretical and empirical work that this thesis focuses on, is to provide methods and means to tests the hidden *black box* of neurocognition which occurs to produce entrepreneurial competency and action.

Therefore, I argue that at this early stage, research in the neuroscience of entrepreneurship may take a broader and less biased view on the entrepreneurial cognition most relevant to study. Staying too specific at such an early point may result in pursuing paths of entrepreneurial cognition research from a theoretical lens, that may later found to be false. In addition, this narrow view may limit the scope of new discoveries to be made about the entrepreneur's mind. Therefore whilst I review the most relevant theoretical accounts of entrepreneurship and cognition that precede my research, this thesis and the methods utilised aim to take broader data-driven approach to researching the entrepreneur's mind.

Advancements in neuroscience, particularly neuroimaging, have led to the development of more sophisticated techniques for studying cognition, which may offer new avenues for research on entrepreneurial cognition. For example, we may begin to explore how the brain can imagine new ideas in uncertainty, adding empirical data to what is currently a largely theoretical assumption of entrepreneurs as effectual beings. Moreover with new methods and tools we have more means to test how such cognition and thinking develops. The next section provides a history of neuroscience and an overview of the cognitive neuroscience methods that could be utilised and harnessed by the field of entrepreneurship.

1.3 The necessary history and methods from cognitive neuroscience

1.3.1 *How does the brain create our thoughts?*

Cognitive neuroscience *is concerned with the scientific study of the neural substrates of mental processes and their behavioural manifestations* (Sandrini, Umiltà and Rusconi 2011), thereby providing the missing piece of the puzzle to entrepreneurial cognition research. As described above, entrepreneurial cognition research focuses on studying theorised mental processes and behavioural manifestations, without the deeper layer of the neural substrates causing this. Neuroscience, particularly neuroimaging techniques, enables us to begin to explore the neural components of the human mind. Allowing us to study how the brain can be shaped and changed through experiences and learning . In this section, I describe how cognitive neuroscience developed as a field and the shift in how we now understand cognitive processes as activity in the human brain. I will introduce how cognitive neuroscience has developed as a field to study key cognitive processes in the brain, with a focus on MRI, setting the scene for how cognitive neuroscience theory and methods can complement existing theories in entrepreneurship.

1.3.2 *From Cognitive Psychology to Cognitive Neuroscience*

Cognitive neuroscience itself was born from the merging of cognitive science (a branch of psychology) and neuroscience. In the first half of the 20th century, psychology was defined by behaviourism, pioneered by the likes of Watson (1913), who asserted that psychologists should abandon any attempt to understand mental processes and instead focus on the observable aspects of human and animal behaviour. Watson's view was that behaviour is learned as a result of interactions with one environment. He asserted a school of thought that any attempt to study mental processes such as perception, imagery, thinking, retention, problem-solving, or consciousness was speculative at best. Therefore the most interesting aspects of the human mind, the conscious and unconscious working of our thoughts, were to some degree left out by behaviourism (Albright, Kandel and Posner 2000). That was until what has been termed the 'cognitive revolution' when Chomsky, a linguist, rejected behaviourist views (G. A. Miller 2003; Chomsky 2002). Behaviourism viewed all human and animal behaviour as *learnt*, which Chomsky believed underplayed the role of human creativity and the human ability to manipulate language.

> *The most striking aspect of linguistic competence is what we may call the 'creativity of language', that is, the speaker's ability to produce new sentences that are immediately understood by other speakers although they bear no physical resemblance to sentences that are 'familiar'* (Chomsky 1966).

This quote not only underlines the shift to a cognitive approach in psychology but also speaks to the core creative nature of entrepreneurship. It is the unique essence of human thought, the ability to bring about new concepts and ideas into language, which although never seen before, can be understood and adopted by others. Chomsky's paper and views, along with many such as G. A. Miller (1956) and Neisser (1967), pioneered what is known as cognitive psychology, which aimed to apply a scientific approach to study human cognition, predominantly in language, perception and memory. This came at a time when computer science and neuroscience as disciplines were beginning to emerge, hence the focus shifted to the information processing capabilities of the human brain (G. A. Miller 2003). Neisser (1967) in particular pointed out that the focus should be on the flow of sensory information, from how it is *transduced* by the appropriate receptors, constructed into human memory and acted upon (Albright, Kandel and Posner 2000). Yet in the 1970s and 1980s, when theories of cognitive psychology were emerging, we did not have the means to directly measure such sensory and perceptual representations, nor the information processing in the brain. The next decade, the 1990s, saw the rapid development and adoption of whole-brain non-invasive functional neuroimaging techniques, such as functional magnetic resonance imaging (fMRI). For the first time, it was now possible to begin to map cognitive functions and information processing to neuronal systems in situ and in near real-time. Hence cognitive neuroscience was born as a discipline.

1.3.3 *Neuroimaging*

In its most primitive form, cognitive neuroscience, which can be seen as mapping brain structures to cognitive functioning, first came about through studying brain-damaged patients. Famous case studies form the basis of our understanding of how the brain processes language and higher-order thinking. One of the early pioneers of this field was Paul Broca, who, in the second part of the 19th century, realised that patients with damage to the left-hand side of the brain suffered language problems (Broca et al. 1861). Phineas Gage is another famous example, of a patient this time, following traumatic injury to his frontal lobe underwent huge personality, intellectual and impulse changes, hinting that the frontal lobe is involved in higher-order reasoning and control (Harlow 1848). It is important to note that, at this point, clinicians could only relate brain structure changes/damages to changes in behaviour. Nevertheless, prior to the advent of modern functional neuroimaging, scientists did attempt to measure the activity of the brain. Perhaps the earliest form, shown in Figure 1.4, involved the human circulation balance machine invented in 1882. Angelo Mosso was the first attempt to measure brain activity, on the premise that more blood flowed to the brain when it worked harder. Although resembling a torture machine, Mosso (1881)'s premise of measuring blood flow actually underlies modern-day neuroimaging techniques such as fMRI.

Neuroimaging techniques are essential in cognitive neuroscience to determine the brain activity behind cognitive processes and move away from behaviourist approaches. This thesis spotlights fMRI, as one of the most popular in cognitive neuroscience due to the fact that it is non-invasive, has good spatial resolution (within mm of active neurons) and can measure the activity of deeper brain structures involved in limbic (emotional) and memory processes. fMRI is rivalled by electroencephalogram (EEG), which is sometimes preferred as it is cheaper and provides better temporal resolution from measuring electrical activity directly from the scalp at the millisecond level (while fMRI measures them at the second level). However, compared to fMRI, EEG has poor spatial resolution and an inability to measure specific deeper brain structures involved in limbic systems and memory. It is

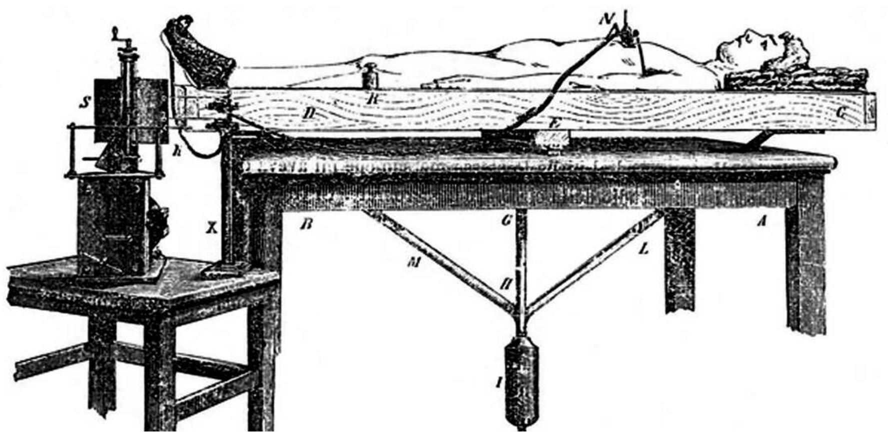

Figure 1.4: The "Human Circulation Balance" machine invented in 1882 by Angelo Mosso aimed to measure blood flow changes in the brain by acting like a seesaw, tipping the balance.

worth noting other techniques such as positron emission tomography (PET), functional near-infrared spectroscopy (fNIRS) and Mmagneto-encephalography (MEG), while less popular, also offer opportunities to study brain function. The choice of imaging techniques hinges on the specific research hypothesis and questions, as well as budgetary constraints and availability to researchers. We include a summary table of neuroimaging methods in cognitive neuroscience and a brief description of how they work in Chapter 2, Table 2.

1.3.4 *What brain activity can we measure with an MRI scanner?*

Every time neurons in the brain are active, releasing neurotransmitters across synapses and propagating electrical activity in the form of action potential across the myriad of neuronal circuits in the brain, they require energy to do so. This energy is given in the form of a compound called adenosine triphosphate (ATP). Produced by the powerhouse in our cells, the mitochondria, ATP synthesis requires glucose and produces carbon dioxide as a waste product. As the brain does not store glucose, the body must respond to the increased local demands triggered by a stimulus by increasing blood flow (containing glucose) to the active areas of the brain. It is worth noting that this does not happen in the exact location of the neuronal activity but within about 2-3mm of it. This increased blood flow leads to more oxygenated haemoglobin, contained within the red blood cells, being available in the areas of increased brain activity (Glover 2011). In fact, an excess of oxygen is often brought to the responding area within 500ms, peaking at about 3-5 seconds after a stimulus (Hillman 2014). This entire process is called the hemodynamic response and is what is measured in blood oxygen level dependent (BOLD) fMRI. Haemoglobin has different magnetic properties depending on whether it is oxygenated or deoxygenated. The deoxygenated form is more attracted to the magnetic fields (paramagnetic) and thus can distort a signal produced by the MRI scanner, causing it to lose signal faster. In contrast, where haemoglobin is oxygenated, it is indistinguishable from other brain tissue (diamagnetic). While it is a common misconception that the BOLD signal directly measures oxygen consumption, the BOLD signal actually increases with local decreases in deoxygenated haemoglobin due to the excess of oxygenated blood supplied (Hillman 2014; Ogawa et al. 1990). The MRI scanner can detect the BOLD signal with a spatial resolution of a few millimetres and a temporal resolution of one to two seconds. fMRI is not an absolute measure of brain activity: fMRI experiments induce different neural states in the brain and obtain activation maps for stimuli by comparing the signals during a task to those at rest, see figure 1.6.

1.3.5 *fMRI task design*

fMRI task design usually involves creating a paradigm or cognitive task using stimuli, visual, auditory or otherwise, to induce cognitive states in the brain whilst continually collecting MRI volumes of the brain every couple of seconds (Amaro Jr and Barker 2006). BOLD fMRI uses a subtraction method. Therefore the brain activity of images acquired when the subject is at rest or undertaking a designed control/baseline condition is subtracted from that of the 'active' task conditions (Donders 1868; Ulrich, Mattes and J. Miller 1999). There are generally two types of experimental design used in fMRI: block-design and event-related (although sometimes these can be mixed); see figure 1.5. A block design was the original design, in which in the most simple format, 'blocks' of, say 20 seconds of task and rest conditions are alternatively presented to the participant. The block design is optimal for reducing the signal-to-noise ratio and detecting activation as the BOLD signal rises and then plateaus with constant neuronal firing during a block. There is often a misconception that block designs are *simple*, and this design has been criticized due to test-retest reliability and the assumptions that underlie the subtraction method (Logothetis 2008). However, statistically speaking, block design provides the most powerful and robust study design, particularly where sample sizes are small or the expected experimental effect is likely to be small (Amaro Jr and Barker 2006). Alternatively, the event-related design, where separate measurable stimuli are presented, is preferred when researchers want to characterise the hemodynamic response's amplitude or timing to a single stimulus. It is, therefore, important when designing a task that careful consideration be taken to decide upon the desired design and ensure a suitable baseline condition.

1.3.6 *Brain Mapping*

Brain mapping, i.e. establishing links between behaviour, cognitive processes and their neural substrates and/or location in the brain, has rapidly advanced since the first fMRI experiments in the early 1990s. The last few decades have been awash with studies in cognitive neur-

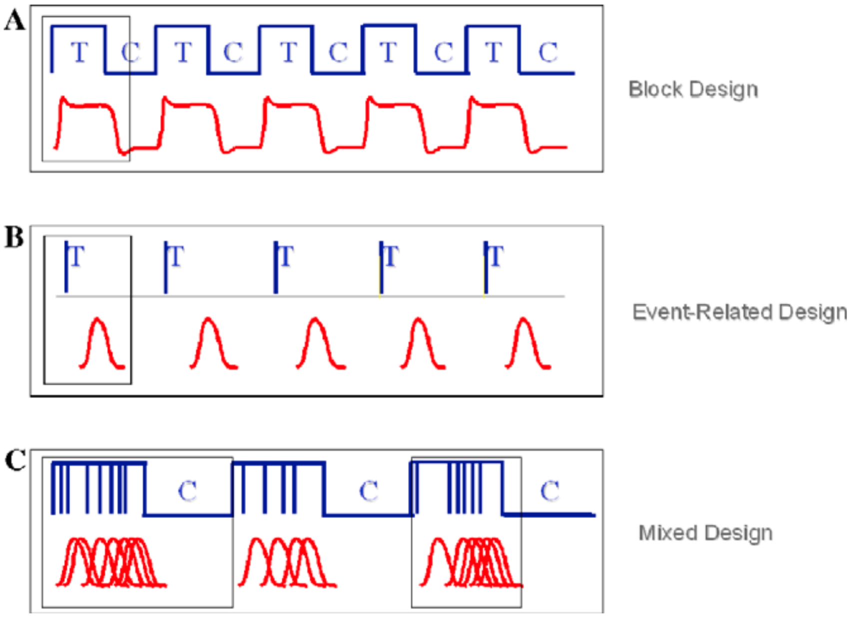

Figure 1.5: Strategies that can be employed for stimulus presentation in fMRI from Amaro Jr and Barker (2006). (A) Block design: in blue is the stimuli presentation with T demonstrating the task (condition and cognitive state you want to test) and C the control (rest or baseline). In red is how the hemodynamic response function (HRF) would respond, peaking and then plateauing for the duration of the block. This demonstrates why the signal-to-noise ratio and power of this design is stronger; (B) Event-related design: individual stimuli are represented with the vertical blue line and the corresponding HRF (red) follows a few seconds later in one short peak; each HRF can therefore be detected and analysed in detail; (C) Mixed design; here each block contains separate time-controlled events, so you can apply both event-related analysis and measures blocks of cognitive states.

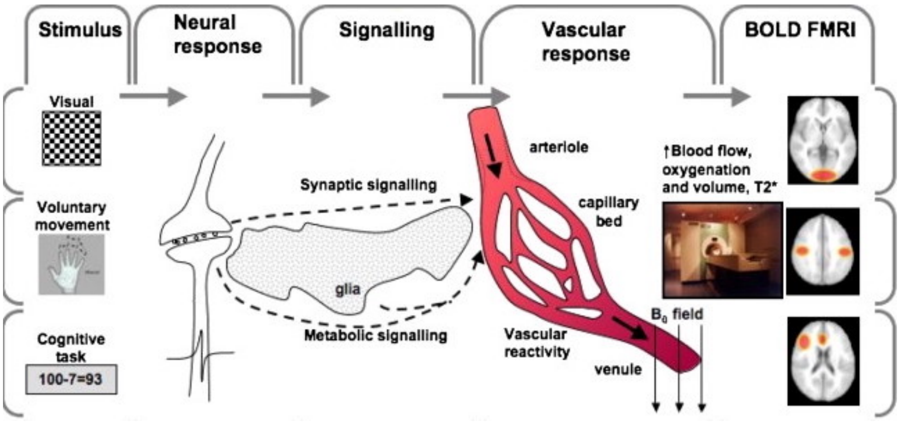

Figure 1.6: BOLD fMRI from Iannetti and Wise (2007). This shows the relationship between the stimuli presented (left), the associated neural response, and the signalling for a vascular response to bring more glucose and oxygen to the site of action. This BOLD response is then detected as an increase in oxygenated blood to the site of action. In fMRI, this decrease in oxygenated blood (and haemoglobin) distorts the magnetic field and produces maps across the volume of the brain to signify which voxels or clusters of voxels contain 'active neurons', i.e., respond to the experimental stimuli.

oscience aiming to map areas of the brain to just about every mental process you could think of. Landmark efforts were focused on visual, motor and sensory functions, likely due to the ease in providing sensory, motor and verbal/written stimuli and to the relative strength of these responses in the brain (Belliveau et al. 1991; S.-G. Kim et al. 1993). Much of this initial work focused on lateralisation of brain functions, particularly of language, which led to the sometimes contested view that the left hemisphere of the brain is dominant in processing language (Bradshaw et al. 2017). Since cognitive neuroscience is a broad discipline, it is no surprise that many aspects of mental processes have now been studied with fMRI from intelligence, memory, attention, decision-making and social cognition (Hampshire, Highfield et al. 2012; Gabrieli 1998; Posner 1995; Fellows 2004) to more subjective processes such as empathy, emotions, self-perception, consciousness and beliefs (Seth 2013; Rameson and Lieberman 2009; Lieberman 2007; Kapogiannis et al. 2009).

1.3.7 *Functional Connectivity fMRI*

Through carefully designed fMRI experimental tasks, it has become possible not just to compare brain states across different experimental conditions to rest but also to investigate different groups of people in how their brain responds (Friston, Jezzard and Turner 1994). This take on neuroscience has dominated much of the work for the last three decades, and it is based on the assumption that the brain is primarily driven by external inputs (Marcus E. Raichle 2015). This is likely a stance adopted from the theories proposed by (Neisser 1967) that cognition should be studied as the flow of information from the sensory input, transduction and use in higher-order processing states.

An alternative to measuring the mental states produced by external input is to study the internal states and oscillations associated with brain activity. Methods exist that measure functional connectivity (FC), meaning the temporal correlation and synchronisation between regions of the brain (Griffa et al. 2020). This explores the organisation, interrelationship and integrated performance of these different regions (Rogers et al. 2007). It allows researchers to look at how areas of the brain *speak* to each other and work together during cognitive processing. This technique has been used to show how the connectivity of brain networks at rest differs between groups of people, such as those with depression, Alzheimer's, schizophrenia, ADHD, and autism (Mulders et al. 2015; Greicius 2008; Hull et al. 2017; Konrad and Eickhoff 2010), albeit there is often heterogeneity in these results and difficulty in replication (He, Byrge and Kennedy 2020; Lechmann and Schnabel 2014).

There are different methods to study FC such as seed-based analysis, principle component analysis, independent component analysis and graph theory. Whilst these can be used to explore the brain's dynamic responses from external inputs and cognitive tasks, a popular approach is to explore FC of the brain at rest, i.e., without any task or stimuli being administered to the participant lying in the scanner. Resting-state fMRI is becoming increasingly common, often added by default to neuroimaging protocols. There has now been a plethora of research in this field, and two of the most important and consistent networks discovered are the multiple demand network (MDN), sometimes termed the task-active or cognitive control network; and the default mode network (DMN), also termed the task-negative network, mind-wandering or resting-state network (Marcus E Raichle et al. 2001; Wen, D. J. Mitchell and Duncan 2018). The MDN is a large network incorporating the dorsolateral prefrontal cortex, extending along the inferior/middle frontal gyrus (IFG/MFG), and including a posterior-dorsal region close to the frontal eye field (pdLFC), parts of the anterior insular cortex (AI), pre-supplementary motor area and adjacent anterior cingulate cortex (pre-supplementary motor area (SMA)/anterior cingulate cortex (ACC)), and intraparietal sulcus (IPS) (Wen, D. J. Mitchell and Duncan 2018). The MDN has been shown to be sensitive to task difficulty such that there is often widespread increases in activation in these regions when cognitive tasks get more difficult, such as with increased working memory load or interfering stimuli (Crittenden and Duncan 2014; Marois, Chun and Gore 2004; Woolgar et al. 2015). In contrast, the DMN is comprised of the posterior cingulate cortex (PCC) and precuneus, medial prefrontal cortex, and bilateral temporoparietal junction. The DMN gained attention when, in contrast to the MDN, its brain activity and connectivity were shown to increase during rest and decrease during externally focused tasks; it has since been associated with self-referential thoughts, autobiographical memory and creativity (Marcus E Raichle et al. 2001; S. M. Smith et al. 2009; McKiernan et al. 2003; Beaty 2020). There are also suggestions that the DMN is involved in the transitions between internally and externally focused attention (V. Smith, D. J. Mitchell and Duncan 2018; Crittenden and Duncan 2014). Other consistent brain networks have been found across healthy participants, see figure 1.7.

1.3.8 *Modern Approaches to Understanding Cognition, Creativity Intelligence and Success*

The merging of brain imaging techniques with comprehensive cognitive assessments is reshaping our understanding of intelligence and cognition, departing from the conventional perspectives born from cognitive psychology. As an example, (Hampshire, Highfield et al. 2012) have employed a large battery of cognitive tasks, combined with functional connectivity analysis, to demonstrate that intelligence can be dissected into two anatomically distinct systems within the MDN. For decades, society has viewed high intelligence as the ultimate benchmark of success. However, the traditional notion of intelligence, particularly as quantified by "IQ", assumes a uni-dimensional concept known in psychology as the *g factor* (Spearman 1904). Beyond the criticisms that traditional IQ tests may be based on outdated theories and that there is more than one measure of intelligence (Carroll 1993), these tests do not consider the strengths that can be found in neurodiverse individuals (Manalili et al. 2023) and that caution has been warned on the literature that links high IQ to job success, Richardson and Norgate (2015). Entrepreneurship is a perfect example of success that can be attained without the need for high IQ or academic qualifications. This suggests that there may be more to human reasoning, creativity, and the capacity for success than traditional IQ measurements can capture.

In a landmark paper, (Hampshire, Highfield et al. 2012) challenged the unidimensional concept of intelligence by using factor analysis on both behavioural scores from a large battery of cognitive tests and functional connectivity from MRI data. They argued that rather than a unitary construct, intelligence and cognitive functioning may be

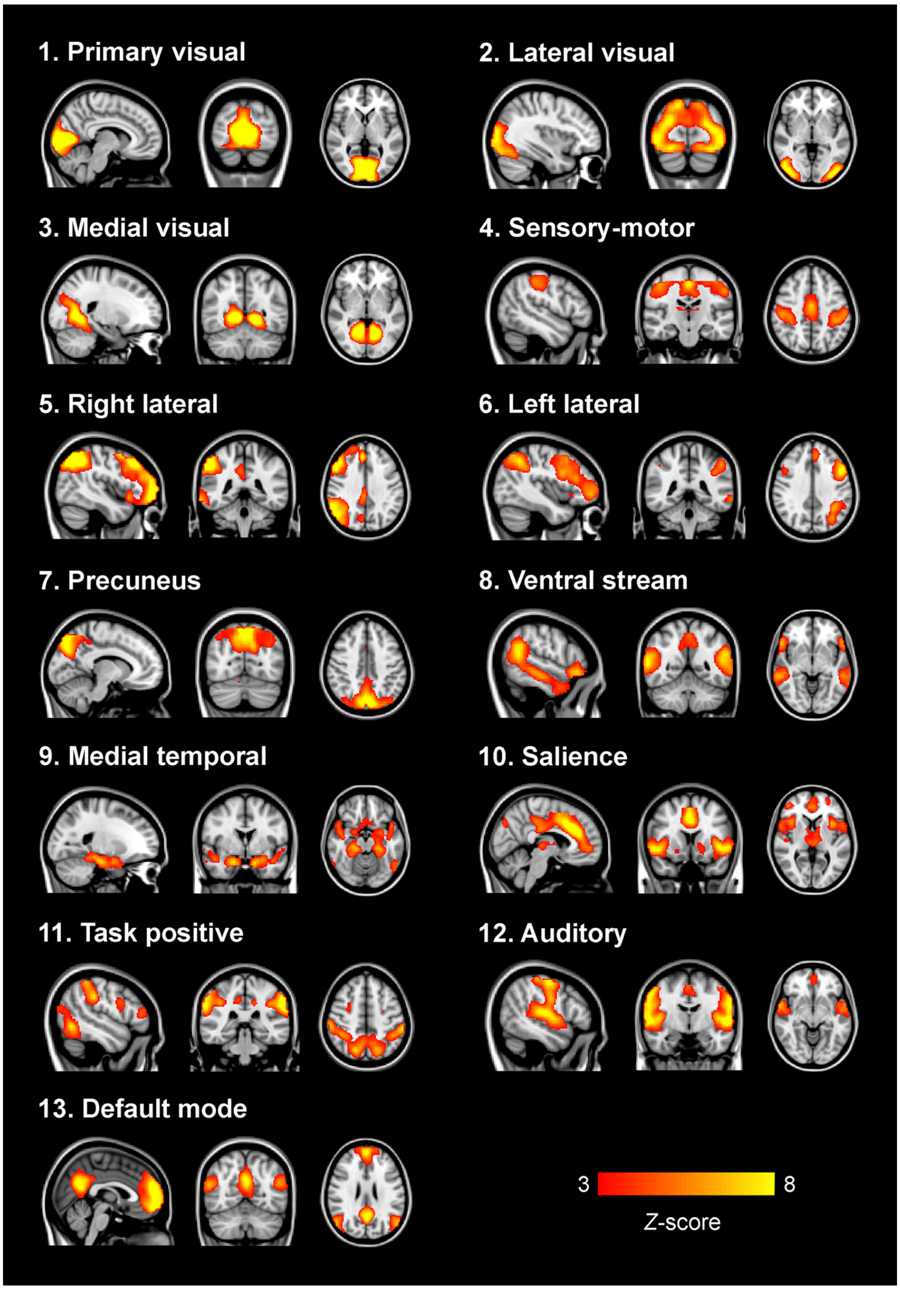

Figure 1.7: The 13 resting-state networks found in Veer et al. (2010) during fMRI, overlaid across a standard brain template. The left hemisphere is shown as the right side in these images.

comprised of at least three distinct neurocognitive systems: a Working Memory Multiple Demand component (wmMD), a Reasoning Multiple Demand component (rMD), and a Verbal Reasoning component (VR).

The wmMD component was associated with the retention and manipulation of information within working memory. Experimental tasks such as spatial working memory, digit span, and visuo-spatial working memory were found to load highly onto this system. The neural components of working memory were found in superior/ventral regions of the MDN, such as the insula/frontal operculum (IFO), the superior frontal sulcus (SFS), and the ventral portion of the anterior cingulate cortex/pre-supplementary motor area (ACC/preSMA).

The rMD component was linked to reasoning, or the transformation of information in the mind, such as in tasks of deductive reasoning, grammatical reasoning, spatial rotations, and colour-word remapping, which loaded highly onto this factor. The neural components of reasoning were found in inferior/dorsal portions of the MDN, such as the frontal sulcus (IFS), inferior parietal cortex (IPC), and the dorsal portion of the ACC / pre-supplementary motor area.

Furthermore, behavioural analysis revealed the third VR component which, rather than being part of the MDN, showed instead a neural basis outside of it, in the left inferior frontal gyrus (IFG) and the bilateral temporal lobes. The left IFG and temporal poles are regions previously shown to play a role in the Semantic Control Network (SCN) (inferior frontal gyrus, posterior middle temporal gyrus, posterior inferior temporal gyrus and dorsomedial prefrontal cortex), which overlaps with the more dorsal portion of the DMN and allows the controlled retrieval of semantic information in novel contexts (Krieger-Redwood et al. 2023). Moreover, the IFG has also been shown to be involved in analogical reasoning, one of the most abstract forms of human intelligence (Hampshire, Thompson et al. 2011). Analogical reasoning is the ability to find a common relationship between two distinct events. For example, if you were to read *"Sojo - the Deliveroo of fashion repairs"* you can instantly understand what the start-up Sojo does - it collects and brings mended clothes back to your door (Webb 2021). Analogical reasoning is argued by some to be the unique aspect of humans that defines our intelligence (Hampshire, Thompson et al. 2011). In the context of entrepreneurship and of the example given, it may indeed underlie the ability to create ideas that can be understood by others, therefore highlighting the role the semantic control network and verbal reasoning may play in entrepreneurial cognition.

Insights offered by cognitive neuroscience and the use of these novel methods offer an opportunity to study and explore the unique aspects of the human mind. The observed dissociation between working memory, reasoning and verbal components to intelligence and the association of the underlying sub-networks within the brain suggest that intelligence may come in multiple forms (Hampshire, Highfield et al. 2012), and that a single measure of intelligence may not account for the complex interaction of cognitive abilities in the human brain. These insights and differing perspectives not only expand our understanding of intelligence and cognition but may also allow us to better understand inter-individual differences in the separate dimensions of intelligence. For example, the same cognitive battery and factor analysis techniques as mentioned above were employed in a study to compare neurosurgeons to rockets scientists (Usher et al. 2021). Aerospace engineers showed better reasoning (mental manipulation) abilities, whereas neurosurgeons were better at semantic (verbal) problem-solving. Neurosurgeons could also solve problems faster than the general population but showed a slower memory recall speed. This therefore demonstrates how we can use such methods to begin to cognitively profile groups of people based on their job roles and experiences. The same methods employed with entrepreneurs would help to characterise the cognitive antecedents that contribute to entrepreneurial thinking. This nuanced understanding offers a more inclusive and comprehensive perspective on the diverse cognitive landscapes that underlie human achievement in various domains.

1.3.9 *Is it time for Cognitive Neuroscience and Entrepreneurship to Join?*

Overall, the wealth of methodology from cognitive neuroscience, which could be utilised to study entrepreneurial cognition is too broad to be covered here. Cognitive neuroscience has come a long way from initial observations by the likes of Broca et al. (1861) and (Harlow 1848), and it isn't standing still. Along with the cognitive testing and brain imaging techniques described above, further advanced techniques available today combine computational models, cognitive tasks and brain imaging. Largely led by work in cognitive science combined with statistics and machine learning, researchers essentially build computational models that model how humans learn and behave (Kriegeskorte and Douglas 2018), positioning the brain as a constant predicting machine, updating our beliefs in an ever-changing world, to optimise our thoughts and actions. One particular success of such an approach is Bayesian models, which optimally combine prior knowledge about the world (in the form of probabilities) with new incoming information (Griffiths et al. 2010). First combined with neuroimaging to model vision (Ernst and Banks 2002), such computational models are also used to understand more complicated phenomena, such as how the brain creates an optimal estimate of environmental uncertainty. Researchers have found that an optimal estimate of volatility is reflected in the fMRI signal in the ACC (Behrens et al. 2007). Hence such models provide insights into the cornerstone of entrepreneurship theories, uncertainty, and how this might be processed in the brain.

There are more approaches in which fMRI, EEG and other imaging techniques could be used in this field as discussed in Massaro et al. (2023). However, I present here the cognitive neuroscience most relevant for this thesis, with a focus on task-based fMRI, resting-state fMRI and a brief introduction to computational methods and cognitive tasks. In Chapter 2 I show how these have begun to be used in entrepreneurship research. What is striking in this introduction is the common threads that can be drawn between entrepreneurship and cognitive neuroscience research throughout history, the concurrent challenges both fields faced from a sole focus on behavioural measures, and the complimentary perspective on the unique ability of humans to create new ideas. It appears almost serendipitous for these disciplines to converge and complement one another at this point in time.

1.4 THE INTERSECTION OF NEUROSCIENCE AND ENTREPRENEURSHIP

The field of neuroentrepreneurship has emerged in the last decade, with a wealth of researchers proposing that neuroscience could address current gaps in the field of entrepreneurship. Neuroscience offers a unique opportunity to complement, deepen and advance our understanding of entrepreneurial cognition (see also Nofal et al. (2018b)). As Nofal et al. (2018a) states, a biological perspective is not to undermine the value of economic, sociological or psychological research, it is instead intended to add value and further explain variance in current models and frameworks. It can complement our understanding of why and how individuals engage in entrepreneurship. Entrepreneurship researchers have proposed that neuroscience, along with other biological approaches such as genetics and physiology, could be used to better understand antecedents of the behaviour and actions of the entrepreneur, in terms of cognition and grappling with uncertainty (Day and Boardman 2017; Krueger and Welpe 2014; Holan 2014; Nicolaou, Lockett et al. 2019; Nicolaou and Shane 2014).

Largely, two emerging streams of research have begun to apply a neuroscience lens to entrepreneurship. The first investigates neurodiversity in entrepreneurship. For example, entrepreneurs show a greater prevalence of ADHD-like and dyslexia behaviours and symptoms (Logan 2009; Wiklund, Yu, Tucker and Louis D Marino 2017a). There is thus initial evidence indicating that differences in cognitive processing underlying behaviour, such as impulsivity may be meaningfully associated with entrepreneurial action. However, while research linking ADHD-like behaviours and entrepreneurship is becoming more popular (Gunia, Gish and Mensmann 2020; Moore, McIntyre and Lanivich 2019; Verheul et al. 2015; Wiklund, Yu, Tucker and Louis D. Marino 2017b; Yu, Wiklund and Pérez-Luño 2021), researchers must tread carefully in commenting on links between the actual disorders of ADHD and entrepreneurship, so as not to imply that every characteristic of the disorder is compatible with entrepreneurship. For example, (Yu, Wiklund and Pérez-Luño 2019) show that while ADHD-like symptoms of impulsivity/hyperactivity positively relate to firm performance, inattention does not, suggesting a need to dissect the type of behaviour (and therefore cognition) that is either beneficial or detrimental to entrepreneurship.

The second approach, and the focus of this thesis, integrates entrepreneurship research with cognitive neuroscience; it dissects specific behaviour and cognition by manipulating task environments and tracking neural responses using neuroimaging techniques such as fMRI. For one example, in Chapter 2 we explore work by Laureiro-Martinez and colleagues, who have studied the neural processes behind entrepreneurial and expert decision-making (Brusoni et al. 2019; Laureiro-Martínez et al. 2015), particularly when looking at the pay-off between exploiting known outcomes or exploring alternatives. Exploring alternative decisions underlies much of the behaviour necessary in entrepreneurs – in which individuals seek something new instead of simply exploiting actions they already know to produce desirable results. Studies have begun to uncover the role of attentional control networks in the brain during explorative decision-making, using computational models, derived from neuroeconomics (Laureiro-Martínez et al. 2015). Neuroscience researchers have also begun to link such findings back to how negative emotions, such as anxiety and fear, interact with one's ability to explore alternative actions (Brusoni et al. 2019). This illustrates how neuroscientists can investigate the brain's adaptation to external environmental demands and the internal factors influencing this, thus advancing our understanding of how such cognitive processing develops, the barriers individuals face when thinking in these ways, and ultimately, how this cognition becomes the actions and behaviour we observe in entrepreneurs.

Whilst there are several review papers and opinion pieces emerging on neuroentrepreneurship, empirical research in these themes is only just beginning to emerge. As such, it is still rather limited, as we explore and describe in chapter 2, where we detail the themes that are emerging and where we show mutual collaboration across the disciplines.

1.5 DEFINITIONS

Defining Entrepreneurs

Perhaps the most difficult question in the study of neuroentrepreneurship that scholars are faced with is "How did you define an entrepreneur", meaning *who* are the people we recruit and study? This is a highly likely, and non-trivial question, particularly when wishing to apply neuroscientific methods, for which the standard is to contrast groups, e.g., patient versus healthy groups, or to diagnose a group based on standardised measures, such as those from the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (Guha

2014). Being an entrepreneur is not a condition and there is therefore no diagnosis for it. In fact, you could argue that the whole endeavour of entrepreneurship research is exploring this very definition. For example,look to the questions posed by research throughout the first section 1.2: *Who is an entrepreneur? How does an entrepreneur think? What does an entrepreneur do? Why do some people recognise opportunities whereas others do not? Why do some try to develop such opportunities whereas others do not?*

Two main types of entrepreneurship definitions are thought to exist. One focuses on entrepreneurship as an 'occupational category', of mainly self-employed and business owners, while the second category focuses on entrepreneurial action and on the actions and processes involved in identifying, creating and/or exploiting opportunities (Gorgievski and Stephan 2016). A consensus among many scholars is that entrepreneurship is a dynamic *process*, in which different skills may be necessary at different stages of success and/or experience (Robert A. Baron 2006).

I position that both definitions could be relevant to neuroentrepreneurship research. We can define entrepreneurship as a process in which people identify, create and/or exploit opportunities, whilst also defining groups of entrepreneurs as those who show real-life evidence of this identifying, creating and exploiting, which, in most cases is likely to be in the form of starting a business. As described in (Shane and Venkataraman 2000) 20% to 50% of the population are thought to engage in entrepreneurial behaviour, which might be even higher if we were to consider entrepreneurship as simply identifying, creating and/or exploiting opportunities. Therefore we cannot assume that this thinking, cognitive or neural processing is unique only to business owners. We *can* otherwise study and define groups of people that have the most experience and expertise in thinking in this way, which is most likely those who have been involved in the creation of new, disruptive ventures, and compare them to selected control groups of people who have no evidence of such experience.

A New Definition: Entrepreneurial Neurocognition

A further notion that is important to define is the *what*, meaning the topic of study in our entrepreneurial research using neuroscience. To recap, for cognitive scientists, cognition is defined as the processes by which sensory input is transformed, reduced, elaborated, stored, recovered and used (Neisser 1967), while in the entrepreneurship literature entrepreneurial cognition has been 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, L. Busenitz et al. 2002). We propose a combination of these definitions to address the neuroscience of entrepreneurship and hope that, in the same way, this will lead to increased collaboration between disciplines. To avoid confusion with the multifaceted entrepreneurial cognition described previously in the literature, I make a clear distinction between this and our interest in neurocognitive function. Neurocognitive function refers to anything involving cognitive functioning and associated structures and processes of the brain. The APA definition of neurocognition is as follows: *cognitive processes or functioning understood in relation to the specific neural mechanisms by which they occur in the brain and any impairment of these mechanisms* (A. Dictionary 2022).

Therefore, I define *entrepreneurial neurocognition* as the neural structures and processes in the brain underlying the way information is processed, utilised, and mediated, which enables someone to identify, evaluate, create, and/or exploit opportunities.

1.6 Summary and aims of the original research presented in this thesis

In this introduction, I have provided an essential background to entrepreneurship and cognitive neuroscience research to understand how the two disciplines converge and complement one another. This thesis will enable new insights into the *thinking skills* (cognition) of entrepreneurs. While theories on entrepreneurial cognition continue to emerge, their development is hindered and largely separate from understanding the brain mechanisms gained from cognitive neuroscience over the last few decades. I position this thesis to exist within the theoretical framework of entrepreneurial cognition, in the form of; mentalism: the study of mental states and resources which either stimulate or proceed entrepreneurial thinking, and process-orientation: the interaction of the brain and environment that develops such mental states.

The unique addition of this thesis is to explore these components in relation to neurocognition, the neural correlates that necessitate entrepreneurial thinking in the brain. In particular, I discuss relevant theories of effectuation from the entrepreneurial cognition literature, as the means by which entrepreneurs create newly imagined ideas by working with the resources to hand (Sarasvathy 2001). This concept of innovation and creativity, despite the inevitable uncertainty, guides the empirical work in this thesis, as I aim to study the neural mechanisms and cognition of entrepreneurs.

My approach entails conducting empirical studies utilising cognitive neuroscience methodologies, with an emphasis on data-driven exploration. By employing neuroscientific techniques to scrutinise entrepreneurs' cognitive processes, we have the opportunity to enrich and challenge existing assumptions about entrepreneurial thinking, moving beyond reliance on self-report methods alone.

Examining the neural mechanisms underlying entrepreneurial thinking will allow us to determine the extent to which this is stimulated internally by the individual, externally by the environment in which they find themselves, or a mixture of both. Without the methods developed over decades in neuroscience, attempts to identify brain processes predictive of entrepreneurial cognition and promises of understanding the unconscious intuitive processing of entrepreneurs are likely to remain unfulfilled. Systematically examining: 1) what defines an expert entrepreneur, 2) what their predispositions, stable (trait) and dynamic (cognitive) characteristics are, and 3) how their brains respond to differing environments provide a comprehensive starting point for work in entrepreneurial neurocognition. There has been a tendency for entrepreneurship research to take binary and polarised views of what should be studied; only look at one aspect of the entrepreneur, their traits *or* their cognition, and study it as a profession *or* a way of thinking. Instead, we show that both approaches can be used to build a comprehensive understanding of entrepreneurship, with the additional layer offered by exploring the neural processing that might underlie the abilities of key facets of entrepreneurship.

This thesis comprises four main parts: a systematic review and three empirical studies. First, we review what current empirical work has used neuroscience methods to study entrepreneurs. Second, we explore the most relevant entrepreneurial competencies for us to study. Third, through a large online study, we explore entrepreneurs' personality and neurocognitive profiles. Fourth, we present the results of an MRI study using task-based and resting-state fMRI approaches on groups of entrepreneurs and working professionals to unveil the neural mechanisms behind entrepreneurial thinking.

The original contributions of this thesis, organised by chapters, are as follows:

1. In Chapter 1 I provide the background to the convergence of cognitive neuroscience and entrepreneurship, creating an agenda for how entrepreneurship can be studied using neuroscience and defining a new term, 'entrepreneurial neurocognition.'

2. In Chapter 2 I critically review what empirical work has been done at the intersection of cognitive neuroscience and entrepreneurship research to explore what we have already uncovered about entrepreneurial neurocognition and to set a future agenda.

3. In Chapter 3 I use machine-learning techniques to test the assumptions about the competencies of entrepreneurs at novice and expert levels.

4. In Chapter 4 I test hypothesis-driven and data-driven approaches to the personality and neurocognitive profile of an entrepreneur.

5. In Chapter 5 I use functional MRI to test how entrepreneurs create new ideas in two differing conditions, and assess the neurocognitive differences between entrepreneurs and working professionals both when undertaking a task and at rest.

Finally, in Chapter 6 I discuss what these findings mean in terms of our understanding of entrepreneurship in general and of entrepreneurial neurocognition. I also discuss the limitations of the original work presented here. Finally, I lay out the practical contributions that such research can make to the training and development of entrepreneurship.

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2

CHAPTER 2: THE ENTREPRENEURIAL BRAIN: CURRENT AND FUTURE POTENTIAL OF JOINT COGNITIVE NEUROSCIENCE AND ENTREPRENEURSHIP RESEARCH.

Previous version available as pre-print at https://osf.io/preprints/psyarxiv/ayve7/

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2.1 PREFACE

The aim of this thesis is to explore the capability of individual entrepreneurs to create and invent new possibilities never imagined before, given the current materials and resources they have access to (mentalism), the context they are within, how this thinking develop within someone (process-orientation) and the corresponding neural correlates of such innovative thinking. I wish to do this by applying neuroscience methodology to the mentalism approach. To successfully achieve this we must ask - what aspects of the entrepreneur's mind have been, or should be studied?

Before we delve into studying the brains of entrepreneurs, as with all research, an assessment of the current state of the field is required. I start by looking at what work has successfully been done and published that can inspire and segment the lines of thinking emerging in such a new discipline. In this chapter I take a systematic approach to findings the current empirical work that uses cognitive neuroscience methodology to study entrepreneurship. The reason I focus only on empirical work is to differentiate from the wealth of review and opinion pieces that comment on how neuroscience could or should be used. Instead I show where such empirical work has been done and provide an in-depth analysis into these studies, what they tell us and how they can inspire more open questions in the field of neuroentrepreneurship. The aim throughout this thesis is to show a different way we might study the entrepreneur's mind, staying evidence-based and data-driven, while considering, complimenting and where necessary, challenging, entrepreneurship research with neuroscience tools, . The translation between neuroscience and entrepreneurship will be best achieved as an ongoing and evolving conversation. To begin the conversation, we must first ask, what cross-collaborative research has been achieved up until now?

2.2 ABSTRACT

Purpose: Can insights and methods from cognitive neuroscience help to understand the distinctiveness of the entrepreneur's brain? Whilst there is a thirst for more neuroscience studies in entrepreneurship research (*neuroentrepreneurship*), empirical work has not yet really taken off and thus our understanding of the entrepreneur's brain is limited and underdeveloped.

Approach: This paper explores where cognitive neuroscience methods have already been used in entrepreneurship research, as a basis for future interdisciplinary work.

Findings: We critically appraise the current empirical research on entrepreneurial neurocognition that met our search criteria in the themes of (1) impulsivity and risk-taking (2) decision efficiency: exploration and uncertainty (3) emotional judgements and (4) interpersonal trust and social cognition. This is followed by a discussion on emerging empirical research in (5) opportunity alertness and (6) creativity, for which a stronger theoretical basis of neurocognition must be developed.

Originality: This is the first review of the cognitive neuroscience methods (e.g. measuring activity and processes within the brain) used to study entrepreneurs, focusing on research at the intersection of both fields. It is also the first to be specific about the new lines of enquiry and methods which would, in the future, continue to integrate cognitive neuroscience and entrepreneurship research.

Practical implications: This paper provides a reference point for researchers to embark on cross-disciplinary work in *neuroentrepreneurship*.

Social implications: Understanding the cognitive and neural processes that drive entrepreneurial thinking would generate even deeper insights for educators and policy makers seeking to support entrepreneurship and its education.

Limitations: Little relevant empirical work has been carried out to date, in small samples and in heterogeneous populations, limiting the scope of this review to a few specific topics.

2.3 INTRODUCTION

2.3.1 *Introduction*

Cognitive neuroscience presents an exciting future angle of entrepreneurship research, with researchers proposing that its methods can help to develop a better understanding of entrepreneur's behaviour and actions (Day and Boardman 2017; Holan 2014; N. Nicolaou and S. Shane 2014; Westhead, Ucbasaran and Wright 2009). Specifically, cognitive neuroscience has the potential to deepen and advance our understanding of entrepreneurial cognition (see also Nofal et al. (2018)). However, the lack of discussion around common domains of interest in neuroscience and entrepreneurship impedes empirical neuroentrepreneurship research to date.

There has long been a thirst to understand what makes some people strive to engage in entrepreneurship and create something new, despite the many challenges and uncertainty they face (A. Corbett et al. 2018; Grégoire, A. C. Corbett and Mcmullen 2011). Entrepreneurship and neuroscience academics have studied how people think, using the term *cognition* to describe the underlying hidden mental processes that ultimately drive human decisions and actions. However, the definitions and methods used to study cognition differ between the fields of entrepreneurship and neuroscience which hinders a fuller utilisation of neuroscience in the study of entrepreneurship. This is because the phenomena being studied in a neuroscience study and even the way cognition is conceptualised is not developed in a way that is conducive to both fields. As further described in the theoretical background of this paper, entrepreneurship scholars access the entrepreneur's mind through retrospective description of participants' internal events and experimenters' coding of cognitive scripts, schemas and knowledge-structures, whilst cognitive neuroscientists aim to directly measure what the mind is doing, by way of neural activity in the brain.

To provide a clearer path forward, we review the current state of research that uses neuroscience methodology in entrepreneurship studies to outline a framework for cross-collaboration between cognitive neuroscience and entrepreneurship research - *neuroentrepreneurship*. After laying out the theoretical background and methodology, we present our review findings in two parts. Firstly, we discuss the themes in which empirical neuroscience work has already begun. Secondly, we discuss emerging areas for exploration and collaboration, succinctly demonstrating what has been done, and what could be done, to better understand the entrepreneurial brain. The topics discussed here are by no means reflective of the full potential of this cross-collaboration; instead, they offer an early discussion of current empirical work, with the addition of a reflection on the cognitive neuroscience methods and concepts that could provide further mutual benefit. As many scholars do not possess expertise in both entrepreneurship and neuroscience research, we argue that the approach taken in this paper simplifies and guides a clear way forward.

2.3.2 *Theoretical Background*

What is cognitive neuroscience? A real-time view of the mind

Cognitive neuroscience deals with the structure and function of the nervous system and the brain, allowing an insight into hidden processes and mechanisms underlying thinking and cognition. Cognition, from a cognitive neuroscience perspective, argues for the underlying scientific assumption of parsimony, that the most straightforward underlying processes naturally explain complex phenomena. For example, the sciences have traditionally defined cognition as the processes by which sensory input is transformed, reduced, elaborated, stored, recovered, and used by the individual (Neisser 1967). Specifically, the prefrontal cortex and its connection to other regions across the entire brain are central in the process of cognitive control and so-called executive functions, which enable the ability to *learn the rules of the game* and carry out any intended action (Miller, 2000). This way of studying cognition has helped us understand the neural correlates of constructs such as, among others, attention, consciousness, learning, memory, language, decision-making, emotions, intelligence and social cognition (Posner and DiGirolamo 2000). Such work has uncovered the brain regions, networks, and computations that underlie specific *neurocognitive* processes that are involved in many concepts conducive to entrepreneurship, such as loss/reward processing, learning, decision-making, attention, goal-orientated action and cognitive control (Camara, Rodriguez-Fornells and Münte 2009). For example, researchers have shown in healthy participants how people learn new information and update their beliefs in volatile and changing environments, the type of environments entrepreneurs commonly operate within (Behrens et al. 2007).

Core methods used in cognitive neuroscience to explore the relationship between behaviour and cognitive structure and function include neuroimaging (such as Magnetic resonance imaging (MRI), electroencephalogram (EEG), positron emission tomography (PET), Functional near-infrared spectroscopy (fNIRS), and Magnetoencephalography (MEG)), but also behavioural and cognitive assessments, eye-tracking, neuropharmacological interventions and measures, as well as advanced computational modelling of human behaviour (Purves et al. 2008). We briefly describe the most relevant cognitive neuroscience methods in Table 2. Due to the nature of cognitive neuroscience research, such methods are often used in lab-based settings, with the aim to gain direct measures of the brain and cognition in *real-time*.

Table 2: Relevant Methods Used in Cognitive Neuroscience Research

Method	Description
Cognitive/Behavioural Tasks	Short game-like tasks are commonly used in neuroscience studies, which tap into different neurocognitive functions such as attention, working memory, reward processing, and more. Outcome measures can be performance or reaction times (Kester and Kirschner 2012).
Computational Neuroscience – Modelling Behaviour	A method of analysis which fits mathematical models to experimental data to uncover algorithms thought to underlie the brain's computations (Wilson and Collins 2019).
Eye-tracking	Eye-tracking can reflect cognitive processes. For example, it can assess an individual's visual search and attentional bias towards certain stimuli (Hayhoe and Ballard 2005; Kowler 2011).
Electroencephalogram (EEG)	Measures event-related potential (ERPs) in the brain via electrical signals picked up by sensors on the scalp of individuals, with good temporal resolution (it can measure neural activity within milliseconds), but mostly restricted to cortical areas (Jackson and Bolger 2014).
MRI – Functional Magnetic Resonance Imaging (fMRI)	Blood-Oxygen-Level-Dependent (BOLD) imaging measures the functional activity of the brain during active cognitive tasks (task-based fMRI) or at rest (resting-state fMRI). This is an indirect measure of neural activity that is modeled from the hemodynamic response of neurons in the brain (Lewin 2003).

MRI – Structural Magnetic Resonance Imaging	Structural MRI measures the volume of white/-grey matter across the whole brain or areas of interest, but also cortical thickness and folding. Other techniques, such as Diffusion Tensor Imaging (DTI), can help visualize the 'tracks' of thick bundles of neurons in the brain (A. L. Alexander et al. 2007).
PET – Positron Emission Tomography	PET is a nuclear medicine imaging technique. Using invasive radioactive 'tracers', it can image blood-flow, metabolism, and receptor-binding in the brain (Muehllehner and Karp 2006).
fNIRS – Functional near-infrared spectroscopy	More tolerant to movement than MRI, fNIRS is an optical imaging technique that measures blood oxygenation levels by shining a near-infrared light into the head and measuring how much light comes back (Pinti et al. 2020).
MEG - Magnetoencephalography	MEG is a functional neuroimaging technique which measures from outside the head. It detects magnetic field changes caused by the electrical activity of the brain as soon as they happen (Ioannides 2009).

How is entrepreneurs' cognition understood?

Cognition, from the perspective of entrepreneurship research, refers mainly to the knowledge structures people use in judgements and decisions that relate to opportunity evaluation, creation and growth (Cacciolatti et al. 2016; R. K. Mitchell, Busenitz et al. 2002). Cognition seeks to explain how entrepreneurs connect and piece together previously unconnected information to identify or create new products and gather resources to start and grow ventures. There is already a rich field of entrepreneurial cognition research. This examines cognitive constructs such as cognitive biases, heuristics, opportunity evaluation, and variables such as overconfidence, planning fallacy, self-efficacy, regretful thinking, entrepreneurial decisions under time pressure, emotionally charged decisions and methods to deal with uncertainty (R. K. Mitchell, Busenitz et al. 2002; Shepherd, Williams and Patzelt 2015). Moreover, situated models of cognition, which also consider the social and environmental context that entrepreneurs operate and think within, have also been explored (R. K. Mitchell, Randolph-Seng and J. R. Mitchell 2011).

The field of entrepreneurial cognition is well developed, however as argued by Grégoire, A. C. Corbett and Mcmullen (2011), entrepreneurial cognition research to date is a *victim of its own success*, with an abundance of empirical and theoretical studies to understand what 'one has'. So far it has failed to understand cognition as a dynamic process. We argue that, to further develop, the field should move more towards understanding what 'one does' and draw more attention to the dynamics that occur between mind, environment and action. Neuroscience provides a set of complementary tools to tackle this agenda allowing 1) the ability to directly manipulate the task environment, 2) the ability to measure hidden processes of the mind in response and 3) the ability to measure the dynamic actions and performance of the participant (i.e., the entrepreneur in our case) and thus the relationship between the environment and the mind.

How can neuroscientists and entrepreneurship scholars co-design experiments to better understand entrepreneurial cognition?

To date, progress in understanding the fine-grained cognitive and neural processes that are involved in entrepreneurship has been slow; there is a dearth of empirical entrepreneurship studies that use neuroscience methods. This may partly be due to differences in the *level* of understanding of cognition from neuroscience and entrepreneurship (Krueger 2009). We argue that these differences in the level of understanding come from the methods used. The methods entrepreneurship scholars most often use are self-report surveys and interview techniques, whilst neuroscientists tend to use neuroimaging methods and cognitive tasks. Whilst entrepreneurship methods provide a higher-level, more complex view of cognition, aided or implicated by the participant's ability to express their internal world, and the experimenters or survey's ability to reliably quantify this psychology (Chan 2010), neuroscience methods provide a deeper-level, unbiased, real-time view of the processes in the brain, but that could be called reductionist and comparatively simplistic. Nicos Nicolaou et al. (2019) set out the potential for neuroscience research, stating it can add value to the field of entrepreneurship in four ways:

1. Creating an opportunity to study hidden mental processes.
2. Informing discriminant and convergent validity between theories.
3. Examining the antecedents and the temporal ordering of entrepreneurial cognition.
4. Refining, constraining, and adjudicating between different theoretical perspectives.

Demonstrating the cross-collaborative field is well versed in where neuroscience adds value in the ways outlined above, and why neuroscience adds value from the practical perspective, through the introduction of neuroscience methods to observe hidden mental processes within the brain. Under-developed however is an understanding or framing of exactly what cognitive processes and neural correlates may be of highest relevance to study in the entrepreneur's brain, and how these can be tested with neuroscience methods.

Despite differences between the fields, a commonality is the subject studied, the human entrepreneur, their mind, actions and behaviour. Both the neuroscientific and entrepreneurial fields aim to understand the differences in human cognition that result from or precede entrepreneurial experiential learning, and how the dynamics of the human mind interact with the current environment to produce action. Cross-collaboration could further explain the cognitive and neural drivers and reinforcers of entrepreneurial behaviour in the brain (Holan 2014), and yet also contribute to neuroscience through further understanding complex cognitions and interindividual differences involved in decision-making and goal-oriented action. We aim to bridge the gap between the two fields, to show exactly what areas of cognition are relevant to study for both the neuroscientist and entrepreneurship scholars and demonstrate examples of where this has been achieved in empirical studies to date. Here we elaborate how entrepreneurial cognition can be studied through a neuroscience lens, defining these concepts with the unifying term - entrepreneurial neuro-cognition. Entrepreneurial neuro-cognition refers to the cognitive processes and corresponding neural correlates of entrepreneurial decision-making and behaviour. We hope that this will help to further drive the future agenda of the cognitive perspectives of entrepreneurship, i.e., understanding what *one does* (Grégoire, A. C. Corbett and Mcmullen 2011).

2.4 RESEARCH METHODOLOGY

Literature Search

We searched for published peer-reviewed empirical papers using cognitive neuroscience methodology to study entrepreneurship, inclusion/exclusion criteria and rationale for which is shown in Table

3. This paper is termed a quasi-systematic narrative review. Whilst we use rigorous systematic search approaches to identify the papers to discuss - rather than aiming to combine observations statistically to assess the power of the existing evidence, we aim to synthesise the existent studies - where the breadth of available observations are small and the evidence base is not yet mature. We take this approach; 1) due to the cross-disciplinary nature of this subject, 2) the paucity of this research and therefore 3) the need to assess current empirical work and create discussion for themes beyond the limited work that has already been done.

We differ in the approach taken by prior research performing a general bibliometric analysis of papers *related to neuroentrepreneurship* (Cucino et al. 2021), as this approach would provide no assessment of the cognitive neuroscience methods used in empirical work and therefore on a more practical and actionable level, what research could be done in the future. Instead, in the same way that Blackburn and Kovalainen (2009) reviewed and categorised the current and future directions of research in small firms using a narrative approach, we synthesise the empirical research using cognitive neuroscience methodology to study entrepreneurship, in 2 themes: current and emerging. The *current* themes meet all search criteria in Table 3, whilst *emerging* themes represent cornerstone theories from the entrepreneurship literature (opportunity alertness and creativity) that are beginning to emerge as areas of interest in neuroentrepreneurship. The latter do not yet fulfill all criteria to be included in the original search.

Table 3: Inclusion/Exclusion Criteria for the Systematic Search of Papers that use Cognitive Neuroscience Methodology in the Study of Entrepreneurship

Criteria	Rationale
From 1976 - 2023	This was the date of the first paper present in our initial search.

We included cohort studies or cohort (longitudinal) studies using cognitive neuroscience methods in entrepreneurs.	We wanted studies which collected experimental data, using cognitive neuroscience methods, in the study of entrepreneurs and/or entrepreneurial cognition.
We included interventions involving Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Near-infrared Spectroscopy (NIRS), Electroencephalogram (EEG), Eye tracking, magnetoencephalography (MEG), behavioural assessment/task or cognitive assessment/task.	These are common methods in cognitive neuroscience (Purves et al. 2008).
We excluded papers that had no empirical data-collection or analysis. We excluded studies if they were not peer-reviewed, such as book chapters, conference papers and pre-prints.	We only included peer-reviewed papers as with neuroimaging methods, many mistakes in analysis and interpretation can be made, such as reverse inferences and circular analysis (Poldrack 2006). These are often scrutinized best through peer-review practices.
We excluded studies if the methods used were only psychological or entrepreneurship surveys.	Our focus is studies which use cognitive neuroscience methods specifically. There are prior reviews which focus on entrepreneurial cognition and psychology (Gorgievski and Stephan 2016; Grégoire, A. C. Corbett and Mcmullen 2011).

Search Methods

We followed PRISMA guidelines (Page et al. 2021) to perform the systematic literature search, as demonstrated in Figure 1. Using English Boolean search terms for our criteria (in Supplementary Material) we searched both; Scopus and Business Source Complete (BSC). Scopus is a multi-disciplinary abstract and citation database for peer-reviewed research in life science, social science, physical and health sciences and BSC is a database for peer-reviewed business journals. After screening, relevant papers were ran through Citation Chaser, for a forward and backward citation analysis (Haddaway, Grainger and Gray 2021).

Screening and Selection

The search in Scopus produced 647 articles. The search in BSC produced 327 articles. Initial screening was carried out on the database result, reading titles and abstracts. Removing obviously irrelevant papers and removing those only discussing personality and survey data (i.e. specifically not using a measure of neural activity or function as a dependent variable) reduced the pool to 75 papers on Scopus and 20 on BSC. Further scrutiny, retaining only the empirical studies, led to 23 articles on Scopus and 6 on BSC. Three of the 6 papers on BSC were identical to some found in Scopus and so were removed. Thus 26 articles underwent full reading. An additional article, not found in any of the searches, was also identified.

Eight papers met our criteria for current empirical work and 2 emerging, in entrepreneurship using cognitive neuroscience methods, as shown in Table 4. We then ran a forward and backward citation on these 10 papers. 2 papers could not be run through, due to having no DOI information. 663 referenced articles and 222 cited articles were exported to Mendeley (Mendeley Desktop Version 1.19.8) and titles

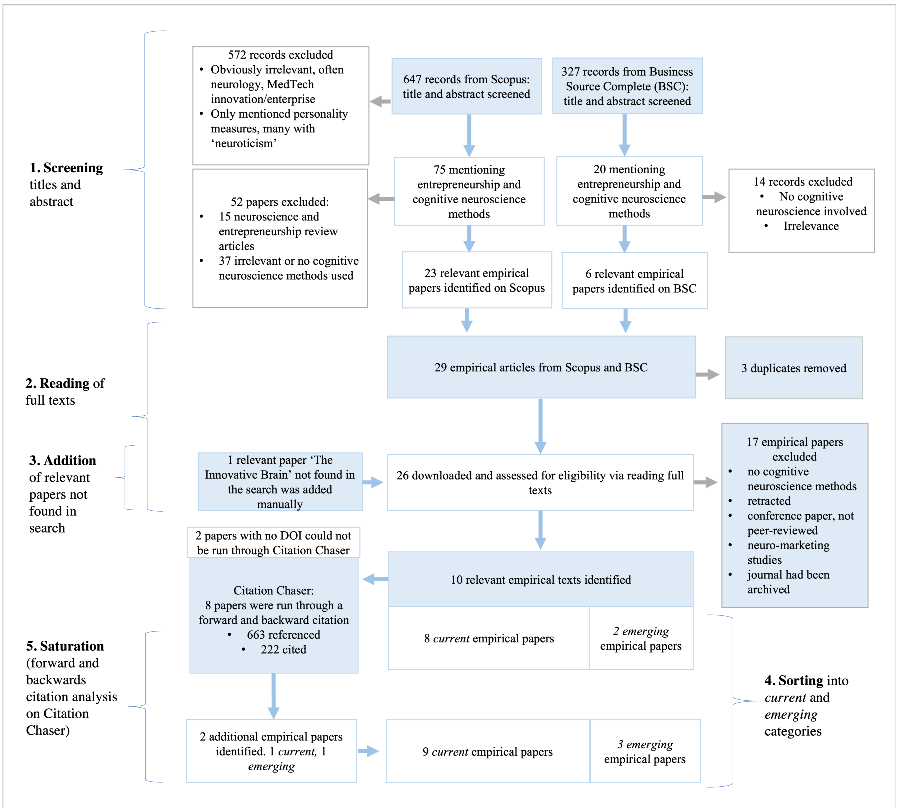

Figure 2.1: The systematic search methodology used to identify peer-reviewed empirical journal articles that use cognitive neuroscience methods to study entrepreneurship. Our methodology was split into stages of; 1. Screening titles and abstract 2. Reading of full texts, 3. Addition of relevant papers not found in the search, 4. Sorting into current and emerging categories and; 5. Saturation (forward and backward citation analysis on Citation Chaser).

and abstracts screened for relevance, this lead to the inclusion of 1 extra relevant current research paper and 1 emerging paper.

Table 4: Articles that Use Cognitive Neuroscience Methodology in the Study of Entrepreneurship.

Article Titles	**Author(s)**	**Journal**	**Year**
Are behavioral and electrophysiological measures of impulsivity useful for predicting entrepreneurship?	Fisch, Franken & Thurik	Journal of Business Venturing Insights	2021
Founder passion, neural engagement and informal investor interest in startup pitches: An fMRI study	Shane, Drover, Clingingsmith & Cerf	Journal of Business Venturing	2020
Why and how do founding entrepreneurs bond with their ventures? Neural correlates of entrepreneurial and parental bonding	Lahti, Halko, Karagozoglu & Wincent	Journal of Business Venturing	2019
Trust cognition of entrepreneurs' behavioral consistency modulates investment decisions of venture capitalists in cooperation	Yang & Li	Entrepreneurship Research Journal	2017
Entrepreneurial and parental love—are they the same?	Halko, Lahti, Hytönen & Jääskeläinen	Human Brain Mapping	2017
Frontopolar cortex and decision-making efficiency: Comparing brain activity of experts with different professional background during an exploration-exploitation task	Laureiro-Martínez, Canessa, Brusoni, Alemanno & Cappa	Frontiers in Human Neuroscience	2014

Brain cortical organization in entrepreneurs during a visual stroop decision task	Ortiz-Terán, Turrero, Santos, Bryant & Ortiz	Neuroscience and Neuroeconomics	2013
Does the ability to make a new business need more risky choices during decisions? Evidences for the neurocognitive basis of entrepreneurship	Nejati & Shahidi	Basic and Clinical Neuroscience	2013
The Innovative brain	Lawrence, Clark, Labuzetta, Sahakian & Vyakarium	Nature Commentary	2008

2.5 Results

2.5.1 *Part 1: Current Empirical Research Themes*

Our search returned 9 current peer-reviewed empirical papers using cognitive neuroscience methods in entrepreneurship research. Three studies involved EEG, 4 used functional magnetic resonance imaging (fMRI), and 2 employed cognitive testing, as summarised in Table 5. To guide future work, this limited empirical research can be split into broad themes which measure entrepreneurial neuro-cognition in (1) impulsivity and risk-taking (Fisch, Franken and Thurik 2021; Nejati and Shahidi 2013; Ortiz-Terán, Turrero et al. 2013) (2) decision efficiency: exploration and uncertainty (Laureiro-Martínez, Canessa et al. 2014) (3) emotional judgments (Halko et al. 2017; Lahti et al. 2019; Lawrence et al. 2008) and (4) interpersonal trust and social cognition (S. Shane et al. 2020; Yang and Li 2017). We next discuss the findings and contributions of these studies in more detail to elaborate our understanding of entrepreneurial neuro-cognition and derive implications for future work on entrepreneurial neuro-cognition.

Table 5: Sample and Methods of Current Empirical Studies at the Intersection of Cognitive Neuroscience and Entrepreneurship

Theme	References	Sample	Grouping criteria	Methods
Impulsivity and Risk-Taking	(Fisch et al., 2021)	Dataset 1: n = 133 52F: 81M Mean age: 22.2 Dataset 2: n = 142 65M:76F Mean age = 20.6	None. All were non-founders, 'nascent entrepreneurs'. Entrepreneurialism was based on continuous measures.	EEG, Cognitive tasks (Go-no-go, Erickson-flanker, BART), Self-report impulsivity (ImpSS-8 scale and ADHD-symptom questionnaire)
	(Nejati Shahidi, 2013)	Entrepreneurs n = 20 mean age = 24.04 17M: 3F Controls n = 20 Mean age= "age-matched" but not specified	Entrepreneurs: Directors of Business Incubators based at Shahid Beheshti University and the University of Tehran in December 2011 Controls: postgraduate students in Shahid Beheshti and Tehran Universities	The Balloon Analogue Risk Taking Test (BART)

	(Ortiz-Terán et al., 2013)	Entrepreneurs N = 25 Mean age = 33 non-founders n = 25 mean age = 31	Entrepreneur: founder entrepreneur who created at least one company. Control: never founded a venture, no entrepreneurial background	Stroop reaction time task; EEG
Decision Efficiency: Exploration and Uncertainty	(Laureiro-Martínez et al., 2014)	Entrepreneurs n = 24 Mean age = 35.5 4F:20M Managers n = 26 Mean age = 34.65 7F:19M	Entrepreneurs: Founded a business based on their idea and actively involved in running the business. Managers: working inside an organization and being constantly involved in strategic decisions in their areas of expertise	fMRI, Cognitive tasks (exploit/explore bandit task), Computational model (Kalman filtering algorithm and softmax choice)
Emotional Judgements	(Lawrence et al., 2008)	Entrepreneurs n = 16 no age or gender data Non-founding managers n= 17 no age or gender data	Entrepreneurs: 'Silicon Fen' cluster of high tech companies around Cambridge UK Managers: non-founding, no experience of venture creation, matched for age and intelligence	Cognitive tasks (Cambridge Gambling Task Tower of London)

	(Halko et al., 2017; Lahti et al., 2019)	Entrepreneurs n = 21 mean age = 33 0F:21M Fathers n = 21 mean age = 35 0F:21M	Entrepreneurs: growth orientation, not serial entrepreneur. From entrepreneurial organisations Helsinki Fathers: no entrepreneurial background, From daycare centres in the city of Helenski	fMRI, Novel behavioural tasks involving pictures of children and firm logo
Interpersonal Trust and Social Cognition	(Yang Li, 2017)	Experienced VCs n = 10 Mean age = not specified 0F:10M Inexperienced VCs n = 8 mean age = not specified 0F:8M	All from the Ling Hang Incubator in Heilongjiang Province in China. Experienced VCs: based on weighted mean of cumulative investment rounds from 2012-2016 Inexperienced VC: lacked investment experiences	EEG (FRN, P300), Cognitive tasks (trust game)
	(Shane et al., 2020)	Investors n = 15 Mean age = 29 5F:10M	None. All investors (those who had personally invested in a business start-up that wasn't their own, excluding VCs and angel investors)	fMRI, Novel behavioural task – shown pitches with high

Note: this table shows peer-reviewed empirical studies which use cognitive neuroscience methods in the study of entrepreneurship. These papers were identified from systematic search of the literature on Scopus and Business Resource Complete, and forward and backward citation analysis on Citation Chaser. We detail the theme being studied, the sample size, age, gender, grouping and methods for each paper.

1. *Impulsivity and Risk-Taking*

While a growing stream of research explores the relationship between Attention Deficit Hyperactivity Disorder (ADHD)-like symptoms, impulsivity, risk-taking tendencies and entrepreneurship (Gunia, Gish and Mensmann 2020; Moore, McIntyre and Lanivich 2019; Verheul et al. 2015; Wiklund et al. 2017; W. Yu, Wiklund and Pérez-Luño 2021), our search identified only three empirical papers that used neurocognitive measures to assess impulsivity and risk-taking in entrepreneurs. The first, based on two large separate datasets of 133 and 142 university students, used a cognitive task of impulsivity and EEG measurements to assess whether behavioural and electrophysiological measures are more useful predictors of entrepreneurship than self-reported measures of impulsivity, (Fisch, Franken and Thurik 2021). Through the testing of multiple regression models, varying the self-report, cognitive and neural predictors of entrepreneurship, they found no cognitive impulsivity or EGG measures to be predictive of *entrepreneurialism*. However, in the first dataset only self-reported impulsivity showed significant association with entrepreneurialism. Cognitive measures were obtained from a Go/No-Go task (measuring motor control impulsivity, in which participants respond by clicking a button for certain stimuli and not for others) and the Eriksen Flanker Task (testing response inhibition, in which participants ignore interfering stimuli and focus on their target). Whilst thorough, and consisting of a large sample size, this study was complex as authors tested 84 coefficients in the models for dataset one and 49 in models for dataset two. Moreover, *entrepreneurialism* seems a poor proxy of any experience in entrepreneurship, measured only by self-report questionnaire scores of Entrepreneurial Personal Attitude, Subjective Norms, Internal Locus of Control, Intention, Intention Percentage, Choice and Orientation. Overall, the authors concluded that, whilst self-report measures of impulsivity were predictive of the entrepreneurial constructs, EEG and behavioural measures of impulsivity added no further insight to predicting the *entrepreneurialism*.

A second study measured the brain's cortical organisation during a cognitive task called the visual Stroop task, along with EEG and personality dimensions (Ortiz-Terán, Agustın Turrero et al. 2013). The Stroop task involves a variety of verbal colours (blue, red, green) printed in visual colours different from the word e.g., the verbal word blue, would be printed in visual colour red. The target was for people to react when they saw a prompted visual colour and not a written one. The sample consisted of 25 founder entrepreneurs and 25 age-matched nonfounders/nonentrepreneurs (NFNE) controls. The methodology included EEG, measuring the N200, P300 and N450 event-related potentials, due to their sensitivity to *higher order cognitive processes* such as selection and working memory. Findings showed the N200 to be shorter in the bilateral supplementary motor area, linked to reduced inhibition and faster reaction times in entrepreneurs during the Stroop task. In addition, the N450 was longer in entrepreneurs, associated with greater activation of anterior frontal regions and perhaps showcasing a *more intense* post-evaluation of the decision. The authors concluded that, whilst the initial reaction time was faster in entrepreneurs, the decision processes overall consumed more time and mental resources due to these post-hoc evaluations of decision within the founders brains. This was linked to the self-reported trait of 'novelty-seeking', found to be greater in entrepreneurs and consisting of sub-components of *exploratory excitability* and *impulsiveness*. This study draws interesting findings for how entrepreneurs' brains make decisions quickly under competing information sources.

Finally, the third study focused on a simple analogue of risk-taking (Nejati and Shahidi 2013). The authors used the Balloon Analogue Risk-Taking Test (BART) a computer simulation which inflates a balloon with each mouse click. With each click, the participants collect more money; however, if the balloon explodes, all money is lost. Twenty entrepreneurs and twenty age-matched controls completed the BART to assess their risk-taking tendencies. Findings showed entrepreneurs to be more likely to over-inflate their balloons (which exploded), which the authors argued indicates higher risk-taking tendency in entrepreneurs relative to the control group. This task involved no imaging methods, yet showed cognitively how entrepreneurs may take more risks, by trying for more money.

Future Research Directions

Studying neurodiversity, including the growing interest in ADHD-like symptoms such as impulsivity in relation to entrepreneurship (Gunia, Gish and Mensmann 2020), offers opportunities for neuro-cognitive tasks to be employed beyond general self-reported ADHD-like tendencies and assess the specific behaviours and cognition underlying ADHD (such as impulsivity). It has been shown that, while self-reported ADHD-like symptoms of impulsivity/hyperactivity positively relate to firm performance, inattention does not (W. Yu, Wiklund and Pérez-Luño 2019). This suggests a need to dissect the type of behaviour (and therefore cognition) that is either beneficial or detrimental to entrepreneurship further, and at what stage.

Impulsivity and risk-taking are often used as interchangeable terms and at *face value* can seem as if they are the same phenomena, represented by acting fast, and seemingly without a thought-out approach. However, in terms of both psychology and neural underpinnings, they are not a unitary construct (Isles, Winstanley and Humby 2019). Impulsivity, in the tasks reviewed, occurs when one fails to inhibit a response, indeed acting without thought and higher order reasoning and arguably making no decision, so-called *fast thinking* (Kahneman 2011). Risk-taking on the other hand, is a decision in which there is risk of a loss, or danger; this could occur from impulsive fast-thinking, or it could occur from a slower calculated risk-taking. What cannot be determined without brain imaging methods in these studies is whether a seemingly risky decision is a thought-out decision or an impulsive one. For example, whether imaging could show the relative engagement of the frontal cortex and so-called higher-order processes that aid the entrepreneurs' decisions in risky scenarios (Groot and Thurik 2018; Floden et al. 2008).

(Fisch, Franken and Thurik 2021) used a large sample size and EEG, and did not find cognitive differences in impulsivity predictive of different entrepreneurial intention measures. However, this study may have benefitted from a more exclusive list of behavioural and electrophysiological measures to serve as predictors, to refine the results and conclusions that can be taken away. Moreover, the lack of relationship between behavioural and EEG measures of impulsivity and entrepreneurial tendencies may likely be due to the sample only containing university students as opposed to practising entrepreneurs. This highlights an issue of poor representative sampling (Dumicic, 2011) and results therefore cannot be extrapolated to entrepreneurs or entrepreneurship in general as these students had no experience of entrepreneurship, moreover there was no longitudinal follow-up to see if they eventually did become entrepreneurs. As neuroentrepreneurship research aims to see the changes in the brain that 1) result from or 2) precede entrepreneurial learning, it is important that the subject groups 1) have undergone some entrepreneurial experiences or 2) researchers measure whether they subsequently enter entrepreneurship. Without these conditions, no conclusions can be drawn on whether entrepreneurs are more/less impulsive.

Two of the impulsivity tasks used, the Erikson Flanker and Go/No-Go task, both test motor inhibition, that is the ability to stop a motor action such as clicking a button. Impulsivity in entrepreneurs decision-making may be more nuanced and not be fully captured by tests involving a simple motor response, thereby calling into question whether more ecologically valid tasks to entrepreneurship should be used. The study by (Ortiz-Terán, Agustın Turrero et al. 2013) takes a slightly more nuanced approach to understanding entrepreneurs impulsivity, with a theoretical background based on prior work in neurocognitive tasks separating the different components of cognition, from initial selection to the monitoring of performed actions. Findings of higher trait impulsivity may, on the surface, indicate a tendency to act with little forethought. The results from the Stroop task however contend with this theory and show entrepreneurs, in-fact, take more time and cognitive effort during a conflict-monitoring task, in which their initial impulses would have to be inhibited. Whilst entrepreneurs may react faster initially, this is due to a focused attention on goal-relevant aspects of the task, e.g., on the target word blue. Indeed, the slower N450 in the prefrontal areas of the brain, may indicate that entrepreneurs were slower and more cautious afterwards at evaluating their decisions than controls.

Overall, whilst trait impulsivity has been found to be higher in entrepreneurs in prior work (W. Yu, Wiklund and Pérez-Luño 2019), there is no evidence of neurocognitive impulsivity, or impulsive risk-taking in entrepreneurs to date. Moreover, simply asking the question of whether entrepreneurs are impulsive or risky in cognitive tasks should be dissociated from one another, and even sub-components of decisions need to be considered - from the monitoring of information, selection of a response and evaluation of this in relation to the outcome. Future work should cast a more critical eye to the narrative of *impulsive and risky entrepreneurs* and expand current cognitive evidence to test empirically whether this is really the case.

Open Lines of Enquiry

a) Do entrepreneurs take impulsive risks (driven by memory and emotional circuits in the brain), or thought-out risks (driven by analysis and greater executive functioning in the brain)?

b) How does trait impulsivity differ from behavioural and imaging measures (e.g., EEG and fMRI) of impulsivity (neurocognitive impulsivity) in entrepreneurs?

c) Are the neuro-cognitive tests of impulsivity and risk-taking ecologically valid to use in entrepreneurs? What new ecologically valid neuro-cognitive tests of impulsivity and risk-taking can be developed?

2. *Decision Efficiency: Exploration and Uncertainty*

Entrepreneurs have long been considered expert decision-makers, operating in volatile and stressful environments (Milliken 1987). A critical feature of the environment for the entrepreneur is a lack of reliable information about the current context, about possible actions the entrepreneur may take, and about the outcomes of those actions, respectively called state, effect and response uncertainty (McMullen and Shepherd 2006). Of interest to researchers is what enables entrepreneurs to make *better* and efficient decisions, when both attachment to familiar choices and fear of the unknown may hinder important explorative choices (Brusoni et al., 2019) and where they need to experiment with new approaches, processes and opportunities within the market (Schmitt et al. 2018). Indeed, Sarasvathy (2001) theory on effectuation positions that, rather than risk-seeking impulsive individuals, entrepreneurs use logic to deal with uncertainty. Effectual thinkers acknowledge that the future is unpredictable. To act in such uncertain territory, rather than attempt to predict the future (casual logic), they focus on what they can control - one's actions.

Next is a study that furthers this view of the entrepreneur as a logical efficient decision-maker, using a cognitive task combined with fMRI and computation models derived from economics, which aim to model human decision-making Laureiro-Martínez, Canessa et al. (2014). This research is largely inspired by the strategic entrepreneurship literature and theories of exploration that exist at the firm level (see Kuratko and Audretsch (2009) and Ireland and Webb (2009)), rather than entrepreneurial cognition and individual's mentalism or process-orientation. However it is included because of its use of relevant cognitive neuroscience methods, and as exploration also represents a fruitful area of research in psychology and neuroscience literature, studied in the context of how humans make decisions (Cohen, McClure and A. J. Yu 2007). Exploratory behaviour, in the decision to try something new, is well suited to the theories of effectuation and to the ability to navigate through uncertainty which underlie the cornerstone of entrepreneurship behaviour (Sarasvathy 2001; McMullen and Shepherd 2006). Laureiro-Martínez, Canessa et al. (2014) compared 26 managers and 24 entrepreneurs undertaking an fMRI bandit task designed to give them the trial-to-trial option to exploit a known strategy or explore a new way to approach a problem. Computational modelling enabled the researchers to uncover the strategies which participants utilised; for example, whether their choice aligned with their belief about which card is most likely correct (exploitative choice with higher degrees of certainty), or if they chose a card with a lower expected chance of reward (explorative choice with a higher degree of uncertainty). Results using a whole-brain analysis showed no group differences between entrepreneurs and non-entrepreneurs, nor interaction effects between the group and choice to exploit or explore. However, entrepreneurs made more efficient decisions (calculated as performance divided by time making a choice) and showed a choice-group interaction effect in a brain region of interest, the frontal polar cortex, which has been previously involved in behavioural switching (Daw et al. 2006). Furthermore, this interaction was driven by higher brain activity in the frontal polar cortex (FPC) for entrepreneurs specifically when choosing to explore, over exploiting.

Future Research Directions

Exploration in entrepreneurship research traditionally refers broadly to concepts such as search, experimentation, play, flexibility, and innovation by individuals or whole organisations

(March, 1991). In contrast, Exploration is studied in cognitive neuroscience as the behaviour of an individual rather than an organisation, to explore new ways of doing things despite the uncertainty, rather than exploit the same reward-based learnings that have worked in the past (Laureiro-Martínez, Brusoni et al. 2015). While the evidence suggests that different brain networks and regions activate during explorative versus exploitative decision-making (Cohen Samuel M.; Yu 2007), the study mentioned above did not show different activity within these regions between entrepreneurs and managers. Instead, entrepreneurs obtained the same results in the task quicker, due to higher activity in areas of the brain involved in task-switching, such as the FPC. However, whilst only the FPC was found to be significantly related to entrepreneur's efficiency in Laureiro-Martínez, Canessa et al. (2014), other regions such as ventromedial PFC, locus coeruleus (LC) and dorsal Anterior Cingulate Cortex (ACC) have also been previously implicated in the optimisation of decision performance, not specifically in entrepreneurs (Hayden et al. 2011).

Future studies could expand findings in entrepreneurs decision-making by exploring the influence of differing levels of uncertainty on exploration networks in the brain, and how this relates to the effectual logic of the entrepreneur (Sarasvathy 2001). For example, future work could also utilise cognitive neuroscience techniques for assessing uncertainty and learning, as was done by Behrens et al. (2007), who showed that an area implicated in exploratory behaviour, the anterior cingulate cortex (ACC), is specifically involved in tracking volatility and the resulting uncertainty in the environment. Even though navigating uncertainty is the cornerstone for most theories of entrepreneurship (McMullen and Shepherd 2006), there have so far been few such experimental manipulations that create uncertain or volatile environments. Such studies could delineate whether entrepreneurs perceive uncertainty differently or simply perceive it the same but use it differently (casual or effectual), aiding exploration.

Open Lines of Enquiry

a) Can research replicate initial findings utilising fMRI that entrepreneurs are more efficient in switching between exploitation and exploration in uncertain task contexts?

b) How do entrepreneur's brains, particularly activity in the ACC measured with fMRI, aid decision-making when the task environment is uncertain and volatile? Does this relate to the effectual reasoning abilities of the entrepreneur?

c) At what time/level does uncertainty appear to play a role for the entrepreneur? Using cognitive tasks and computational modelling, can we distinguish if uncertainty processing differs during perception of the environment's volatility, or is this is processed the same for entrepreneurs but mediated later by higher order processes in the frontal cortex?

3. *Emotional Judgements*

Entrepreneurship scholars have long discussed the importance of considering emotional processes in entrepreneurs cognition decision-making, sometimes termed *affect* (Baron, 2008). This indicates a reciprocal interface, such that the feelings and moods of individuals affect cognition, and vice versa. Our literature search returned two empirical papers looking at emotional processes involved in entrepreneurs (Halko et al. 2017; Lahti et al. 2019) and one Nature Commentary by Lawrence et al. (2008) comparing hot and cold decision-making in entrepreneurs.

The first two studies show that strong emotional attachment to ventures may disadvantage decision-making efficiency, due to an interaction with self-regulation and reward systems within the brain. Halko et al., (2017) looked at how 21 entrepreneurs and 21 fathers bonded emotionally with their ventures/children. Using fMRI, they showed that similar areas of the brain involved in parent-child affective bonding, particularly the caudate nucleus often associated with rewards, come into play when entrepreneurs assess their ventures. This study thus identifies neuro-cognitive correlates of entrepreneurial passion (Cardon et al. 2009). Moreover, in a further paper involving the same 21 entrepreneurs and 21 parents, it was shown that self-confidence and the extent to which entrepreneurs consider their ventures as part of *the self* (in a similar way that parents view children as part of *the self* influence their ability to make objective assessments, as reflected by suppressed activity in the temporoparietal junction (TPJ) involved in social and moral judgements (Lahti et al. 2019).

A further study showed how entrepreneurs decision-making differs between tasks where there is an emotional or reward-based element (hot tasks) versus tasks with no emotional component. Lawrence et al. (2008) investigated how entrepreneurs performed in hot versus cold decision-making tasks compared to managers (16 entrepreneurs, 17 non-founding managers). Hot decision-making has an emotional element in the form of uncertainty around reward and punishment, and was tested using the Cambridge Gambling Task (Rogers et al. 1999). The cold decision-making task was the Tower of London task, a planning task without monetary reward or punishment. The study found that entrepreneurs made riskier decisions than managers on the *hot* task, but there was no difference in decision-making performance on the *cold* task. This suggests that differences in entrepreneur's decision-making may become more apparent in *hot* contexts with more uncertainty or with loss and reward outcomes, thus requiring emotional control rather than just *cold* decisions around planning. However, this difference could, in part, be due to the volatile and often emotional context that entrepreneurs must learn to successfully navigate, hence suggesting that cognitive differences could only be found in entrepreneurs when there is a more pronounced emotive content to decisions.

Future Research Directions

The above studies have small sample sizes (even for imaging studies in the case of the first two), so results at this stage can only be used as preliminary evidence. However, they do indicate the differences that may arise in entrepreneurs decisions when they involve either reward and loss, or an attachment to the venture. This highlights the importance of a more holistic view of entrepreneurial decision-making as it demonstrates the interplay between decisions and emotions in the brain.

While the limbic system has long been recognized to be the network of brain regions involved in processing emotions and memory (Papez, 1937), there is, unfortunately, no real consensus on the specific brain structures involved. Nevertheless, the limbic cortex (cingulate gyrus and parahippocampal gyrus), hippocampal formation, amygdala, septal area and hypothalamus all form the complex network shown to control emotions (RajMohan and Mohandas 2007). Indeed, the ACC, mentioned earlier, as being involved in processing uncertainty, and has also been implicated in emotional processing, conflict and error coding, pain and effortful control (Vassena, Holroyd and W. H. Alexander 2017). As well as understanding irrational judgements, researchers have begun theorising how emotional states, such as fear and anxiety, may hinder the ability to make novel, explorative decisions (Stefano Brusoni et al. 2019). Although fear is commonly discussed in terms of fear or failure or as a barrier to entry to entrepreneurship (Cacciotti and Hayton 2015), currently no empirical work has been conducted to study fear and anxiety in the brain of entrepreneurs.

Open Lines of Enquiry

a) How can positive emotions, such as passion or attachment in the *limbic system*, affect rational judgements in an entrepreneurs' brain as measured via MRI techniques?

b) How do specific emotions, such as fear and anxiety affect tolerance to uncertainty, activity within the ACC through fMRI, and thus exploratory decision-making behaviour?

4. *Interpersonal Trust and Social Cognition*

Social cognition refers broadly to the cognitive processes used to understand and store information about others, the self and interpersonal norms, enabling someone to effectively navigate a social world and take advice from others (Adolphs 1999; Adolphs 2009; Blakemore 2008; Diaconescu et al. 2017; Overwalle 2009). Humans exist as social beings, with everything we do shaped by social context, norms and cultures, therefore entrepreneurship is contextually embedded in our social culture (Welter 2011). Evidence on the importance of social context for entrepreneurs comes from research showing how social capital, social support and socially supportive contexts engage in entrepreneurship and entrepreneurs success (Rauch et al. 2016; Stephan and Uhlaner 2010). Current empirical studies found through our literature search have focused on investors trust in entrepreneurs and the responses to entrepreneurial passion during pitches. For example, one study used EEG to look into venture capitalists (VCs) andentrepreneurs interaction as a measure of interpersonal trust (Yang and Li 2017), while another used fMRI to investigate investors' reactions to passion in entrepreneurs' pitches (S. Shane et al. 2020). In both studies, the entrepreneur was not the subject being studied. However, we include them in our discussion for their methodologies, limitations, and relevance to entrepreneurship.

Firstly, Yang and Li (2017) studied VCs trust in and cooperation of entrepreneurs whilst undergoing EEG assessments. The authors describe how two EEG measures, feedback-related negativity (FRN) and P300, can be used to understand VC's decisions. FRN is an EEG measure reflecting the degree of difference between prior expectation and feedback when people make a decision, and P300 represents participants' concentration on the task at hand. VCs were shown profiles of entrepreneurs before entering a trust game with them, which involved investment decisions. At the start of each game, the VCs were given 10 points, and, through a series of rounds, they aimed to gain the highest return on investment. The learning rates of the VCs were modelled using a reinforcement learning model to understand how they updated their trust cognition throughout the experiment. The results from the modelling and EEG data show that VCs' investment decisions were not only based on the cooperation during the game, which was continuously updated, but they were also heavily influenced by the prior information (the background profile of the entrepreneurs), sometimes regardless of the behaviour that then followed. This study consisted of only eight controls and ten male VCs.

Secondly, in an fMRI study, S. Shane et al. (2020) placed 15 informal investors (those who had personally invested in a business start-up that was not their own, excluding VCs and angel investors) within an MRI scanner and showed them founders' pitches, varied for different levels of passion. Investors watched videos of 10 actors pitching, who delivered their pitch twice, one with high passion and one with low passion, based on voice tone, energy level and facial expressions. Investors were shown 10 out of 20 pitches, 5 with high passion and 5 with low passion. The authors compared engagement between high and low passion pitches within individuals across 111 brain regions of interest to test neural engagement. They argued that higher correlation across the whole brain is indicative of higher engagement. They found significantly higher neural engagement in high passion pitches, and higher neural engagement correlated positively with investor interest. However, a non-significant effect was found when testing whether neural engagement mediates the passion-investor interest relationship. They could not confirm whether neural activity in investors affects their interest in passion pitches and concluded by commenting on the implication of this research to pitch training in entrepreneurs and predicting success rates.

Future Research Directions

The sample size in both studies is too small to draw firm conclusions. Using larger sample sizes in future studies will help expand and strengthen these findings in interpersonal cognition in entrepreneurship. S. Shane et al. (2020) conclude that higher passion increases engagement and thus activity across widespread brain regions of the investors. However, they also state that boundaries or thresholds for what constitutes *high* or *low* engagement are not widely established in neuroscience, as most studies examine within-experiment fluctuations and their resultant influence. This makes it difficult to interpret whether these high and low cross-correlation findings reflect engagement. Moreover, the value of this study to entrepreneurial training is unclear, as neuroimaging, especially fMRI, is extremely costly and thus unlikely to be a viable method to study how passionate and engaging a pitch is beyond the investor's actual opinion and interest. Other limitations of S. Shane et al. (2020)include not having a control group to compare to, and using many regions of interest and comparisons, which may result in false-positive findings, a common issue in neuroimaging studies that do not adequately control for multiple comparisons.

Studies would be strengthened by pre-defining regions of interest, for example those shown in prior studies to be involved in social processes such as the medial prefrontal cortex (mPFC), the anterior cingulate cortex (ACC), the inferior frontal gyrus, the superior temporal sulcus (STS), the amygdala and the anterior insula (Blakemore 2008). Utilising this knowledge and methodology from cognitive neuroscience, fMRI studies in entrepreneurs social cognition could cast more light on the specific phenomena relevant to entrepreneurship.

For example, researchers could explore the factors previously shown to be involved in an engaging pitch, such as the neurocognition involved in eye-contact and facial expressions, personalisation, visualisation and contextualisation during pitching (Villiers Scheepers, Barnes and Garrett 2021). Research in trust and cooperation in entrepreneurs (Yang and Li 2017) could also be expanded, for example through investigating the weight entrepreneurs put on social advice during decisions. The use of reinforcement and Bayesian learning models would enable to explore the extent to which entrepreneurs themselves trust investors and integrate social advice into decisions, through studying how an individual learns about the probability of receiving an uncertain financial reward, whilst at the same time learning about the fidelity of the advice being given to them (Behrens et al. 2007; Diaconescu et al. 2017). Such models can give measures of how much weight someone puts on advice from others, compared to their own beliefs, whilst dealing with uncertain scenarios. As much of the learning in entrepreneurship comes from both social and financial gain/loss, such tasks could be highly relevant to the field as they could provide an understanding of the multiple elements that may motivate or mediate entrepreneurial behaviour.

Open Lines of Enquiry

a) What are the neural correlates that occur in audience members from eye-contact, facial expressions, personalisation and/or contextualisation during an entrepreneur's pitch?

b) Can we see differences in how much weight entrepreneurs put on social advice given to them and how this corresponds to functional activity in the brain during fMRI experiments? For example, is an entrepreneur more successful when following their judgement or when integrating others' viewpoints into their decision-making?

c) Can we see neuro-cognitive differences between entrepreneurs' trust in advisers, mentors, colleagues, and investors?

2.5.2 *Part 2: Emerging Themes*

In the following section, we transition from reviewing established current themes where cognitive neuroscience methods have been effectively employed, to exploring thematic areas that demonstrate promising cross-disciplinary collaboration. While our initial focus was on identifying current themes, it's important to acknowledge themes in the entrepreneurship literature that form the basis of many popular theories. Among these emerging themes, two noteworthy areas—opportunity identification and creativity—have not garnered attention from cognitive neuroscience. Although empirical research in these domains has begun to surface, it did not fully meet our initial systematic search criteria, which specifically targeted the intersection of cognitive neuroscience and entrepreneurship (Rahmati et al. 2014; Saggar et al. 2017; Zaro et al. 2016). The decision to categorize them as emerging rather than current themes was based on their preliminary nature, such as being pilot studies, or their indirect relevance to entrepreneurship *per se*, despite their applicability to current theoretical frameworks. Nevertheless, these studies offer valuable insights into potential avenues for cross-disciplinary collaboration and pose interesting questions for future investigation. To address this gap in our discussion, we introduce the concepts of opportunity recognition and creativity from an entrepreneurship perspective and discuss how neuroscience methods can further explore these areas. Table 6 provides further details on these studies.

Table 6: Sample and Methods of Emerging Empirical Studies at the Intersection of Cognitive Neuroscience and Entrepreneurship

Theme	References	Sample	Grouping	Methods
Opportunity alertness	(Zaro et al., 2016)	Entrepreneurs N = 7 Mean age = 35 Non-entrepreneurs N = 7 Mean age = 34	Entrepreneurs: founders, for over 3.5 years and still actively involved Non-entrepreneurs: age-matched, non-founders	Ecologically valid methods, videos for opportunity identification; EEG recording whilst watching the videos.
Creativity	(Rahmati et al., 2014)	Primary school students N = 48 Age = 7–12 Neurofeedback n =16 Play n= 16 Control n= 16	Randomly assigned to one of three interventions; neurofeedback play or control.	EEG neurofeedback during visual game; 20 x 1-hour sessions; Torrence Test of Creative Thinking; entrepreneurial traits
	(Saggar et al., 2017)	Healthy adults N = 36 Age not specified Creative Capacity Building Program (CCBP) n = 15 Language Capacity Building Program (LCBP) n = 15	Randomly assigned to either the CCBP or LCBP intervention.	fMRI pre- and post- intervention; Torrence Test of Creative Thinking

a) *Opportunity alertness*

Entrepreneurial alertness is defined as the ability of an individual to see opportunities where others do not, often driven by expertise, knowledge, and motivation (Kirzner 1973; Maran et al. 2021; R. K. Mitchell, B. T. Mitchell and J. R. Mitchell 2009). Kirzner's account of the entrepreneur is one of individuals being *passively alert*, meaning that they can notice changes where others do not (Kirzner 2009). Tang, Kacmar and Busenitz (2012) offer a more proactive view of entrepreneurial alertness, which is more easily studied through neuroscientific research. Their contribution, which builds on Kirzner's (1973) early work on cognition theory and McMullen and Shepherd (2006)'s theory of uncertainty in entrepreneurship, presents alertness in three dimensions; (1) scanning and searching, (2) association and connection, and (3) evaluation and judgement. For example, in previous empirical studies, researchers gave novice and expert entrepreneurs the same amount of information and measured their ability to spot opportunities within texts (Westhead, Ucbasaran and Wright 2009).

One study involves a pilot using EEG methodology to assess entrepreneurial alertness to new opportunity (Zaro et al. 2016). They recruited 7 male entrepreneurs and 7 male non-entrepreneurs. The authors used two ecologically valid video tasks to assess how established entrepreneurs searched for opportunities (a video with jewellery pieces with wholesale prices, indicating a possible business opportunity), and then used these to calculate the risk of investments (deciding on loan options for investment in the jewellery market). They suggest entrepreneurs engage different brain networks during both tasks than non-entrepreneurs. Entrepreneurs engage the right and left frontal circuits during both search and calculating risk, while non-entrepreneurs engage frontal, medial and temporal areas during the business opportunity, and more posterior areas and a right frontal circuit during the evaluation of risk. The authors suggest that entrepreneurs used their memory of the information presented in the first videos more when evaluating the investment risk, whilst non-entrepreneurs rely more on personal context. Whilst an interesting pilot to begin to explore how ecologically valid tasks might be used in conjunction with imaging methods, much of the neuroscience theoretical background, and methodology would need to be further developed to provide any true insight. For example, the authors do not build any theoretical basis for which cognition, areas and circuits on the brain are involved in opportunity search, nor explain how this relates to prior empirical findings in the entrepreneurship or neuroscience literature.

Future Research Opportunities

Opportunity identification skills in entrepreneurs are attributed to mental models and cognitive frameworks that allow them to connect the dots better (Baron 2006), however pattern recognition expertise has only just begun to be studied from a neuroscience perspective. Previous work in neuroscience have utilised eye-tracking combined with functional MRI to explore chess expertise, in terms of object and pattern recognition (Bilalić et al. 2010), comparing novice and expert chess players. Participants played both chess-related and non-chess-related visual search tasks. Eye-tracking showed that expert players focused on relevant aspects of the chess-task more quickly, while novice players also explored irrelevant visual aspects of the task. fMRI was able to distinguish between object-recognition and pattern recognition through their association with, respectively, the bilateral occipitotemporal junction and medial collateral sulci. It is therefore possible to distinguish the different visual processing streams behind pattern and object recognition within the real-world context that experts operate in. Similar research, building on the ecologically valid experiments of Zaro et al. (2016), yet with a stronger theoretical basis of pattern recognition from both the entrepreneurship and neuroscience literature, could test whether entrepreneurial experts demonstrate any difference (1) in scanning and searching for market opportunities, and (2) in association, connection recognition abilities, and the corresponding cognitive and neural processes involved in this bottom-up processing when evaluating these opportunities. The use of functional MRI, due to its higher spatial resolution than EEG, may better allow researchers to distinguish the networks in the brain involved in an entrepreneur's ability to better recognise market opportunity.

Open Lines of Enquiry

(1) Use cognitive-neuroscientific methods to understand whether entrepreneurs possess passive/unconscious alertness to new opportunities, or whether more deliberative top-down opportunity recognition processes are involved? (2) Do entrepreneurs direct attention to relevant stimuli more and/or faster than non-entrepreneurs? (3) Do entrepreneurs brains have a better ability to *connect the dots* for business opportunities and is this a general cognitive skill or one specific to their expert domain?

b) *Creativity*

Creativity is the production of novel and useful ideas by an individual or group working together (T. M. Amabile 1983; T. M. Amabile 1988; Teresa M Amabile 1997) and has long been considered critical both for successful business creation and to sustain the competitiveness of entrepreneurs businesses in the long term (Nyström 1993). Creativity differs from alertness: while the latter involves the alertness to changes and opportunities, the former can be argued to create internal opportunity (Kirzner 2009). Neuroscience can shed light on whether and which entrepreneurs predominantly engage alertness to external cues or internally-stimulated creativity, thus offering the opportunity to test these opposing approaches. Moreover, cognitive neuroscience methods and tests offer a complementary, more objective way of assessing creativity. We found two such studies in our search, which in-fact used interventions aimed at improving creativity, one employed EGG neuro-feedback itself as the intervention, whilst the other used fMRI to study the effect of a creative intervention.

The first study tested the effect of an EEG neurofeedback intervention on the entrepreneurial traits of creativity, locus of control and risk-taking (Rahmati et al. 2014). Forty-eight students from 7 to 12 years old were randomly assigned the experimental (20 sessions of neurofeedback), play (20 sessions of undefined imaginative mind games) and control (held on a waiting list) intervention. The neurofeedback intervention involved 20 one-hour sessions, lasting 1.5 months, during which students were asked to play a video game, only using their mind. The EEG sensors on the scalp respond to changes in neural (electrical) activity and so the student must figure out what *type of thinking* creates the desired effect in the game. This is defined as *agent conditioning* as participants learn to perform better and to increase their brain waves frequencies when they decrease. The authors showed improvement in creativity, measured by the Torrance Test of Creative Thinking (Runco et al. 2010) in the neurofeedback compared to the play group. However, this study would have been strengthened by better explanation of the areas of the brain involved in the neurofeedback condition and theoretical contributions to why this increases creative performance.

Second, was a study that better builds a neuroscience basis for creativity and the neural changes associated with creative capacity. Its authors state the importance of creativity, as an essential skill for entrepreneurial success (Saggar et al. 2017). This study, measured functional brain activity pre- and post- intervention in healthy adults with the use of fMRI, thereby building a better neural basis for why this intervention improves creativity. By assessing performance on the Torrence Test of Creative Thinking, they showed that a 5-week design-thinking intervention can boost participants creative capacity. This was associated to reduced task-related activity in the right dorso-lateral pre-frontal cortex (dlPFC), anterior cingulate gyrus, supplementary motor area and increased cerebellar-cerebral connectivity, suggesting that increased creativity is associated with reduced engagement of executive functioning regions and increased involvement of spontaneous implicit processing.

Future Research Opportunities

Creativity in neuroscience refers to the novelty and volume of ideas produced, or to the flexibility of the mind (Dietrich

2004; Guilford 1950). Due to its multifaceted nature, creativity may be studied (1) by way of insight, (2) by the whole process of producing something novel, and (3) through the association of cues to pre-existing knowledge (Fink et al. 2007). The findings in the second intervention study fit in with a consensus in the neuroscience field; that creativity generally arises through both a defocus and refocus of attention, associating cues in the environment to past knowledge (Gabora 2010). For example, current theories depict the disengagement of cognitive control and engagement of the default mode network (DMN) in creative thinking (Chrysikou 2019). The DMN comprises brain regions such as the medial prefrontal cortex (mPFC), lateral and medial parietal regions and the medial temporal lobe. The DMN has been shown to be involved in internally-stimulated thought, mind-wandering, autobiographical memory retrieval and perhaps in facilitating creative thoughts (Beaty et al. 2014; Raichle 2015). Creativity requires a variety of cognitive abilities such as working memory, sustained attention, and cognitive flexibility. Furthermore, newly emerging fMRI studies show that a degree of *controlled* semantic cognition, at the intersection of the DMN and multiple-demand network, is required for unique links and thus creative processes during creative language tasks (Dietrich 2004; Krieger-Redwood et al. 2023).

Many task-based assessments of creativity, such as the commonly used Torrence Test, as well as remote association tasks, test the divergent nature of creativity and could therefore be employed in future studies of entrepreneurs, assessing if they are indeed more creative (Wu et al. 2020). Moreover, general neuro-cognitive processing abilities which would contribute to creative capability, such as semantic cognition, working memory, flexibility and attentional abilities, have not been studied in entrepreneurs. In the case of entrepreneurship, using such methods borrowed from the cognitive neuroscience research in creativity could help researchers understand how one comes to arrive at seemingly unique or creative ideas that lead to venture creation and innovation.

Open Lines of Enquiry (1) Are entrepreneurs more creative than non-entrepreneurs in lab-based objective cognitive neuroscience creativity tasks? (2) Do brain networks involved in creative processes, such as the default-mode and semantic control networks, show more robust connectivity in entrepreneurs and correlate with increased creative insights?

2.6 DISCUSSION: WHERE DO WE GO FROM HERE?

The question which underpins all work discussed in this paper is: Can insights and methods borrowed from (cognitive) neuroscience help us understand the distinctiveness of the entrepreneur's brain? Currently, empirical evidence for differences in the entrepreneur's brain is limited and inconclusive. Indeed, there is a lack of understanding of the brain-behavior relationship that drives entrepreneurial thinking, decision-making and action. Through performing a systematic search, we identified only 9 current relevant papers in peer-reviewed journals, which we grouped into four themes of neuro-cognition; (1) impulsivity and risk-taking, 2) decision-efficiency: exploration and uncertainty (3) emotional judgements, and (4) interpersonal trust and social cognition and 3 emerging papers, grouped into the themes of; (5) opportunity alertness and (6) creativity.

There are many open-ended questions on what makes up the dynamic neuro-cognitive profile of an entrepreneur. Are they impulsive or calculated risk-takers? Driven by emotions and passion or in control of them? Swayed by others' advice or stuck to their vision? Alert to opportunity or creative in making opportunities happen? This quasi-literature review demonstrates that, whilst many popular emerging theories exist, such as those that link entrepreneurship to ADHD-like symptoms (e.g., impulsivity), the empirical evidence to date in neuroentrepreneurship is scarce (Fisch, Franken and Thurik 2021). Established theories of effectuation combined with early neuroscience research are starting to shed light on the fact that, perhaps, rather than being reckless or impulsive, entrepreneurs in fact make more efficient decisions in uncertainty. Indeed, behavioural tasks can tap into the ability of entrepreneurs to make fast decisions or explore and experiment with alternative options in the most efficient way during decision-making and uncover the brain networks involved in task switching (Laureiro-Martínez, Canessa et al. 2014). Moreover, as only theorised so far, future empirical work showing how emotions, such as fear and anxiety, might hinder exploration, or how social advice might be considered, may allow a more humanistic explanation of entrepreneurs thinking (Stefano Brusoni et al. 2019). As has already been shown, feelings, such as self-confidence and bonding toward the venture can mimic that of a parent-to-child relationship in the brain, to the degree that it impacts entrepreneurs rational judgements (Lahti et al. 2019; Halko et al. 2017).

Critically appraising these studies helped to identify the benefits and challenges of the cognitive neuroscience methodologies involved. Based on this appraisal, we suggested open lines of enquiry to help cross-collaboration in cognitive neuroscience and entrepreneurship research. Additionally, we illustrate the potential usefulness of cognitive neuroscience methods for entrepreneurship research by discussing emerging topics that align with neuro-cognitive concepts studied in neuroscience, such as opportunity recognition and creativity, yet need a stronger theoretical basis built.

Limitations

Reviewing only the empirical work, whilst intentional, means that we end up with specific and deeper discussions only about the experiments and neurocognitive studies that have been done. We do not believe what *has been done*, should limit ideas of the possibilities of what *could be done*. There are many more topics in which neuroscience tools could be used to study the hidden mental processes, discriminate between theories, examine the antecedents of entrepreneurial cognition and adjudicate between different theoretical perspectives (Nicos Nicolaou et al. 2019). Our aim in this paper is to look through the lens of neuroscience to explore what we currently know (or indeed how little we know) of the entrepreneurs' neurocognition and brain. This strategy means that we were able to show examples of where this collaboration has been successfully achieved so far and where it could lead.

The findings from this review, however, do also highlight important methodological limitations to consider in neuroentrepreneurship empirical work. As shown in Table 5, the sample sizes in most of the between-group comparisons are small, which is not uncommon, particularly in many neuroimaging studies due to the cost of methods such as fMRI. Research in the neuroscience of entrepreneurship is still very much in its infancy, however, the replication of studies may enhance the strength and reliability of the findings in the field so far (Turner et al. 2018). A further important consideration for researchers is the nature of the groups studied in empirical studies, which were very heterogeneous. For instance, researchers compared entrepreneurs to managers, non-entrepreneurs (non-founders), students and fathers in a few studies mentioned earlier, thereby taking the occupational view of entrepreneurship, in that it is the *role* of the individual (Halko et al. 2017; Lahti et al. 2019; Laureiro-Martínez, Canessa et al. 2014; Zaro et al. 2016). However, this approach could wrongly assume that managers, students, fathers and non-founders possess no similar neuro-cognition. An alternative view of entrepreneurship, is the actions and processes involved in identifying, creating and exploiting opportunities (Scott Shane and Venkataraman 2000). This may include screening questions testing for entrepreneurial behaviour, skills, and outputs, and was proxied in one of the studies (see, Fisch, Franken and Thurik (2021) who focused on entrepreneurial intentions). However, in that study, none of the participants (students) had any experience in entrepreneurship or founding a venture, nor was a follow-up study performed to see if they did eventually enter entrepreneurial endeavours. Studies of entrepreneurs at different stages in their entrepreneurial journey, from conception, innovation, growth to exit are thus particularly needed. A compromise to the weaknesses of both approaches may involve combining the occupational and process approaches, by selecting individuals/groups based on their entrepreneurial outputs and experience, whilst also measuring their entrepreneurial skills and behaviours.

Implications for practitioners

The main point to be highlighted to practitioners from this paper and systematic search is the lack of evidence at present that there is anything different about the entrepreneur's brain and neurocognition. There is certainly potential in the themes we have reviewed for cross-collaboration, and the emerging work that compliments theories on how entrepreneurs make decisions and plan in uncertainty (Laureiro-Martínez, Canessa et al. 2014). We think that, before we can ask the question most relevant to entrepreneurship practitioners; can entrepreneurial neurocognition be trained? Much more empirical work must be carried out.

For example, the studies in our emerging themes (Rahmati et al. 2014; Saggar et al. 2017) begin to show evidence for this next level of neuroentrepreneurship research, testing whether such thinking, in this case creativity, can be trained using neuroscientific interventions. However, we argue that it is still too early to use techniques such as neurofeedback more widely. This is because neurofeedback interventions in other contexts, such as in children with ADHD, are conducted within a theoretical framework and with specific neural targets. For example, ADHD neurofeedback training targets dysfunctional frontal regions and connections, thought to underlie poor self-control, with the aim to strengthen connectivity within these regions (Rubia et al. 2001). These regions have been shown by prior meta-analysis to be implicated in ADHD and are therefore a clear target (Hart et al. 2013) Nevertheless, this technique is not the panacea as most studies to date have been pilot / proof-of-concept studies, and a recent double-blind clinical trial has found this neurotherapy to be inefficient in ADHD in improving clinical symptoms and cognition (Lam et al. 2022). Furthermore, in the case of entrepreneurship, there is currently no such strong evidence of which regions or networks in the brain should be the neurofeedback target(s). For example, from the sparse evidence reviewed, it is not clear whether more or less self-control would be desired in entrepreneurship and how this may change at different stages of the process (Fisch, Franken and Thurik 2021; Laureiro-Martínez, Canessa et al. 2014). Neuroentrepreneurship research must firstly understand what, if anything, is different in the brains of those who think entrepreneurially during different entrepreneurial stages, before focusing on how to develop these skills further.

Conclusion

We approached this review from a neuroscience lens, with the aim to unify the two disciplines with their common research interests and to showcase areas of neuro-cognition that could enhance our understanding of how entrepreneurs think, make decisions and act. We hope that this paper can guide future cross-collaborations by presenting evidence for where the two fields have, so far, empirically worked together. Further studying the topics presented here would have more potential benefit for both fields, complementing entrepreneurship cognition theory in what *one does* (Grégoire, A. C. Corbett and Mcmullen 2011), whilst also contributing to neuroscience as a discipline aiming to uncover potentially subtle intra-individual differences related to recognising new opportunities, coming up with creative solutions and navigating uncertainty.

In the context of this thesis we have explored areas of work and themes that can guide hypotheses to test in cognitive neuroscience. We may validate, challenge or expand future empirical work in the areas of (1) impulsivity and risk-taking, 2) decision-efficiency: exploration and uncertainty (3) emotional judgements, and (4) interpersonal trust and social cognition as well as emerging themes of; (5) opportunity alertness and (6) creativity. Within each theme I have given the relevant entrepreneurship theory to these topics and provides examples of how neuroscience methods can be used to address these aspects of mentalism. One conclusion to be taken away from this review is that the science is already influenced by pop-culture views of entrepreneurship. For example there has already been a stream of cognitive neuroscience papers looking at risk-taking behaviour and studies which only compare male entrepreneurs to fathers, not considering female entrepreneurs in their sample. Therefore a different approach may be needed to reduce our biases and assumptions in the cognitive tests given to entrepreneurs. The field needs to delineate what *neurocognitions* are most relevant to study in entrepreneurship. The resulting research could compliment and provide additional layers of understanding to how entrepreneurs think (mentalism), and how this develops (process-orientation).

In the next two chapters I present results from an online experiment which aimed to distil down the necessary competencies and corresponding cognitive profiles to study within entrepreneurs. First in Chapter 3 I evaluate entrepreneurial competencies using a machine learning approach and create discussion around what the necessary qualities an entrepreneur must possess at different stages of the entrepreneurial process. Then in chapter 4 I employ hypothesis-driven cognitive tests in two of the themes drawn out from this review to investigate what neurocognitive and personality traits underlie entrepreneurial competency, testing whether there are differences in entrepreneurs' (1) impulsivity and risk-taking and (2) decision-efficiency: exploration and uncertainty. I also employ innovative approaches to show the new insights we can gain from the data-driven analysis of large batteries of cognitive tests.

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Zaro, Milton Antonio et al. (May 2016). 'Cognitive Brain Mapping Used in the Study of Entrepreneurial Behavior – Pilot Test with the Use of Electroencephalogram - EEG during the Process of Identification of Business Opportunities'. In: *American Journal of Educational Research* 4.6, pp. 472–478. ISSN: 2327-6126. DOI: 10.12691/education-4-6-5. URL: http://pubs.sciepub.com/education/4/6/5/index.html (cit. on pp. 132, 134, 136, 143).

2.8 SUPPLEMENTARY MATERIAL

2.8.1 *Literature Review Search Terms*

We used two databases; 1) Scopus (Library Database), and 2) Business Resource Complete (BRC), to perform our initial literature search.

In Scopus on the 10/11/22, we used the Boolean search query: (TITLE-ABS-KEY (neuro*) OR TITLE-ABS-KEY (*mri) OR TITLE-ABS-KEY (magnetic AND resonance AND imaging) OR TITLE-ABS-KEY (pet) OR TITLE-ABS-KEY (positron AND emission AND tomography) OR TITLE-ABS-KEY (near-infrared AND spectroscopy) OR TITLE-ABS-KEY (*nirs) OR TITLE-ABS-KEY (eeg) OR TITLE-ABS-KEY (electroencephalogram) OR TITLE-ABS-KEY (eye AND tracking) OR TITLE-ABS-KEY (meg) OR TITLE-ABS-KEY (magneto-encephalography) OR TITLE-ABS-KEY ((behavourial OR behavorial) AND (assessment OR task)) OR TITLE-ABS-KEY (cognitive AND (assessment OR task))) AND (TITLE-ABS-KEY (entrepreneur*) OR TITLE-ABS-KEY (neuroentrepreneurship))

On BSC, on 29/11/22: AB (neuro or neuroscience or cognitive or cognitive neuroscience or mri or magnetic resonance imaging or pet or positron emission tomography or eeg or electrocephalogram or eye tracking or magnetoencephalography or meg or nirs or near-infrared spectroscopy or behavourial task or behavorial task or behavourial assessment or behavorial assessment or cognitive task or cognitive assessment) AND AB (entrepreneur or entrepreneurship or entrepreneurs or neuroentrepreneurship)

3

CHAPTER 3: DISRUPT AND RESOURCE: SELF-PERCEIVED COMPETENCIES OF NOVICE AND EXPERT ENTREPRENEURS

> The critical ingredient is getting off your butt and doing something. It's as simple as that. A lot of people have ideas, but there are few who decide to do something about them now. Not tomorrow. Not next week. But today. The true entrepreneur is a doer, not a dreamer.
>
> — Nolan Bushnell

3.1 PREFACE

The purpose of this thesis is to explore the cognitive and neural correlates of entrepreneurial thinking and competency, to gain insight into how this develops and thus can be trained. In the previous chapter, I described the themes and areas of neurocognition that compose entrepreneurial thinking according to current literature. It is clear from this that entrepreneurship is multifaceted and that the means to explore what neurocognitive resources make up entrepreneurial competency could be explored from many angles; from the initial stages of ideation and creativity, to the subsequent risk and uncertainty which follows, the emotions and passion for one's ideas, or the trust and relationships that endure and guide an entrepreneurial journey. However, the neurocognitions that underlie entrepreneurship are also used universally, with creativity, passion, uncertainty and relationship-building vital in nearly all walks of life, and not exclusive only to entrepreneurship. With such a broad scope, it may be necessary to distil down and explore what are the core and vital competencies an entrepreneur needs expertise in, over and above non-entrepreneurs.

In many ways, to be entrepreneurial means to be the most responsive (or even the catalyst) for change, coming up with new ideas, and, most importantly, acquiring the resources to take action. To achieve a process-view of entrepreneurship which considers how the context and environment build entrepreneurial cognition, studies of entrepreneurs at different stages of the entrepreneurial journey, from conception to growth, are needed. This can be achieved by selecting individuals/groups based on their entrepreneurial outputs and experience while measuring their entrepreneurial competencies. Much work has already been done to define entrepreneurial competencies for education purposes. However, many of these suggested entrepreneurial competencies have not been validated in real-world samples of entrepreneurs. It is unknown what competencies are most prevalent in practising entrepreneurs and which competencies should be relied on at different stages of entrepreneurship. Understanding the competencies and skill sets that established entrepreneurs possess early can help inform the types of cognition and behaviour we study in neuro-entrepreneurship research. In this paper, we test a popular entrepreneurial competencies framework to assess self-perceived competencies in practising entrepreneurs of different expertise, to address this gap in the literature and aid our subsequent studies by better defining our entrepreneurial groups, the behaviour and neurocognition we are most interested in studying.

3.2 ABSTRACT

This study aimed to examine the self-perceived *transferable* entrepreneurial competencies of non-entrepreneurs, novice entrepreneurs, and expert entrepreneurs, using the EntreComp framework as a reference point. A survey of 18 competencies was administered to participants from each group, and a reduction technique, a factor analysis, was conducted to identify the underlying factors of entrepreneurial competencies. These reduced factors were compared between the three groups of increasing entrepreneurial expertise to determine any significant differences. This study provides a valuable tool for entrepreneurship educators and researchers to identify, and help develop, the most relevant competencies at different levels of entrepreneurship.

3.3 INTRODUCTION

3.3.1 *Theoretical background*

Government and policymakers have noted the importance of entrepreneurship training to individuals and a country's economy. At the same time, entrepreneurial competencies are increasingly being recognised as beneficial to all areas of professional development and not only to venture creation. A limited number of scholars believe entrepreneurship is a trait that intrinsically exists "within" a person and is subsequently "simply" recognised (Adcroft, Willis and Dhaliwal 2004). On the other hand, there is a large group of educators, policymakers and researchers that believe the characteristics that make someone entrepreneurial are developed through teaching and experiential learning (Kirby 2004; Pittaway and Cope 2007; Bacigalupo et al. 2016; A. Penaluna and K. Penaluna 2021).

Those researching how entrepreneurship develops, primarily in educational contexts, argue it should be taught as a particular method of thinking and acting, allowing for a portfolio of techniques to 'create' (Neck and Patricia G Greene 2011). However, most traditional pedagogy focuses on knowledge due to its ease of teaching and testing its development through standardised assessments (Komarkova, Conrads and Collado 2015). To measure entrepreneurship as a process or method of thinking or even to recognise the entrepreneurial potential within an individual who has not yet undertaken specific venture-building activities, it is thus necessary to measure transferable competencies and evaluate how these differ at different stages of entrepreneurship. A consensus among most approaches is that entrepreneurship is a dynamic process in which different competencies may be necessary for different stages of success (Gorgievski and Stephan 2016; Frese et al. 2009; Zwan and Thurik 2017; Baron 1998).

Therefore empirical assessments of real-life entrepreneurs at different stages may complement the frameworks created thus far.

While competency refers to the overall ability of someone to perform a task or role, competencies refer to the specific skills, knowledge, and characteristics that contribute to effective performance and behaviour in a specific role or situation (C. Dictionary n.d.; Bacigalupo et al. 2016). Entrepreneurial competencies were defined by Mitchelmore and Rowley (1995) as underlying characteristics such as specific knowledge, motives, traits, self images, social roles and skills which result in venture birth, survival and/or growth. Most importantly, competencies can be learnt, and thus it is necessary to identify what specific entrepreneurial competencies are for training and education purposes (Mitchelmore and Rowley 2010). Yet, the search for entrepreneurial competencies has been likened *"to the pursuit of the holy grail"* (Mitchelmore and Rowley 2010), mostly due to disparate methods and studies which *diverge* rather than *converge* our understanding of the key underlying competencies necessary for entrepreneurship.

Traditionally, entrepreneurial competence has focused on those specific attributes which help one recognise business opportunities and create a venture/business. Chandler and Jansen (1992) developed a questionnaire which distinguished three roles of an entrepreneur: (1) the entrepreneur role, (2) the managerial role, and (3) the technical-function role. Using this self-assessed questionnaire, the authors showed that firms with higher growth and earnings rated themselves highly in all three roles. They also found that business education and experience in general managerial positions contributed to greater performance in these roles. In addition to Chandler and Jansen (1992), numerous other studies have attempted to distinguish the specific entrepreneurial competencies through 1) self-reported questionnaires or 2) script-cue recognition methodology and 3) reviews of existing empirical studies (Chandler and Hanks 1994; Shane and Venkataraman 2000; Man, Lau and Chan 2002; Baum 1994). In a review of entrepreneurial competencies and existing frameworks, Mitchelmore and Rowley (2010) summarised these into four main themes of 1) entrepreneurial competencies, 2) business and management competencies, 3) human relations (HR) competencies and 4) conceptual and relationship competencies.

However, the existing models of entrepreneurial competencies summarised in (Mitchelmore and Rowley 2010) do not explore competencies and behaviour that exist in people independent of venture creation. This means that current assessment methods cannot directly translate to individuals who have not yet started a business or to people wishing to evaluate entrepreneurial skills from a process-oriented rather than an occupational approach. The occupational approach defines entrepreneurship as an occupation and focuses on the competencies to found, manage, and own a business. On the other hand, the process approach defines entrepreneurship as a process and focuses on competencies involved in entrepreneurial actions, such as identifying, creating, and exploiting opportunities (Gorgievski and Stephan 2016). By exploring entrepreneurial competencies from the process approach, we can better understand the underlying human behaviour and practices that are *transferable* to entrepreneurship.

The EntreComp framework is one of the most comprehensive frameworks that includes many of the *soft skills* of entrepreneurship and does not require one to have previously or currently be creating a business/venture. It builds upon a broad definition of entrepreneurship; *to develop cultural, social or economic value*. It incorporates different types of entrepreneurship, such as intrapreneurship, social, green and digital entrepreneurship (Bacigalupo et al. 2016). Based on a literature review of entrepreneurial traits, characteristics, and skills, with input from over 400 experts in the field, EntreComp provides a useful 'dictionary' for researchers to use when studying entrepreneurial competencies and their development. Yet despite the strengths of the EntreComp framework as a measure of the transferable competencies (outside of starting a venture), the EntreComp has not been made into a questionnaire or tool, nor validated in samples of entrepreneurs to see if they do indeed possess the presumed set of competencies.

This paper builds upon and validates the existing knowledge of entrepreneurial competencies as outlined in the EntreComp framework. We have chosen to focus on this framework due to its thorough development by practitioners and researchers, its integration into education agendas within the EU, and the authors' recognition of it as a reference framework for entrepreneurial competencies. Developed by the European Commission, the EntreComp framework is comprehensive, looking at 15 competencies. However, its current form is hard to translate into quantitative survey measurements, and has not been tested in sample of real-life entrepreneurs, to see if they do have the presumed competencies described in the framework. As noted by (Mitchelmore and Rowley 2010), there is a need to build frameworks based on more empirical evidence, opposed to theoretical assumptions. There we propose the optimal strategy would be to initially consider a comprehensive spectrum of competencies, utilising input from entrepreneurs who take a survey and machine learning analysis to narrow down the list and determine the most critical competencies for entrepreneurs at various stages of development. This research aims to validate these self-assessed competencies within novice and expert entrepreneur populations.

3.4 METHOD

3.4.1 *Participants*

Recruitment

Ethical Approval for this study was granted by the PNM Research Ethics Panel at King's College London (LRS-19/20-15026). The questionnaire was deployed online as part of the Entrepreneurial Brain Challenge (EBC) (Link: https://entrepreneur.cognitron.co.uk/), which included several other questionnaires and cognitive tests. Three types of communications and adverts were created to target different audiences; (1) people with no interest in entrepreneurship, (2) those with interest but no experience and (3) founders and people who identify as an entrepreneur. Communication was sent out externally via mailing lists, blog posts, Twitter, LinkedIn, and internal research recruitment streams.

Screening

All participants answered screening questionnaires online to ensure eligibility, confirming that they were; over the age of 18, had not suffered a traumatic brain injury, stroke or surgery to the brain, and had no diagnosed neurological or neuro-degenerative disorder (for example, brain tumours, Parkinson's Disease, Alzheimer's Disease, Huntington's Disease, Amyotrophic Lateral Sclerosis (ALS) / Motor Neuron Disease (MND)). They also answered a demographic questionnaire on sex, age, language, country of origin, education and entrepreneurial experience (founded, managed and owned a business, barriers in the way, how many businesses, longest-running business, sector etc.).

Grouping

Data was then grouped into non, novice and expert entrepreneurs as follows

1. **Novice Entrepreneur** - Participants who had founded, managed and currently own a business
2. **Expert Entrepreneur** - Participants who, in addition, had at least ten years of experience running a business or had founded three or more ventures.
3. **Non-Entrepreneurs** - Participants who fit neither of the above categories.

3.4.2 *Protocol*

Building the Questionnaire

The EntreComp framework identifies 15 competencies, including spotting opportunities, creativity, vision, valuing ideas, ethical and sustainable thinking, self-awareness & self-efficacy, motivation & perseverance, mobilising resources, financial and economic literacy, mobilising others, taking the initiative, planning & management, coping with ambiguity, uncertainty & risk, working with others, and learning through experience. Practitioners and researchers collaborated to adapt these competencies into an online questionnaire, the Entrepreneurial Competency Quesionniare (ECQ) with sliding scale statements from 0 'no aptitude at all' to 100 'very high aptitude'. The questionnaire questions are shown in Table 7.

A slider scale was chosen, rather than a Likert scale, for two reasons. Firstly, the slider is preferable for an interval scale for statistical analysis opposed to ordinal responses. Secondly, it allows for better validity in responses, as participants place their perceived competency along a continuous scale rather than conform to ordinal metrics (and labels of likert points) that may not represent the view of themselves (Imbault, Shore and Kuperman 2018). Additional questions were added, and some statements were split into multiple questions. For example, questions were added relating to (1) subject-specific knowledge and (2) asking whether they seek support from others. This was done due to practice-based insight into the importance of specialist (rather than generalist) knowledge in entrepreneurship and observations of resilience in how people lean on, seek and turn to others for advice. Moreover, some competencies which contained many elements were split into separate questions. For example, one competency statement around *coping with uncertainty, ambiguity and risk*, was divided into three questions (1) make decisions in uncertainty, (2) adapt when things go wrong and (3) prototype from an early stage to reduce risk of failure. The final questionnaire contained 18 competency questions, shown in Table 7. A final additional question (Q19) was added to gauge how *entrepreneurial* people believed themselves to be, based on their answers to the competency questions. This is because research and theory suggest that beyond the knowledge and skills (competencies) required to be entrepreneurial, part of the learning experience in entrepreneurship is that of developing an *Entrepreneurial Identity* (Almamari and Traynor 2021). The questionnaire was piloted on ten educators who specialised in entrepreneurship education at HE institutions to ensure the wording and language were suitable for the target audience.

Table 7: Competency statements presented to participants

	Competency Statement
Q1	I identify and seize opportunities to create value by exploring the social, cultural and economic landscape. By identifying needs and challenges that need to be met.

Q2	I develop several ideas and opportunities to create value, including better solutions to existing and new challenges. I explore and experiment with innovative approaches, combining knowledge and resources to achieve valuable effects.
Q3	I imagine the future and develop a vision of how I would like it to be.
Q4	I recognise the potential an idea has for creating value and identify suitable ways of making the most out of it.
Q5	Within the value-creating process, I include structured ways of testing ideas and proto-types from the early stages, to reduce risks of failing.
Q6	I reflect on my needs, aspirations and wants in the short, medium and long term. I identify and assess my strengths and weaknesses. Reflecting and learning from both success and failure.
Q7	I am able to make decisions when the result of that decision is uncertain, when the information available is partial or ambiguous, or when there is a risk of unintended outcomes.
Q8	I adapt to unforeseen changes and change my course of action if current actions are not working. Handling fast-moving situations promptly and flexibly.
Q9	I encourage and empower team members in order to achieve valuable outcomes.
Q10	I demonstrate effective communication, persuasion, negotiation and leadership. In presentations, media and any other outputs.
Q11	I initiate processes that create value. Take up challenges, act and work independently to achieve goals, stick to intentions and carry out planned tasks. I minimise the amount of procrastination.

Q12	I can get and manage the resources (material, non-material and digital) needed to turn ideas into action. Making the most of what limited resources I have.
Q13	I set long-, medium- and short-term goals. Define priorities and action plans.
Q14	I am patient and keep trying to achieve my long-term individual or group aims. I am resilient under pressure, adversity, and temporary failure.
Q15	I am able to turn to others for help when I am struggling or unable to complete a task myself.
Q16	I have (myself) or am able to get (from others) competences needed at any stage, including technical, legal, tax and digital competences. For example through suitable partnerships, networking, outsourcing and crowd sourcing.
Q17	I estimate the cost of turning an idea into a value-creating activity. Putting into place and evaluating financial decisions over time. Manage financing to make sure my value-creating activity can last over the long term.
Q18	I have strong subject-specific knowledge relating to my venture.

3.4.3 *Analysis Plan*

Data cleaning and factor analysis followed a pipeline from Imperial College London, previously used to clean online datasets from the Cognitron platform (that the Entrepreneurial Brain Challenge is created from), and subsequently applied research papers. This cleaning pipeline aims to ensure that we only use data from participants with sustained attention and consistency in online reporting, and to remove variables that may confound the data. The analysis pipeline enables a reduction of large sets of cognitive tests and survey data into a smaller number of variables that can be compared between groups of interest.

Data Cleaning

Nine hundred seventy-six participants completed the screening, demographic and competency questionnaire. Of these participants, 65 were removed, as they either A) did not meet the study eligibility criteria, B) did not answer all questions or C) responded to the questions improbably fast (e.g. far too quickly to have *read* the questions - less than 560 ms), resulting in a usable sample size of 911 individuals. To control for potential effects of no interest within these data, we fit individual linear regression models to each questionnaire score to account for variance in the outcome variable associated with age, gender, language, country, ethnicity and education collected in the demographics questionnaire. The residuals from these linear models were carried forward into the analysis. All statistical analyses were performed using MATLAB (Inc. 2022), while group comparisons and final figures were produced using R (R Core Team 2023).

Factor analysis

Principal Component Analysis (PCA) with varimax rotation was used to identify the optimal number of cross-competency 'Factors', which most efficiently and comprehensibly explained the variance of the 18 EntreComp competencies.

Two common methods used for dimentionality reduction are Exploratory Factor Analysis (EFA) and PCA, often giving approximately the same results. An EFA aims to measure and hypothesise an underlying construct which is not directly measurable. The PCA is a reduction technique that reduces the observed variables to a smaller number of principal components, which account for most of the variance in the observed data. Whilst EFA focuses more on the relationship among variables, PCA has more emphasis on data reduction. As stated in Alavi et al. (2020) *"Principal component analysis is used to simplify complex data by identifying a small number of principal components which capture the maximum variance"*. For the purposes of our aim to *narrow down the list and determine the most critical competencies for entrepreneurs at various stages of development*, PCA is the most useful technique for this study. With PCA we can therefore reduce the long list of competencies down to a smaller set of factors to test between our different groups.

Firstly the cleaned data was windsorised (to 8 standard deviations). As the data was not normally distributed, we performed an inverse-rank order transformation to the data. To determine the number of factors for further analysis, we used the scree plot method (Cattell 1966) to balance the trade-off between explained variance of the data and the interpretability of the resulting constructs.

Descriptive statistics and data visualisation

Histograms and Shapiro-Wilk tests were used to examine the normality and distribution of the factors and scores obtained, these are shown in the supplementary material 3.9 in Table 11 and figure 3.6. Due to multiple results failing to show normal distribution, non-parametric tests were performed on all scores. Descriptive statistics of the data are reported as medians and interquartile ranges for each group.

Group Comparisons

Once the entrepreneurial competencies are reduced down to a smaller set of underlying factors, this provides a set of variables to test between groups of non-, novice and expert entrepreneurs. This enables easier interpretation of the underlying competencies in entrepreneurship. Group comparisons were performed with a Kruskal-Wallis rank test; the independent variables were the groups of non-, novice and expert-entrepreneurs, whilst the dependent variable in each comparison were the five residual factor scores obtained from the factor analysis. The p-value was adjusted using FDR correction. Any significant differences were further tested between groups using pair-wise comparisons of the mean ranks with a Dunn test. Power calculation using G*power (Faul et al. 2007), indicated that for KW tests, with 3 groups, to achieve a medium effect size, at the .05 alpha level, with a power of 0.95, required a total sample size of 159 (53 within each group).

3.5 RESULTS

3.5.1 *Descriptive statistics*

Of the 976 participants who completed the questionnaire, 911 remained after cleaning. Not all demographic data was available due to participants opting out of answering questions ('prefer not to say'), or the data was missing, leading to 113 missing scores. The complete data set of residual scores used in the analysis was, therefore, n=798, consisting of non-entrepreneurs (n=620), novice entrepreneurs (n=116) and expert entrepreneurs (n=62). This is to put in the context of the above power analysis that indicated that we required 53 participants in each group. Table 8 shows the descriptive statistics of the demographics for each group. Confounding factors (age, gender, languages, ethnicity, education, handedness) were removed through linear modelling to leave residual scores for every question for each participant. The split of sectors where participants had experience is shown in Figure 3.1.

3.5.2 *Factor analysis*

The Principal Component Analysis on 798 participants' residual scores, examination of the scree plots and interpretation of the factors revealed five competency factors underlying the 18 original competency statements. We have named these Disruption, Growth, Resourcing, Communication and Planning. The questions loaded onto these five factors are shown in Table 9. The overall factor loading structure for each question is shown in figure 3.2. Three questions were retained as independent competencies that did not load onto any factors; validation, help from others, and subject-specific knowledge.

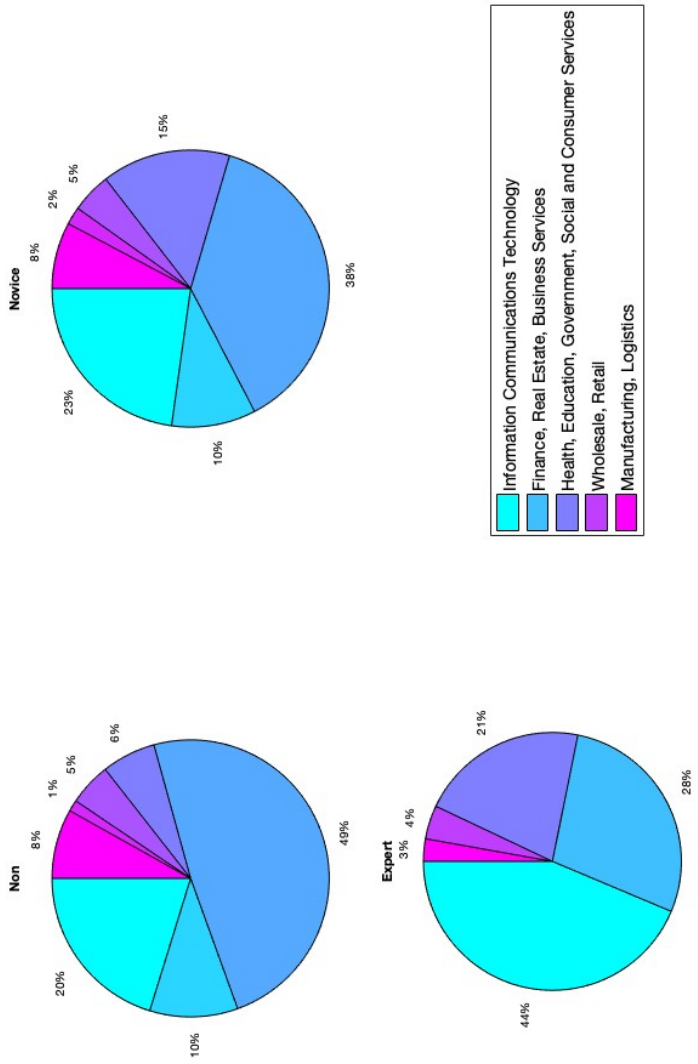

Figure 3.1: Professional sectors of the participants in each group; non-entrepreneurs, novice and expert entrepreneurs.

Table 8: Demographics of Participants who completed the Entrepreneurial Competency Questionnaire n = 798

Variable	Group		
	Non-Entrepreneur	Novice	Expert
n	620	116	62
Age Mean (SD)	28 (10)	32 (11)	41(13)
Age Range	18-72	18-69	20-64
Gender (ratio F : M : N)	413 : 202 : 5	66 : 50	21 : 41
No of. Languages	48	26	13
% First Language = English	52%	59%	66%
No. of Ethnicity's	19	14	9
No of. Nationalities	71	26	25
Handedness (RH : LH : A)	535 : 64 : 18	107 : 6 : 3	51 : 3 : 8
Business Information			
Number of Businesses Mean (SD)	–	1.28 (0.45)	3.60 (1.80)
Years of Business Running Mean (SD)	–	3.32 (1.90)	10.32 (7.26)
Years of business Running Range	–	1-9	2-35
Sectors			
Information Communications Technology	127	28	29
Finance, Real Estate, Business Services	65	18	17
Health, Education, Government, Social and Consumer Services	299	25	11
Wholesale, Retail'	39	26	3
Manufacturing, Logistics'	32	4	2
Agriculture, Extractive, Construction	8	3	0
Charity, NGO, Social Enterprise	50	12	0

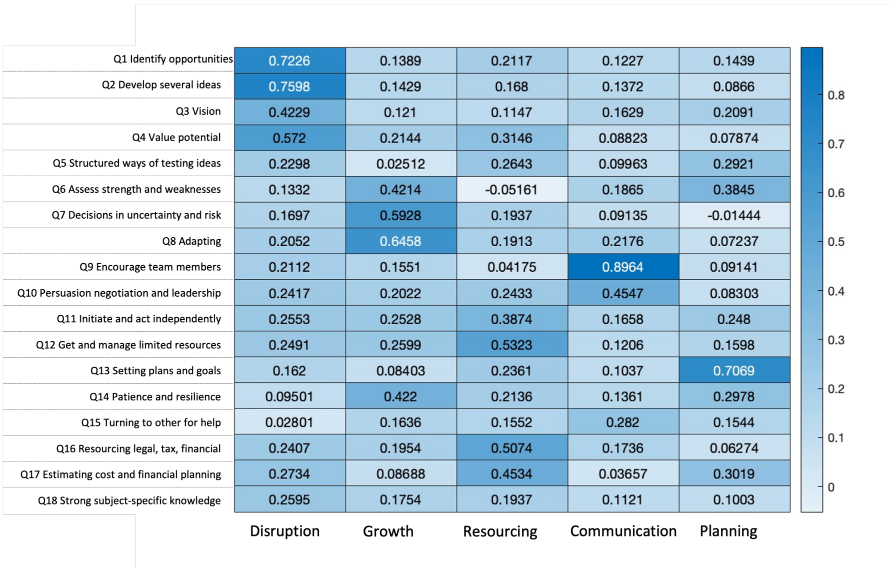

Figure 3.2: Heatmap of how each of the 18 questions in the questionnaire loads onto the five factors. Y-axis indicates the question numbers from 1-18, whilst the X-axis shows the five factors. Darker blue indicates a higher *loading* onto that factor, from 0 to 1.

Table 9: Factor Loading's for the Entrepreneurial Competency Questionnaire

Factor	Questions with ⩾ .35	Eigen Value (Ascending)
F1: Disruption	Q2 Develop several ideas	.76
	Q1 Identify opportunities	.72
	Q4 Value potential	.57
	Q3 Vision	.42
F2: Growth	Q8 Adapting	.65
	Q7 Decisions in uncertainty and risk	.59
	Q14 Patience and resilience	.42
	Q6 Assess strength and weaknesses	.42*
F3: Resourcing	Q12 Get and manage limited resources	.53
	Q16 Resourcing legal, tax financial competencies	.51
	Q17 Estimating cost and financial planning	.45*
	Q11 Initiate and act independently	.39
F4: Communication	Q9 Encourage team members	.90
	Q10 Persuasion negotiation and leadership	.46
F5: Planning	Q13 Setting plans and goals	.71
	Q6 Assess strength and weaknesses	.38*
Independent	Eigen Value ≪ .35	
I1: Validation	Q5 Structured ways of testing	
I2: Help from Others	Q15 Turning to other for help	
I3: Subject Knowledge	Q18 Strong subject-specific knowledge	

note: *FDR adjusted p-value at .05 alpha level

3.5.3 *Group Comparisons*

The median scores and IQR scores for the non (n=620), novice (n=116) and expert entrepreneurs (n=62) for each factor are shown in Table 10. Complete statistical tests for each factor are shown in Table 10. Boxplots for all five factors and the KW results are shown in figure 3.3.

Table 10: Descriptive Statistics on Competency Factor Scores for Non, Novice and Expert Entrepreneurs

Factor Scores (from PCA)	Median (IQR)			FDR p-value	95% CI
	Non-Entrepreneur (n=620)	Novice (n=116)	Expert (n=62)		
F1: Disruption	-0.14 (1.10)	0.27 (1.18)	.45 (0.95)	8.51e-10**	[0.04,1.00]
F2: Growth	-.08 (1.04)	0.14 (1.12)	0.27 (1.04)	.07	[9.90e-04,1.00,]
F3: Resourcing	-0.10 (0.94)	0.26 (0.89)	0.34 (0.68)	1.15e-06**	[0.02,1.00]
F4: Compelling Communication	0.02 (1.16)	-0.16 (1.28)	0.22 (1.56)	.09	[9.43e-04,1.00]
F5: Planning	0.03 (0.03)	-0.06 (-0.06)	-0.07 (-0.07)	.22	[5.71e-04,1.00]
Independent Question Scores					
I1: Validation (Q5)	3.12 (42.10)	-1.75 (39.11)	5.65 (48.23)	.57	[4.78e-05, 1.00]
I2: Help from Others (Q15)	6.04 (40.90)	-1.25 (39.57)	13.11 (39.42)	.07	[1.94e-03,1.00]
I3: Subject-specific Knowledge (Q18)	1.76 (31.46)	4.80 (28.73)	11.13 (23.21)	.03*	[2.82e-03,1.00]
Entrepreneurial Identity					
How entrepreneurial do you believe you are?	-0.49 (36.20)	14.93 (29.74)	19.73 (19.18)	9.70e-18**	[0.08,1.00]

note: *FDR adjusted p-value at <.05 alpha level, **<.001

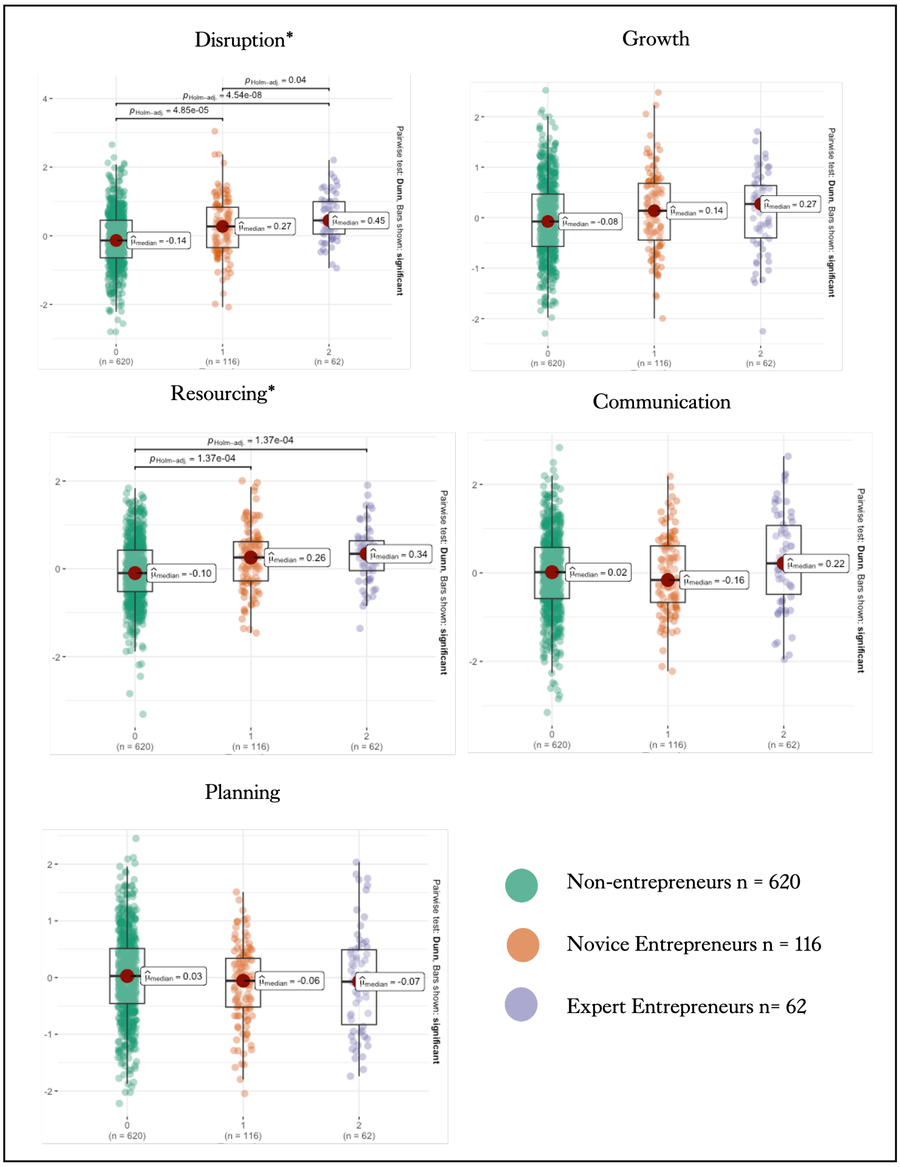

Figure 3.3: A principal component analysis (PCA) on the questionnaire scores revealed five underlying factors; disruption, growth, resourcing, communicating and planning. The 5-factor scores were run through separate Kruskall-Wallis tests to compare the difference between non, novice and expert entrepreneurs. These charts show boxplots from the Kruskall-Wallis test with post-hoc Dunn pairwise comparisons. Starred items correspond to statistically significant differences at <.05 alpha level.

Factor 1: Disruption

There were significant differences between the groups for disruption ($\chi2(2) = 44.78$, $p < .001$), with a stepwise increase in median scores of -.14, .27 and .45 for non-entrepreneurs, novice entrepreneurs and expert entrepreneurs respectively. This test produced a medium effect size (η^2=.060) and 95% confidence intervals [0.04, 1.00]. Mean ranks were significantly higher in novice ($p < .001$) and expert-entrepreneurs ($p < .001$) when compared to non-entrepreneurs. A significant difference was also revealed when comparing novice to expert entrepreneurs ($p = .03$).

Factor 2: Growth

There was no statistically significant effect of group membership for growth ($\chi2(2) = 6.35$, $p = .07$), with a stepwise increase in median scores of -.08 for non-entrepreneurs, .14 for novice entrepreneurs and .27 for expert entrepreneurs and a small effect size ($\eta^2 = .008$) and 95% confidence intervals [0.003, 1.00].

Factor 3: Resourcing

A statistically significant difference was found between the groups for resourcing ($\chi2(2) = 29.55$, $p < .001$), with a stepwise increase in median scores of -.10 for non-entrepreneurs, .26 to novice entrepreneurs and .34 for expert entrepreneurs and a medium effect size (η^2=.04) and 95% confidence intervals [0.02, 1.00]. Mean ranks were significantly higher in novice ($p < .001$) and expert entrepreneurs ($p < .001$) when compared to non-entrepreneurs. No significant differences were shown when comparing novice to expert entrepreneurs.

Factor 4: Communicating

No statistically significant differences were found between the groups for communication ($\chi2(2) = 5.29$, $p = .09$), with median scores of .02 in non-entrepreneurs, -.16 for novice entrepreneurs and .22 for expert entrepreneurs and a very small effect size (η^2=.007) and 95% confidence intervals [0.001, 1.00].

Factor 5: Planning

No statistically significant difference was found between the groups for planning ($\chi 2(2) = 4.04$, $p = .23$), with median residual scores of .03 in non-entrepreneurs to -.06 in novice entrepreneurs and -.07 in expert entrepreneurs, an effect size of η^2=.005 and 95% confidence intervals [0.001, 1.00].

Independent Questions

Boxplots and statistical test results for the independent questions are shown in figure 3.4. Question 18, focusing on subject-specific knowledge, showed a significant difference between the groups ($\chi 2(2) = 8.22$, $p = .03$), with median scores increasing with expertise, with 1.76 for non-entrepreneurs, 4.80 for novice and 11.13 for expert entrepreneurs, with a small effect size (η^2=0.01) and 95% confidence intervals [0.003, 1.00]. Post-hoc pair-wise comparisons revealed mean ranks were significantly higher in expert entrepreneurs than non-entrepreneurs (p=0.02); however, not between non-entrepreneurs and novice entrepreneurs nor between novice and expert entrepreneurs. Question 5, focusing on validation (structured ways of testing prototypes), showed no significant difference between the groups ($\chi 2(2) = 1.13$, $p = .07$) showed medians of 3.12 for non-entrepreneurs, -1.75 for novice entrepreneurs and 5.65 for expert entrepreneurs, with a very small effect size (η^2=0.001) and 95% confidence intervals [0.0001,1.00]. Question 15, focusing on turning to others for help, showed no significant difference between the groups ($\chi 2(2) = 6.16$, $p = .07$) with median scores of 6.08 for non-entrepreneurs, -1.25 for novice and 13.11 for expert entrepreneurs, with a small effect size (η^2=0.007) and 95% confidence intervals [0.0004, 1.00].

Entrepreneurial Identity

The final question, question 19, asked participants to score how entrepreneurial they believe they are based on the questions answered. We found a significant difference between the groups for entrepreneurial identity ($\chi2(2) = 82.74$, $p = <.001$), with median residual scores that increased from -0.49 in non-entrepreneurs to 14.93 in novice entrepreneurs and 19.73 in expert entrepreneurs, with a large effect size (η^2=.10) and 95% confidence intervals [0.08, 1.00]. Mean ranks were significantly higher in novice ($p < .001$) and expert entrepreneurs ($p < .001$) when compared to non-entrepreneurs. No significant differences were shown when comparing novice to expert entrepreneurs.

3.6 DISCUSSION

3.6.1 *Summary*

Five crucial factors contribute to the comprehensive skillset of successful entrepreneurs. These factors encompass disruption, growth, resourcing, communication, and planning. Our findings revealed that the perception of these competencies varies depending on an individual's experience level. Specifically, we have observed that individuals who have founded a business tend to excel in competencies related to disruption and resourcing. They also have a strong sense of entrepreneurial identity and possess subject-specific knowledge, further strengthening their competencies. Our results complement prior studies by condensing an extensive list of competencies from

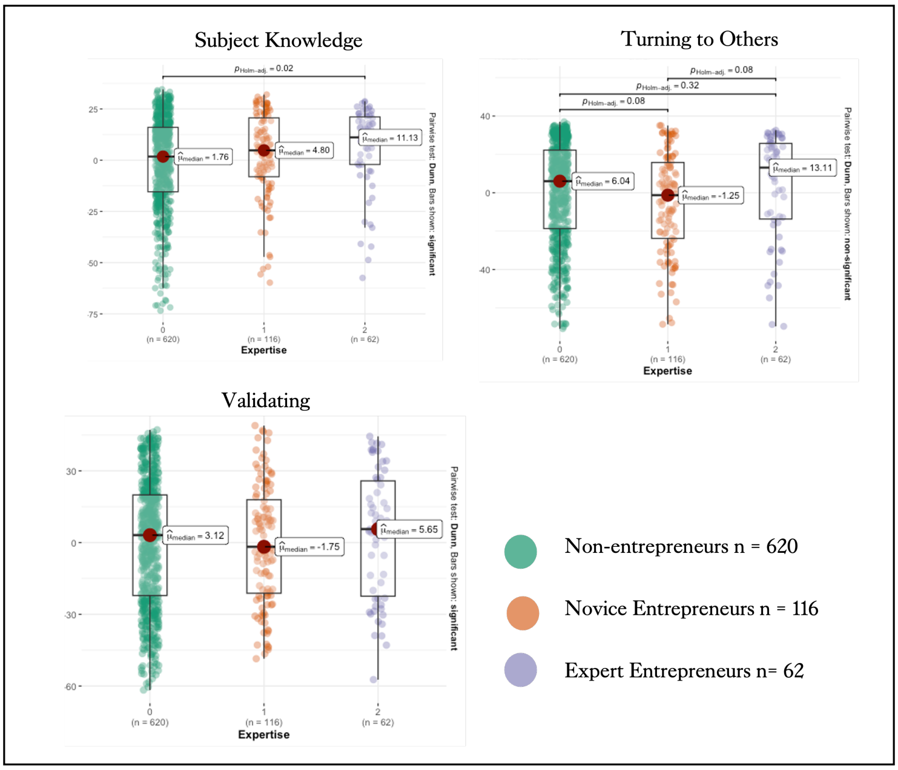

Figure 3.4: Independent questions that did not sufficiently (>0.35) load onto any of the factors; therefore, the scores from these were treated as three further independent competencies: subject-knowledge, turning to others and validating. This figure shows box-plots and results from the Kruskall-Wallis test with post-hoc Dunn pairwise comparisons.

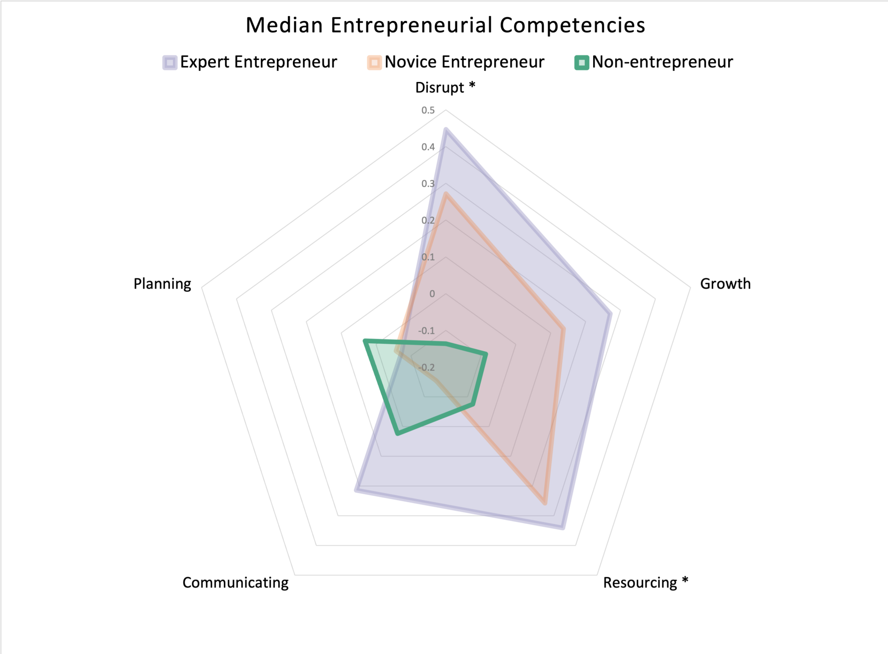

Figure 3.5: Median Factor Scores for each group. Starred items correspond to statistically significant differences at <.05 alpha level.

the EntreComp into a smaller set of underlying factors by conducting a factor analysis on results from a self-report survey (McCallum et al. 2018). Moreover the factors of disruption/opportunity and resourcing show good consistency both conceptually and in other empirical studies which also performed factor-analysis on self-report data (López-Núñez et al. 2022).

Using a data-driven approach to reduce and group the questions interestingly support a popular 'process-orientated' model of entrepreneurial intention, which suggests intent is structured by both rational/analytic thinking (goal-directed behaviour) and intuitive/holistic thinking (vision) (Boyd and Vozikis 1994; Bird 1988). The competencies which highly load onto *Factor 1: Disruption*, included competency statements related to intuitive/holistic (vision) thinking such as vision, idea creation, opportunity identification and value potential, see Table 9. Whilst *Factor 3: Resourcing*, represents the rational/analytical (goal-directed) thinking, which is required to take an idea to action; this was made of questions in our survey such as getting and managing limited resources, resourcing legal, tax and financial competencies, estimating cost and financial planning and initiating acting independently. Our results, along with this model, therefore support the notion that ideas alone do not make someone entrepreneurial, but the ability to take action on these ideas does. However, it is important to consider how self-efficacy, experience, and influence may impact self-reported competency scores (Boyd and Vozikis 1994).

3.6.2 *Step-wise Increases in Disruption and the Influence of Power*

Most notably, disruption (i.e., idea creation, validating ideas, vision) was more significant in novice entrepreneurs than non-entrepreneurs and even greater in expert entrepreneurs than novices. This factor included competency statements such as developing several ideas, identifying opportunities, recognising the value potential and having a solid vision of the future. This factor was identified as *disruption* due to its close relationship to disruptive thinking. Disruptive thinking has been defined as *the action of breaking, in a planned way, how something is accomplished or understood, thereby seeking to create something new or different from what already exists* (Márquez and Ortiz 2021), closely related to the concept of innovation and Schumpterian theories of entrepreneurship as "creative destruction" (Schumpeter 2013). This argues that entrepreneurs drive economic growth through innovation by introducing new products and technologies that disrupt existing market structures. This step-wise increase in the perception of disruptive capabilities with experience may suggest that perceived disruption improves with more years of experience and more businesses produced. Alternatively, individuals become more confident in their ability to be disruptive, highlighting this as a continuously developing competency.

Interestingly, prior scholars have suggested that disruptive thinking is easier when in a position of power or privilege. Márquez and Ortiz (2021) argues for *The Fiction of Applicability* in disruptive thinking, meaning that its applicability within the workplace and the business world is not as common or easy as presumed. This is because power structures often prevent significant changes brought about by what they term 'base personal'; instead, changes often occur from the 'vision' of those with considerable influence and power. This may indeed show why the competence of Disruption is perceived to be greater in those expert entrepreneurs who likely have vast experience in positions of influence. These findings draw attention to how we can create environments that encourage, teach and promote disruptive thinking-particularly for individuals in less senior positions. Or, how can we permit people who lack the experience and power positions to think disruptively, which would allow them to do so.

Recent work has looked at the types of environment that promote creative thinking in both children in education and adults in the workplace. For example a systematic review, noted limited empirical works, but consistent themes associated with creative learning environment such as: flexible use of space and time; working outside the classroom/school; 'playful' or 'games-bases' approaches with a degree of learner autonomy; respectful relationships between teachers and learners; opportunities for peer collaboration; non-prescriptive planning (Davies et al. 2013). Whilst recent work in entrepreneurship has begun to move towards viewing creativity as a state and considering personal factors that may effect this such as age, sleep and stress. Promoting the importance of 'recovery' time and the creative problem-solving that can in occur in out-of-work hours (Weinberger et al. 2018). However the importance of disruption posed by both self-perceptions in this sample and classic theories of entrepreneurship, little is currently known empirically about how to develop a disruptive, innovative or creative state of thinking—highlighting this as an essential future angle of empirical research.

3.6.3 *Resourcefulness: a necessary component to taking the leap*

Despite the idea creation and vision that comes with *Disruption*, *Resourcing* was also shown to be significantly greater in novice and expert entrepreneurs when compared to non-entrepreneurs. This factor contained statements relating to getting, learning, and managing resources, including tax, legal and financial resources, estimating costs and initiating and acting independently. Whilst there are no significant differences between novices and experts in resourcing competencies, both entrepreneur groups reported to be significantly better at resourcing than non-entrepreneurs. This factor was termed resourcing due to the definition of Resources as *...the materials, money, and other things that they have and can use to function appropriately* (C. E. Dictionary 2022). The questions loading onto this factor involve the resourcing of people, money and materials needed to turn ideas into action; interestingly, they also seem to underlie competencies engaged in initiating and acting independently. Suggesting, entrepreneurs may gain such resources and knowledge through self-motivated and independent learning. Resourcing is a concept well researched in entrepreneurship literature (Alvarez and Busenitz 2001). Most notably, knowledge-based resources are seen as key to competitive advantage in firms and individuals, as these can be hard to imitate (Wiklund and Shepherd 2003). Moreover, an entrepreneurs network is one of the most important aspects noted in resourcing theories, as it is through a social network and environment that knowledge is gained, then through capitalisation on ones resources that ideas can be exploited and acted upon (Sullivan 2010; Brush, Patricia G Greene and Hart 2001).

Resourcing as a competency does not significantly differ between novice and expert entrepreneurs, making it a necessary quality that differentiates those who have started a business from those that do not, rather than one that increases through entrepreneurial experience. The low ratings in this competency in non-entrepreneurs suggest it is an area of focus for entrepreneurial educators. In particular, one statement relates to resourcing the needed legal, tax and financial competencies, whether in themselves or others, and another relates to estimating costs and financial plans. This competency factor incorporates what is sometimes termed the 'hard skills' of entrepreneurship, meaning no confidence or competence in finance and legal knowledge, could seriously impede one's entry into entrepreneurship.

3.6.4 *Jack-of-all-trades?*

In addition, we also found significant differences in higher self-perception of subject-specific knowledge in expert entrepreneurs, empirical data that challenges the popular *jack-of-all-trades* notion in entrepreneurship. Lazear originally proposed that entrepreneurs should not be experts in a single skill but more of a generalist (Lazear 2005). This position argues that the estimated probability of becoming self-employed increases with varied work experience. However, this has also since been disputed, with studies such as Lechmann and Schnabel (2014) showing that whilst entrepreneurs need to perform more tasks and thus possess a greater variety of skills, they also need to be technical experts in some particular skills to add real value. Our findings only test the entrepreneurs' self-perception, and thus we obtained no data on how many tasks they carry out in their job nor objective measures of their skills or expertise in their business area. However, it is interesting to observe, in the context of opposing generalist versus specialist theories, that the expert (over ten years of experience and/or more than businesses), and arguably successful entrepreneurs perceive themselves as subject-matter experts in our data.

3.6.5 *Entrepreneurial Identity*

Finally, when asking a question relating to entrepreneurial identity, *how entrepreneurial do you believe you are?* Unsurprisingly entrepreneurs (who founded, managed and owned a business), regardless of whether they were novices or experts, rated themselves significantly more entrepreneurial than non-entrepreneurs. Researchers argue that how an entrepreneur identifies plays a critical role in the early formation of the business, setting them apart from the rest, and then later in the time and passion they put into acquiring the resources needed (Radu-Lefebvre et al. 2021). However, despite its undeniable importance, identity is often left out of entrepreneurship training. As shown by Donnellon, Ollila and Middleton (2014), identity construction is as necessary to develop as the knowledge and skills required for entrepreneurship; authors also argue the critical component to developing entrepreneurial identity is a 'learning *through* doing' approach. Which is largely supported by our findings that those in our sample with the real-life experience self-report greater entrepreneurial identity, as well as higher competence in disruptive thinking and resourcing. In particular, we show that self-reported competence in disruptive thinking and resourcing continues to rise with more expertise. However, we have discussed how power dynamics can play into the permission and ability to be disruptive. We feel these findings support a process-approach model of entrepreneurial intention, which describes an entrepreneur as one who can have the vision from disruptive thinking but apply analytical goal-directed behaviour to resource what is needed, often from their network. This, combined with strong confidence in their subject-specific knowledge and entrepreneurial identity (knowing what sets them apart from the rest), seems to be the makeup of entrepreneurial competence.

3.6.6 *Limitations*

Now, there are important aspects of entrepreneurship that we found no difference in, such as; growth, communication, and planning. Due to the reliance on self-report in this questionnaire, it can be difficult to speculate whether this is due to there really being little difference in those competencies between entrepreneurs and non-entrepreneurs or whether confidence and experience largely bias the results we see.

This reliance on self-report data also underlies a limitation of this whole study. Since the questionnaire asks individuals to reflect on their own competencies, therefore, it is important to note that the results of this study represent participants' perceptions of their own competencies rather than a direct measurement of those competencies. Despite this limitation, the results of this study are still significant in the field of entrepreneurship training. This is because confidence, also known as self-efficacy, is a critical factor in determining entrepreneurial action (Gielnik, Bledow and Stark 2020; McGee et al. 2009; Wilson, Kickul and Marlino 2007; Chen, Patricia Gene Greene and Crick 1998). Self-efficacy is shown to be a strong predictor of entrepreneurial intentions and ultimately action (Bird 1988; Boyd and Vozikis 1994). Moreover, research suggests that an individual's entrepreneurial self-efficacy can be elevated through training (Florin, Karri and Rossiter 2007; Mueller and Goic 2003; Zhao, Seibert and Hills 2005). By identifying areas where individuals feel less confident, this study provides valuable insights that can be used to guide training and development programs, such as focusing on helping non-entrepreneurs to develop confidence in disruptive thinking, resourcing and entrepreneurial identity. Future research should explore how self-efficacy impacts perceptions of these competencies. By focusing on improving those areas where entrepreneurs feel less confident, such programs can help to build a strong foundation of self-efficacy, which can, in turn, drive action and increase the likelihood of success.

Another limitation of this study is the online context in which the data was collected due to the Covid-19 pandemic. While the convenience and reach of online surveys can provide valuable insights, there is always the risk of reduced engagement and attention among participants (Van Selm and Jankowski 2006). This can affect the validity of the results, as it is not possible to determine the extent to which individuals fully understood and engaged with the questions. To minimize this limitation, we cleaned the data and removed any instances where participants appeared to click through the questionnaire without giving proper consideration to the statements. However, it is still possible that some participants may have rushed through the questionnaire without fully reflecting on their competencies. This highlights the importance of future studies to validate the results and explore the robustness of the questionnaire in different contexts.

3.7 CONCLUSIONS

3.7.1 *Recommendations for practitioners who train or teach entrepreneurship based on this study*

1. The two most important things to teach aspiring entrepreneurs who have no experience starting a business are; 1) disruptive thinking (develop several ideas, identify opportunities, recognise value potential and vision) and 2) resourcing (getting and managing limited resources, resourcing the legal, tax and financial

competencies, initiating and acting independently). These two ingredients create someone who is a visionary but also a doer.

2. More understanding and research are needed on how to help encourage disruptive thinking. A potential roadblock of disruptive thinking; is position and perceived power; how can you create environments that permit and empower individuals or groups to think disruptively?

3. Don't ignore the confidence lacking in resourcing skills, tax, and legal knowledge. Provide masterclasses in this and build networks which can help individuals develop such knowledge and competence.

4. Focus on efforts to develop confidence in their subject-specific area and encourage them to develop this niche. Although they may have to take on many tasks and roles, they should also focus on becoming an expert in some of these and try not to adopt a stereotypical jack-of-all-trades approach.

5. Help them build an entrepreneurial identity and self-efficacy in entrepreneurship, mainly by a learning-through-doing approach.

In conclusion, this study presents a comprehensive overview of self-perceived entrepreneurial competencies, which are often difficult to quantify. It offers a machine-approach that reduces them to a manageable set of underlying factors. Our findings provide a valuable framework for identifying critical areas for training and development at different stages of entrepreneurship, but also areas that need to be explored further from a research perspective, e.g. how do we develop disruptive thinking? The strength of this study is that it generates a framework based on the reported competencies of real-life entrepreneurs. The questionnaire we developed can assess individual competencies and guide the development of weaker or less confident areas.

Future research directions could explore the correlation between these competencies and measures of success in entrepreneurship, as well as examine any discrepancies between self-reported and observed competencies. Overall, we believe the results of this study have the potential to inform and enhance extracurricular programs aimed at developing essential soft skills and competencies in aspiring entrepreneurs. Whilst training competencies related to growth mindsets, communication, and planning may be useful across the board, we show that training focusing on disruptive thinking and resourcing, and even in developing confidence around their niche or expertise, may be most useful specifically for those non-entrepreneurs wishing to take 'the leap' and develop entrepreneurial identity.

In the context of this thesis, this reaffirms the importance of disruptive and creative thinking for entrepreneurship, as well as the ability to resource. This data complements the theory of effectuation coming from the entrepreneurial cognition literature, as the means by which entrepreneurs create newly imagined ideas by working with the resources to hand. In the next chapter, I explore the cognitive components that underlie disruptive and resourcing capabilities.

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3.9 SUPPLEMENTARY MATERIAL

Measure	p
F1: Disruption	0.3413
F2: Growth	0.1379
F3: Resourcing	0.002409*
F4: Communication	0.8649
F5: Planning	0.7621
I1: Validation	1.527e-10*
I2: Turning to Others	2.2e-16*
I3: Subject Knowledge	2.2e-16*

Table 11: Shapiro-Wilk's Normality Tests: whereby a significant p-value indicates the data significantly deviates from the normal distribution and thus non-parametric tests should be performed. This was shown for F3 (resourcing), and the independent questions of I1 validation (Q5), I2 Help from Others (Q15) and I3 Subject Specific-knowledge (Q18).

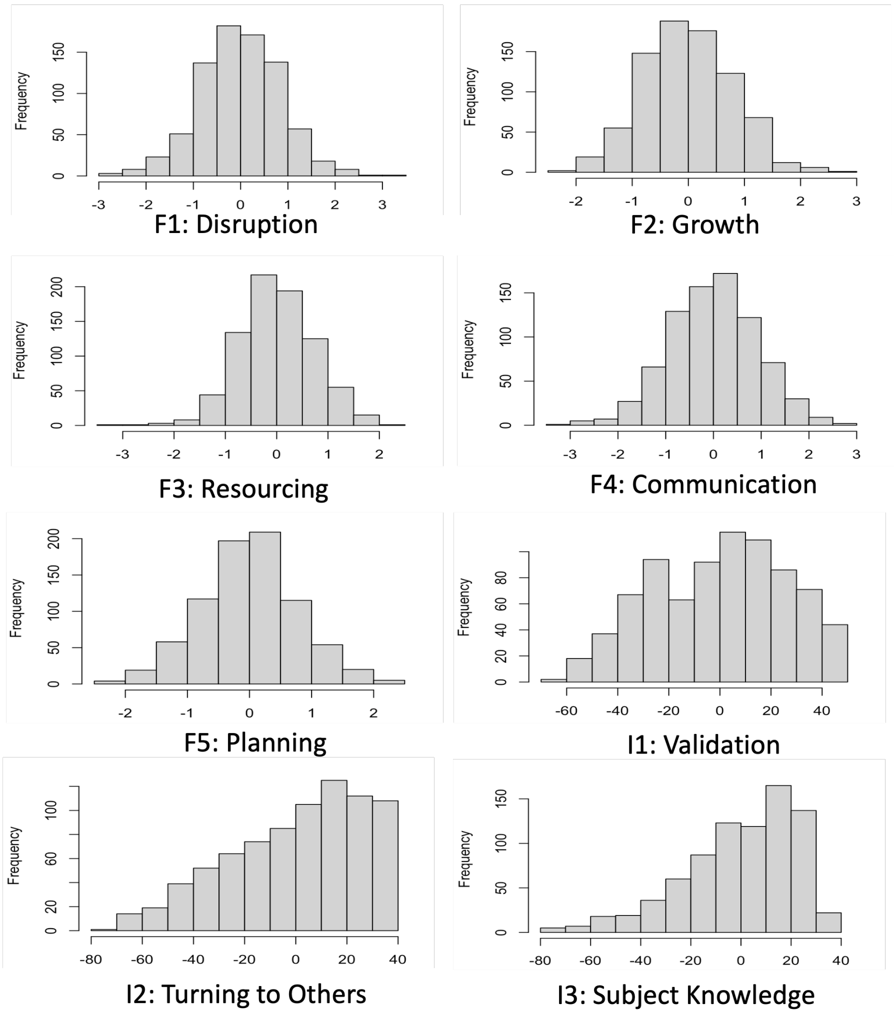

Figure 3.6: Histograms showing the frequency spread of data for each of the factors and independent scores.

4

CHAPTER 4: BEYOND THE STEREOTYPES: INVESTIGATING THE NEUROCOGNITIVE AND PERSONALITY TRAITS OF ENTREPRENEURS

> In leadership, life and all things, it's far wiser to judge people by their deeds than their speech - their track record rather than their talk.
>
> Rasheed Ogunlaru

4.1 PREFACE

In this chapter, I bring together both the entrepreneurship theory introduced at the start of this thesis, the findings from the literature review and reports on entrepreneurial competencies, to begin to test how entrepreneurs think with neuroscience methods, in this case neurocognitive testing.

I showed in the previous chapter the self-perceived importance of competencies of disruptive thinking (creativity to coming up with ideas) and resourcing (gathering the means to action such resources) in entrepreneurship. I also commented on how well this ties back to entrepreneurial cognition theories on the effectual logic and thinking of entrepreneurs, as creating something never previously imagined with the resources to hand. However, such competencies are self-reported and exist on a macro-level, meaning that there is a broad set of underlying factors that likely make up each competency and the actual behaviour of an individual. As shown in chapter 1, competencies such as creativity, are built from three domains (Amabile 1998):

1. Expertise: Domain-relevant knowledge.

2. Thinking Skills: Cognitive and personality profiles conducive to innovative thinking.

3. Motivation: Attitude toward the task, with intrinsic motivation being more crucial than extrinsic motivation.

Due to the focus on cognitive neuroscience techniques, this chapter delves into the thinking skills that underpin such competencies, exploring the neurocognitive and personality profiles that may drive creative and resourceful capabilities within entrepreneurs. As previously discussed, a challenge for entrepreneurship education is discerning which components of a competency are inherent to individuals and thus precede entrepreneurship, versus those developed through experience and therefore viable targets for education and training. This chapter begins to test assumptions regarding the cognition underlying entrepreneurial competency and examines the stable (trait) and malleable (cognitive) aspects of these thinking skills.

The Entrepreneurial Brain Challenge was an online study created to explore entrepreneurs' personality and cognitive profiles. It was born out of a wish to shift the pop-culture views of *what it takes to be an entrepreneur*. A range of online neurocognitive tasks and questionnaires were administered during an hour-long test session which individuals accessed from home. Due to the infancy of cross-collaboration in the neuroentrepreneurship research field, we used the past literature review and themes identified to create relevant hypothesis-driven cognitive testing. Also, we administered a novel neurocognitive testing approach to explore, from a data-driven perspective, what might be different about an entrepreneur's neurocognitive profile which enables such disruptive thinking. The Entrepreneurial Brain Challenge results were then used to define and design the experiments given to entrepreneurs in the MRI scanner, in Chapter 5.

4.2 ABSTRACT

This study aims to investigate the neurocognitive and personality characteristics of the entrepreneur, using both hypothesis-driven and novel data-driven approaches. The study utilises the Cognitron online testing platform for three experimental tests, exploring 1) impulsivity, 2) uncertainty tolerance, and 3) a standard battery of neurocognitive and personality tests. The results demonstrate that entrepreneurs have higher self-reported tolerance of uncertainty, but this is not reflected in how they perceive volatility on a cognitive level. No significant differences are found in information sampling or self-reported impulsivity. A binomial logistic regression shows that entrepreneurial status can be predicted by subtly different neurocognitive abilities, including greater episodic memory, lower verbal reasoning, and traits of lower conscientiousness and neuroticism, but higher openness. This research contributes a novel methodological approach to studying entrepreneurs, highlights discrepancies between self-report and cognitive test results, challenges popular assumptions of the entrepreneur, and shows the subtle differences in the neurocognitive profile of entrepreneurs that may inform future work further exploring neurodiversity and creativity in entrepreneurship.

4.3 INTRODUCTION

4.3.1 *Background*

What makes one person more innovative, creative or successful? That depends one what you define as success. For decades, success for many is dictated by traditional measures of intelligence; intelligence earns you good grades, a good degree and then a good job. However this simple model doesn't stand the test of time. In fact the model is completely broken down in many entrepreneur's anecdotal stories, those school or university dropouts who had the creativity to form a unique idea. Our methods and approaches to studying intelligence in neuroscience are only just catching up with the idea that there may be more than one definition of success, and thus different and diverse neurocognitive strengths may be considered for a more rounded approach to studying the brains of successful individuals. For example, Hampshire, Highfield et al. (2012) have shown how intelligence is not one universal 'g' factor, but can be fractioned into separate components. Therefore highlighting the unique and diverse skill sets different people may harbour, that aid them in succeeding in different careers, roles and lifestyles.

One group of people who embody the ability to succeed outside of education are entrepreneurs: they create and invent ideas that solve problems yet also demonstrate the resourcing capability to carry ideas forward. It is no wonder that this group has been studied for decades from the economic, social science and psychological angles, and this has led to many theoretical models of entrepreneurial cognition, described as an ability to be "dynamic, flexible, and self-regulating in [their] cognition given dynamic and uncertain task environments" (Haynie et al. (2010), p.218). Yet methods for testing entrepreneurs' cognition have been so far limited to survey and think-aloud scenarios.

Therefore the elusive 'black box' of what neurocognitive processing happens inside an entrepreneur's brain is unknown.

4.3.2 *Gaps*

Understanding the entrepreneur's brain is no easy endeavour. Empirical research is needed to identify differences in the brains of those with entrepreneurial potential. Scientists have begun exploring the effects that neural processing, genetics, hormones such as testosterone and even parasites may have on stimulating entrepreneurial behaviour (White, Thornhill and Hampson 2006; Nicolaou, Shane et al. 2008; Johnson et al. 2018), with growing interest in how neuroscience can complement our understanding of the entrepreneur (Krueger and Welpe 2014; Lawrence et al. 2008; Nicolaou and Shane 2014; Nicolaou, Phan and U. Stephan 2021; Tracey and Schluppeck 2014). A neuroscientific knowledge of the entrepreneur would provide an additional piece to the puzzle of how entrepreneurship can be nurtured, along with the social, political, and economic factors at play. The breadth of empirical work in the neuroentrepreneurship field is largely undeveloped (Clements et al. 2021). Therefore many assumptions about the entrepreneurial brain have yet to be tested with neuroscience methods.

Due to the lack of empirical work, there is a need to test some of the assumptions made about entrepreneurs' cognition with new methods, as we set up in 1.2, subsection 1.2.3, noting discussions from Katz and Dean A Shepherd (2003) about the sporadic use of cognition work and the error in theoretical accounts of entrepreneurs as risk-takers, which was later shown to be incorrect.

In light of this, in this study I aim to employ methods from cognitive neuroscience (cognitive tests) and computational analysis to study a population of entrepreneurs from an online cohort. The primary purpose is to test if and what differences occur in neurocognitive domains between entrepreneurs (those who have founded, managed and own a business) and non-entrepreneurs (a matched-sample from the general population). I first test popular views of entrepreneurs through a hypothesis-driven approach, focusing on uncertainty processing and information sampling, using two neurocognitive tasks and standardised questionnaires. Secondly, I employ an extensive battery of validated and standard neurocognitive tests, ranging from memory and reasoning to social cognitive difficulties, and ending with a personality questionnaire. This analysis employs a data-driven 'profiling' approach, exploring which, if any, cognitive skills from an extensive battery of tests differ between entrepreneurs and non-entrepreneurs. I aim to show a novel approach to studying entrepreneurship, exploring new aspects of entrepreneurs' cognition whilst challenging stereotypical views.

4.3.3 *Methodological Development*

Neurocognitive testing is commonly used in psychology and cognitive neuroscience research to assess brain health and cognitive abilities. It originated from neuropsychological assessments traditionally used in clinical settings to evaluate brain damage or the impact of known or suspected brain conditions on cognition, behaviour, or mood. (Goldstein and Hersen 2000; Robinson and Radakovic 2021). Researchers usually select or design specific neurocognitive tests to explore facets relevant to the group's naturalistic observations, from domains such as attention and psychomotor speed, executive functions, memory, emotion and social cognition. Whilst neurocognitive testing can be viewed as an over-simplified model of cognition, the behaviour observed in practice can generally be identified through differences in neurocognitive performance in a controlled setting more conducive to empirical scientific research. This can be evidenced, for example, by the rich and varied research already done comparing patients and healthy control groups in domains such as executive dysfunction and social deficits in autism, deficits in behavioural inhibition, attention, and executive function in ADHD, or the evidenced continuous cognitive decline shown in an ageing population (Zwick 2022; Barkley 1997; Shimada et al. 2014).

Less common, however, is the testing of more subtle differences in groups where both populations would be considered 'healthy' individuals, with different trajectories or social groupings, such as in their job roles. Traditionally, such research has taken a 'general' approach to cognitive ability, labelling this generalised mental ability as '*g*' through a series of papers claiming that measures of *g* or IQ were much more predictive of job performance than any specific cognitive measures, the so-called *not much more than g era* (Almamari and Traynor 2021; Ree, Earles and Teachout 1994; Murphy 2017). Contending and contemporary theories argue that different cognitive abilities can be separated into multiple independent factors of human intelligence, also showing that each of these specific behaviour matches onto distinct functional networks in the brain (Hampshire, Highfield et al. 2012). From this research, Hampshire and his colleagues developed novel approaches to allow cognitive scientists to deliver multiple short tests to individuals in one online sitting and then use machine learning dimensionality reduction approaches to reduce the results into key underlying cognitive factors, as explained in Chapter 1, Section 1.3.8. The cognitive factors may then be compared between groups of people, as has previously been done to reach those who contracted Covid-19 versus those who had not, and even to compare rocket scientists to neurosurgeons (Usher et al. 2021; Hampshire, Trender et al. 2021). In this case this cognitive battery can be used to compare entrepreneurs to the general population.

4.3.4 *Objective*

The differences and effects of such testing in healthy populations are expected to be very small. However, due to the infancy of work exploring the neuro-cognition of entrepreneurs, we aim to take both a more traditional hypothesis testing approach and an exploratory cognitive battery approach which tests many different neurocognitive domains. We aim to compare the results from these two methodological approaches in studying the entrepreneur. In experiments 1 and 2, we test impulsivity and uncertainty processing in entrepreneurs, two of the themes identified previously as areas of interdisciplinary work between entrepreneurship and cognitive neuroscience in Chapter 2. In experiment 3, we administered 12 short neurocognitive tasks to test whether neurocognitive and personality measures can predict entrepreneurship group membership.

4.3.5 *Hypothesis*

The first two hypotheses are drawn from themes identified in Chapter 2, due to their popularity in entrepreneurship research, and from the insight they may draw to components of cognition that underlie the disruptive and creative competencies entrepreneurs possess. We take a methodological approach here to test popular assumptions about entrepreneurs' cognition, and whether these findings are echoed or contested in neurocognitive testing.

Hypothesis 1: Impulsivity in decision-making is higher in entrepreneurs than in the general population, and this difference can be identified via cognitive testing.

Prior research has tested impulsivity and risk-taking in entrepreneurship using neurocognitive tasks such as the Stroop Task, Balloon-Analogue Risk-Taking (BART), Go No-Go Task and Erikson Flanker Task (Fisch, Franken and Thurik 2021; Ortiz-Terán et al. 2013; Nejati and Shahidi 2013). However, this work has often used tasks focusing on motor inhibition or has only tested impulsivity in a sample of university students, as explored and discussed in Clements et al. (2021). Moreover, whilst ADHD-like traits of impulsivity and hyperactivity have been suggested to be beneficial to entrepreneurship (Yu, Wiklund and Pérez-Luño 2021), there is a shortage of empirical work that tests impulsive decisions in entrepreneurs. I instead employ the information sampling task (IST), to measure reflection impulsivity, which assesses the amount of information people accrue before making a decision (Kagan 1966). We aim to test the premise from prior research that entrepreneurs make faster decisions with less information, and are thus more impulsive.

Hypothesis 2: Entrepreneurs' perception of and use of uncertainty in decision-making differ from that of the general population.

Navigating uncertainty is the cornerstone for most theories of entrepreneurship (McMullen and Dean A. Shepherd 2006). For instance, in order to drive forward any new and creative endeavour, an entrepreneur must deal with the uncertainty that comes with doing so. Moreover, even once established, an entrepreneur must continue to adapt to changing markets and demands that they cannot foresee. There have so far been few such experimental manipulations that create uncertain or volatile environments, and see how an entrepreneurs neurocognition may differ or respond in such contexts. To measure uncertainty processing, we administer the Bandit task, helping us to explore how individuals learn in uncertainty. Previously this task has been used alongside computational modelling and functional magnetic resonance imaging (fMRI) to show how the perception of volatility (rate of change) in the environment is used to update people's learning and beliefs. In particular, the fMRI signal in the anterior cingulate cortex (ACC) has been shown to reflect volatility estimates and predict how much the change will impact future outcomes (Behrens et al. 2007; C. D. Mathys et al. 2014). Even without imaging, this task, combined with computational models, can help us understand how an individual perceives and uses information and changes in the environment to learn and update their beliefs (Reed et al. 2020). Despite common consensus that uncertainty and entrepreneurship are two sides of the same coin, it not known whether the tolerance to uncertainty that entrepreneurs posses is due to fundamental differences in their cognitive processing and view of the world, or whether they have developed strategies to cope with ambiguous situations. I aim to test for the first time whether there are any differences in the way an entrepreneur *computes* and processes uncertainty.

Hypothesis 3: Performance on standardised cognitive tasks and personality scores can predict entrepreneurship grouping.

In the early stages of interdisciplinary research between traditional entrepreneurship and neuroscience, and with limited neurocognitive testing on entrepreneurs, we aim to predict group membership in entrepreneurship through an extensive battery of cognitive and personality testing. This offers more holistic neurocognitive testing than simply selecting a few neurocognitive tasks. Moreover, rather than being biased and confined by prior assumptions about a group, this approach enables researchers to explore many validated facets of cognition to see where differences might arise, for example, in different career trajectories such as entrepreneurship. By administering the Big-5, a well validated personality questionnaire, we can see together the effect of neurocognitive and personality dimensions on entrepreneurship and indeed to neurodiversity that may allow better competency in disruptive thinking.

4.4 METHODS

Ethical Approval for this study was granted by the PNM Research Ethics Panel at King's College London (LRS-19/20-15026). A graphical representation of the study design and the three experiments derived from this online study are shown in Figure 4.1.

4.4.1 *Participants*

Recruitment

Recruitment outreach took place between July 2020 – January 2021. Participants were recruited for the online testing via adverts for The Entrepreneurial Challenge (EBC) (URL: https://entrepreneur.cognitron.co.uk/). Three different adverts were deployed to target 1) entrepreneurs, 2) those with entrepreneurial interest and 3) those with no interest in entrepreneurship. Adverts were placed on social media such as Twitter, LinkedIn and Facebook. Emails were sent to student and entrepreneurship mailing lists within KCL, and external entrepreneurship centres promoted the online study on their channels. An advert was also placed on the internal KCL fortnightly circular research recruitment email. In addition, participants were also recruited from the Cambridge Judge Entrepreneurship Centre, All Party Parliamentary

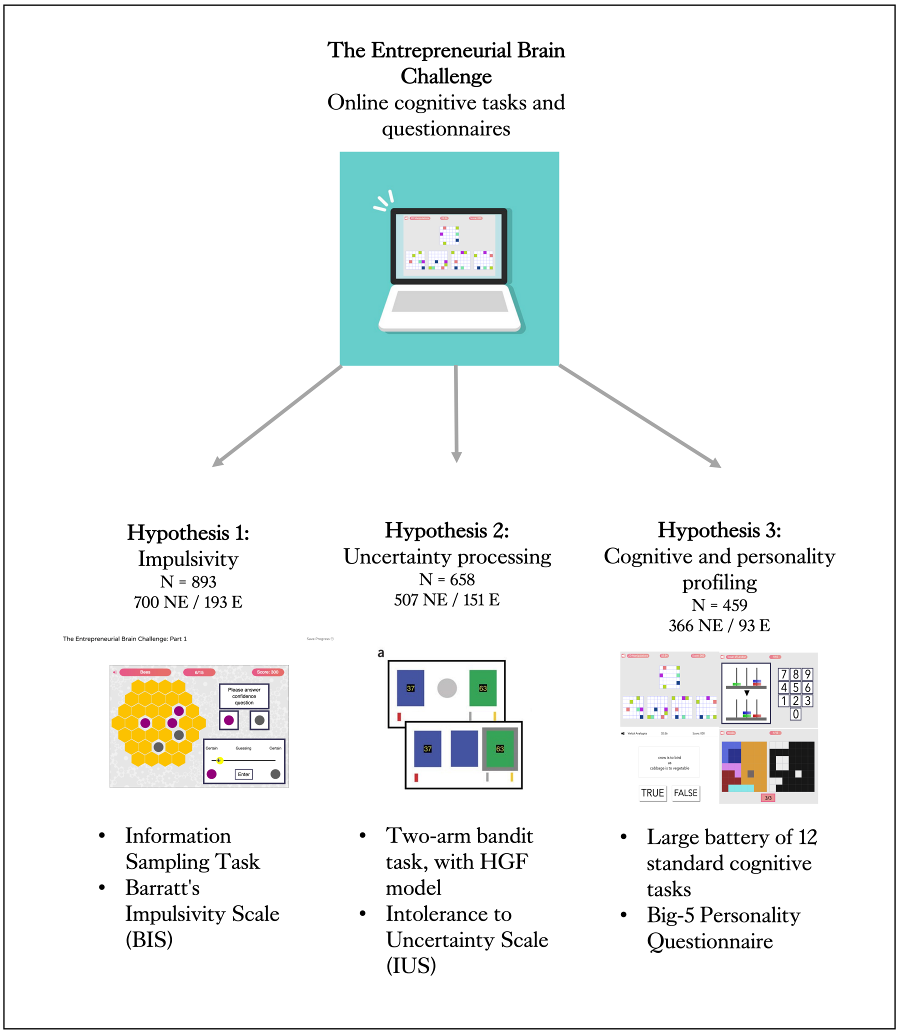

Figure 4.1: Shows the three data sets derived from the Entrepreneurial Brain Challenge and the methods used to assess each hypothesis in this study.

Group for Entrepreneurship, The Entrepreneurs Network, Hong Kong Science and Innovation Park (including the 8 HK universities they work with), and the website and social media of the Great British Entrepreneurship Awards.

Sample and Grouping

1664 people completed the screening questionnaire for the EBC. Of these, 942 completed the entire demographics questionnaire, which was required to determine the experimental group. Of these subjects, The data was cleaned to retain only those participants who met the inclusion criteria (over 18, and no diagnosed neurological or neuro-degenerative disorders or brain injury that may substantially affect cognition). We further excluded subjects where the data were incomplete. After cleaning the data, sample sizes for each hypothesis testing are shown in figure 4.1.

In the demographic questionnaire, participants answered questions about their experience starting a business, career and motivation or barriers to entrepreneurship. We defined entrepreneurs as founders who actively managed and owned a business. All other participants were grouped into the control group of 'non-entrepreneurs'. Our grouping is based on entrepreneurial output so that we could assess the cognitive and personality differences in those who demonstrate actionable experience in entrepreneurship compared to the general population.

4.4.2 *Protocol*

Participants accessed the online testing from their own devices and in a place of their choice. Before starting the tasks, information about the study was given and informed consent was obtained. Total testing took one hour and was split into two parts to allow for a break and retain participants' attention. The first part of the EBC contained screening, questionnaires, and two hypothesis-driven cognitive tests; the information sampling task (impulsivity) and the probabilistic learning task (uncertainty). The second part contained 12 standard cognitive tests and the Big-5 personality questionnaire. Upon completing the first part, participants gained feedback on their entrepreneurial skills. On completing both parts, they had access to their full cognitive results in the form of a spider diagram and a resource document on developing their entrepreneurial skills, which was co-created with the Entrepreneurship Institute at King's College London.

4.4.3 *Hypothesis 1: Impulsivity in decision-making is higher in entrepreneurs than in the general population, and this difference can be identified via cognitive testing.*

Neurocognitive Task: Impulsivity.

We employed a pre-existing information sampling task called the 'Bee's Task', developed by Clark et al. (2006). . Participants are shown a panel of hidden coloured *bees*. Their task is to ascertain, in each trial, which bee colour is most common by choosing how many panels to reveal on each trial, shown in figure 4.2. We chose this task to test how entrepreneurs gather and evaluate information when making decisions, with more impulsive decisions reflected in measures of Average Sampled (the number of panels sampled), Colour Difference (the difference between the colours when the decision is made) and Total Score (the score at the end of the game). Participants gained 100 points for a correct answer and lost 100 points for an incorrect answer.

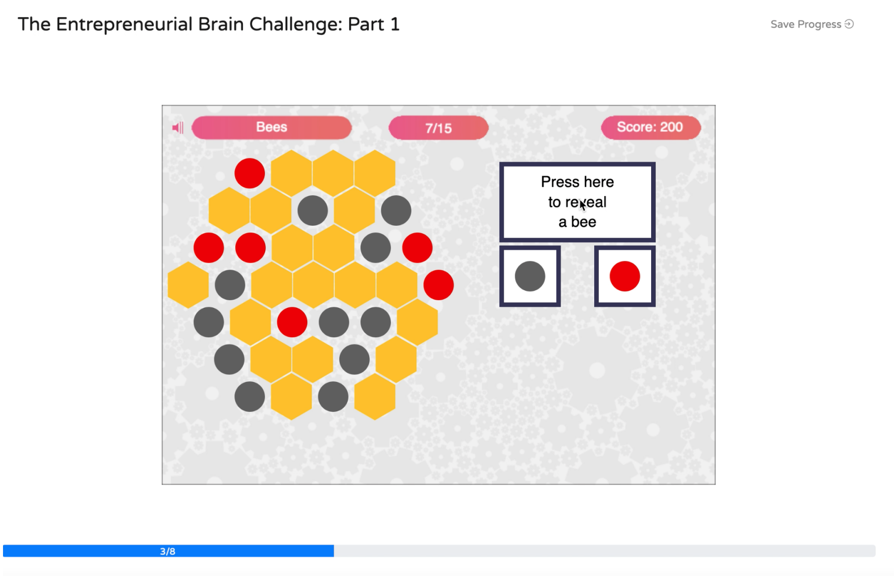

Figure 4.2: The Information Sampling Task asked participants to guess which colour 'bee' is most common. Participants can reveal however many panels on the screen as they wish, with bees hidden underneath, before selecting the colour of the bee they think is most common.

Questionnaire: Impulsivity

The Barrat's Impulsivity Scale (BIS) was administered to measure trait impulsivity (Patton, Stanford and Barratt 1995). The BIs is a 30-item questionnaire for which people answer statements such as, "I do things without thinking", rating themselves from 1 = "rarely/never" to 4 = "almost always/always." Total scores range from 30-120, with a higher score indicating greater trait impulsivity. To score as a uni-factorial tool, scores are added together with some scores reverse-scored, such as Q1, "I plan tasks carefully" (as well as Q7, Q8, Q9, Q10, Q12, Q13, Q15, Q21, Q29, Q30).

4.4.4 *Hypothesis 2: Entrepreneurs' perception of and use of uncertainty in decision-making differ from that of the general population.*

Neurocognitive Task: Uncertainty

The bandit task was delivered in the first half of the challenge and is illustrated in Figure 4.3. We adapted the one-arm bandit task, in which people have to guess the correct card out of two choices, to measure probabilistic learning, as in Behrens et al. (2007), into a shorter task for online use (from 40 minutes down to 13 minutes). Participants have to decide to pick blue or green rectangles in each trial based on two aspects (1) past success and (2) the reward associated with each colour (yellow number in the centre of each blue/green rectangle). They aim to move the red bar at the bottom of the screen (representing total reward) towards the silver or gold bar. There are 120 trials in total, lasting 6 seconds each. For 60 trials, the probability of a blue outcome is 75%, representing a stable environment. For the other 60 trials, reward probabilities switched between 80% blue and 80% green every 20 trials, representing a volatile environment. Therefore, This task can assess how someone learns about a task environment and estimates how it changes in both stable and volatile periods.

This task is theoretically based on the premise of how we learn in expected and unexpected uncertainty. In expected uncertainty, individuals may expect the environment to be volatile and therefore treat events which violate their assumption as less surprising as they expect variable outcomes. In contrast unexpected uncertainty, as modelled in this task, is the perceived changes in the underlying statistic of an environment which they did not expect, i.e. *the world or task is changing* (Reed et al. 2020). Unexpected uncertainty is modelled by changing the probability of which card is correct halfway through the experiment e.g. from a stable period of 75% blue for 60 trials to

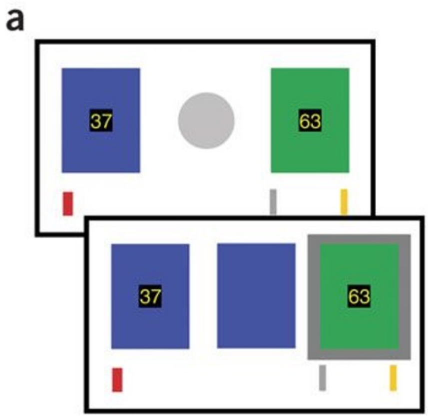

Figure 4.3: In the Probabilistic Learning Task (2-arm bandit), participants decide between blue and green rectangles in each trial, based on two aspects (1) past success and (2) reward associated with each colour (yellow number in the centre of each square). They attempt to move the red (total reward) bar at the bottom towards the silver or gold bar.

a volatile environment which switches between 80% green and 80% blue every 20 trials.

Model

In order to draw estimates of the hidden cognitive states such as perceived volatility of the environment and the weight placed on these changes to update beliefs and learning. We used a combined Hierarchical Generative Filtering (HGF) model with a Response model as has been used in previous studies of uncertainty and learning (Reed et al. 2020; Andreea O Diaconescu et al. 2014). This modelling can be performed with the MATLAB TAPAS toolbox, version v.5.3.1. This toolbox is freely available for download in the TAPAS package at https://translationalneuromodeling.github.io/tapas (C. D. Mathys et al. 2014). The package was run in MATLAB R2022b using the statistics toolbox (Inc. 2022). The form of the equations which make up the Bayesian model here, particularly for the way in which two of the parameters are updated (μ2 and μ3), can be compared to those of classic reinforcement learning models (Rescorla–Wagner) such as

$$\text{prediction}^{(k)} = \text{prediction}^{(k-1)} + \text{learning rate} \times \text{prediction error}$$

Figure 4.4: The figure shows the Reinforcement Learning (RL) update equation which forms the basis of most RL computational models, from (C. Mathys et al. 2011). The HGF model in this paper can be interpreted in terms of RL, as individuals update their beliefs in terms of their prior beliefs, learning rate and in light of incoming information (prediction errors).

in figure 4.4. The difference in the HGF model is the hierarchical levels which integrate all the information about the task environment available and update learning based on the combination and weighting of all these different perceptions. Full accounts of the computational and mathematical differences between RL and Bayesian models can be found in C. Mathys et al. (2011).

The model assumes observers act in a way reflecting ideal Bayesian inferences – optimally updating beliefs on hierarchical coupled states in a trial-by-trial fashion; on the basis of prediction errors multiplied by ratios of precisions, details and equations for which can be found in (C. D. Mathys et al. 2014; Daunizeau et al. 2010). When these models are inverted they provide a complete mapping from the manipulated experimental input of card probability to the subjects dependent beliefs (Daunizeau et al. 2010). The HGF therefore enables the ability to quantitatively estimate 'hierarchically coupled hidden states' that describe how subjects learn about the probability and volatility of the cards in the bandit task, while the beliefs about the card are weighted in the response model dependent on their relative precision to form the response. This enables us to see if their are any difference in how entrepreneurs computationally process uncertainty, and use this information in their responses on a neurocognitive task.

However, there are often competing computational models of learning and decision-making (meaning we don't always know exactly how our sample is making decisions). Therefore when computational models are used to analyse task data and group differences, an important step is to compare which model of decision-making best fits the data (K. E. Stephan et al. 2009). We compared 5 model versions: (1) 3-level HGF, (2) 2-level HGF, 3) Rescorla-Wagner learning model, 4) Sutton Model and 5) 3-level HGF with a volatility response model, as in Reed et al. (2020). The winning model is selected using Bayesian random effect model selection. Parameter recovery analysis was performed by inverting the model to obtain $\omega 2$, $\omega 3$, κ and $\mu 3$ estimates for each participant. We explain what these parameters represent in figure 4.5.

Questionnaire: Uncertainty

The Intolerance to Uncertainty Scale (IUS) is a 27-item questionnaire to assess how people perceive and react to uncertainty (Buhr and Dugas 2002). Measuring for much people associate with 4 factors: uncertainty is stressful and upsetting, uncertainty leads to the inability to act, uncertain events are negative and should be avoided, and being uncertain is unfair. Participants score statements such as 'unforeseen events upset me greatly' on a Likert scale from 1 = "not at all characteristic of me" to 5 = "entirely characteristic of me." To score as a unifactorial model, all scores are added together for a final score, where a higher score indicates a great intolerance of uncertainty.

4.4.5 *Hypothesis 3: Performance on standardised cognitive tasks and personality scores can predict entrepreneurship grouping.*

Neurocognitive Tasks: Battery of 12

For hypothesis 3, 12 neurocognitive tasks were administered in the second half of the challenge; the battery was identical to those in the Great British Intelligence Test, previously delivered to over 500,000 people, of which normative z scores can be compared to our sample.

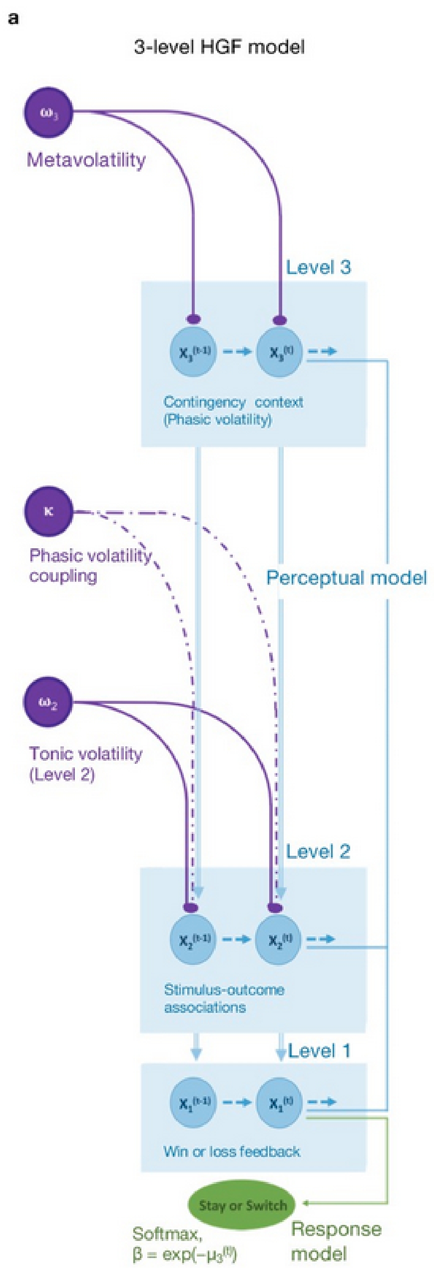

Figure 4.5: The 3-level HGF model from Reed et al. (2020). Level 1 represents the trial-by-trial estimates of the card probabilities, level 2 the stimulus-outcome association and level 3 the overall perception of the volatility of the task. Parameter values obtained from the model for analysis included: ω2 ω3, κ and μ3. ω2 = how much the participant updates their beliefs on the probability of a card being correct. ω3 = how much the participant updates their volatility estimates. κ = couples the third and second levels in the 3-level HGF model; this is the extent to which the participant uses volatility estimates to infer card probabilities. μ3 = the participants' prior/initial belief on volatility before the task began.

The tasks consisted of 1) Prospective Memory Words Immediate (Short-term Memory), 2) Blocks (spatial intelligence), 3) Tower of London (planning), 4) Digit Span Task (verbal working memory), 5) Spatial Span (spatial working memory), 6) Verbal Analogies (verbal reasoning), 7) Target Detection (attention), 8) Emotional Discrimination (social cognition), 9) Word Definitions (verbal comprehension), 10) 2D Manipulations (mental rotation/imagery), 11) Faulty Towers Task (3D spatial reasoning), 12) Prospective Memory Words Delayed (long-term memory). Each task had an instruction period before beginning and lasted roughly 3 minutes each.

Questionnaire

The 50-item Big-5 Personality Questionnaire measuring the traits of Openness, Consciousness, Extraversion, Agreeableness and Neuroticism, was given following the neurocognitive battery (Goldberg 1990). As introduced in Chapter 1. The five-factor structure has also been shown to remain consistent across different cultures (McCrae et al. 1998) and shows good test-retest reliability, even with short versions such as the 50-item one used here (Gosling, Rentfrow and Swann Jr 2003).

4.4.6 *Statistical Analysis Plan*

Data Cleaning and Pre-processing

All data was sourced from an online cohort and cleaned thoroughly. Duplicates, excluded participants, nonsense responses, long off-screen time (>2500ms), machine errors, and low median reaction times were removed. In addition, all scores were run through linear models to remove the effect of co-variates, such as age, sex, handedness (left or right), first language, ethnicity, nationality and the device they used. The residual scores from the models for each participant were carried forward into the analysis. All analyses were performed on MATLAB R2022b and R Studio (R Core Team 2023; Inc. 2022).

Shapiro-Wilk tests were used to examine the normality and distribution of the scores obtained, these are shown in the supplementary material in Table 18. All data sets contained non-normally distributed scores. Therefore, for consistency non-parametric testing was applied throughout.

Dataset 1: Information Sampling Task and Barrat's Impulsivity Scale

Behavioural measures from the Information Sampling Task (IST) were 1) mean samples: indicating the average number of panels that were sampled/revealed over all trials; 2) mean difference: indicating the difference in the number of colours at the point the decision was made and 3) total points: indicating the points scored in the task. The three IST scores and the Barratt Impulsivity Scale (BIS) were run through separate Mann-Whitney U Tests to test for group differences between entrepreneurs (1) and non-entrepreneurs (0), using FDR correction to control for multiple comparisons. Power calculations of G*Power (Faul et al. 2007), indicate for a Mann-Whitney U Test, a total sample size of 244 (122 in each group) is required for 0.05 alpha level, medium effect size and power of 0.95.

Dataset 2: Probabilistic Learning (2-arm bandit task) and Intolerance to Uncertainty Scale

Model fitting, selection and inversion were run on MatLab, with SPM12 (Inc. 2022; K. E. Stephan et al. 2009; Rigoux et al. 2014). Model selection was determined by fitting each model to the data from each participant, to obtain the log model evidence (LME) . Fixed-effects and random-effect Bayesian selection are then performed on the LME using "spm_BMS". Fixed effect assumes there is no random variability across subjects or measurements, whilst the random effects take into account both fixed effects and random variability. The perceptual parameters are then obtained from the winning model, as these represent the objective values and computations of our sample learning. Shaprio-Wilks and visualisation of histograms tested for normality in R. Parameters from the probabilistic learning task (Omega2, Omega3, Kappa, Mu3) and Intolerance to Uncertainty Scale (IUS) were run through separate Mann-Whitney U Tests to test for group differences between entrepreneurs (1) and non-entrepreneurs (0), using FDR correction to control for multiple comparisons on R (R Core Team 2023). Power calculations of G*Power (Faul et al. 2007), indicate for a Mann-Whitney U Test, a total sample size of 244 (122 in each group) is required for 0.05 alpha level, medium effect size and power of 0.95.

Dataset 3: Battery of 12 Standardised Cognitive Tests and Big 5 (OCEAN) Personality Questionnaire

A factor analysis (Principle Component Analysis (PCA)) was performed on the 12 cognitive task residual summary scores to establish the underlying factor structure in this sample. We ran models with factor structures ranging from 2 to 7 to test which best fitted our sample. The factor structure is determined by a) the levelling off of eigenvalues on the scree plots after five factors and b) a logical theoretical underpinning to the factor loadings. The tasks loaded onto a structure are examined, and the constructs are labelled. Any tasks not loaded onto a factor were considered independent factors to be tested between groups. A GLM then incorporated the factor scores and personality measures as predictors of group membership (entrepreneurs (1) and non-entrepreneurs (0)), using FDR correction to control for multiple comparisons. Odds ratios and the corresponding confidence intervals are also reported to gain an understanding of the effect and significance of each predictor variable in the model. Power calculations of G*Power (Faul et al. 2007) indicate for binomial logistic regression, a total sample size of 1299 would be required for 0.05 alpha level, medium effect size and power of 0.95.

4.5 RESULTS

4.5.1 *Hypothesis 1: Impulsivity in decision-making is higher in entrepreneurs than in the general population, and this difference can be identified via cognitive testing.*

Dataset 1 consisted of n = 893 samples (700 non-entrepreneurs and 193 entrepreneurs). Descriptive statistics are shown in Table 1. Potential confounding effects of age, gender, education, language, ethnicity, handedness and device were removed through linear modelling and the residual scores were carried forward to group analysis. Raw and residual median scores and SEMs are shown in Table 12.

Group Differences in Impulsivity

Separate Mann-Whitney-Wilcoxon tests were carried out for each score from the information sampling task, with independent group membership variables; violin plots are shown in Figure 4.6.

Mann-Whitney-Wilcoxon tests with independent variables of group membership and examination of confidence intervals (entrepreneur vs non-entrepreneur) showed no significant differences between groups for Average Samples (W = 62659.50, p = .25, CI = [-0.16, 0.02]), Colour Difference (W = 63384.50, p = .25, CI = [-0.15, 0.03]) and Total Scores

Table 12: Entrepreneurial Brain Challenge Experiment 1: Demographics for the Dataset of the Information Sampling of Entrepreneurs n = 893

Demographics	Non-Entrepreneur	Entrepreneur		
n	700	193		
Age Mean (SD)	28 (10)	36 (12)		
Age Range	18-72	18-69		
Gender (ratio F:M)	484:216	96:97		
Business Information				
Number of Businesses Mean (SD)	–	2.17 (1.73)		
Number of Businesses Range	–	1-10		
Years of Business Running Mean (SD)	–	5.91 (5.73)		
Years of business Running Range	–	1-35		
Solo-founder n	–	93		
Co-founder n	–	100		
Information Sampling Task				
Raw Scores				
Average Sample, Median (SEM)	22.83 (0.37)	24.40 (0.72)		
Colour Difference, Median (SEM)	4.33 (0.05)	4.47 (0.10)		
Total Score, Median (SEM)	1100 (11.64)	1100 (21.14)		
Total Score, Range	-100 - 1500	100-1500		
Residual Scores - demographics modelled out			Mann-Whitney U	CI
Average Samples, Median (SEM)	0.0 (.36)	1.6 (0.92)	p = .25	[-.16, .02]
Colour Difference, Median (SEM)	-0.04 (0.05)	0.09(0.10)	p = .25	[-0.15, 0.03]
Total score, Median (SEM)	0.00 (11.34)	42.31 (20.81)	p =.55	[-.12,.06]
Barratt Impulsivity Scale				
Total Raw Score, Median (SEM)	61 (0.39)	62 (0.62)		
Total Residual Score, Median (SEM)	-0.97 (0.32)	0.75(0.60)	p = .07	[-0.20, -0.02]

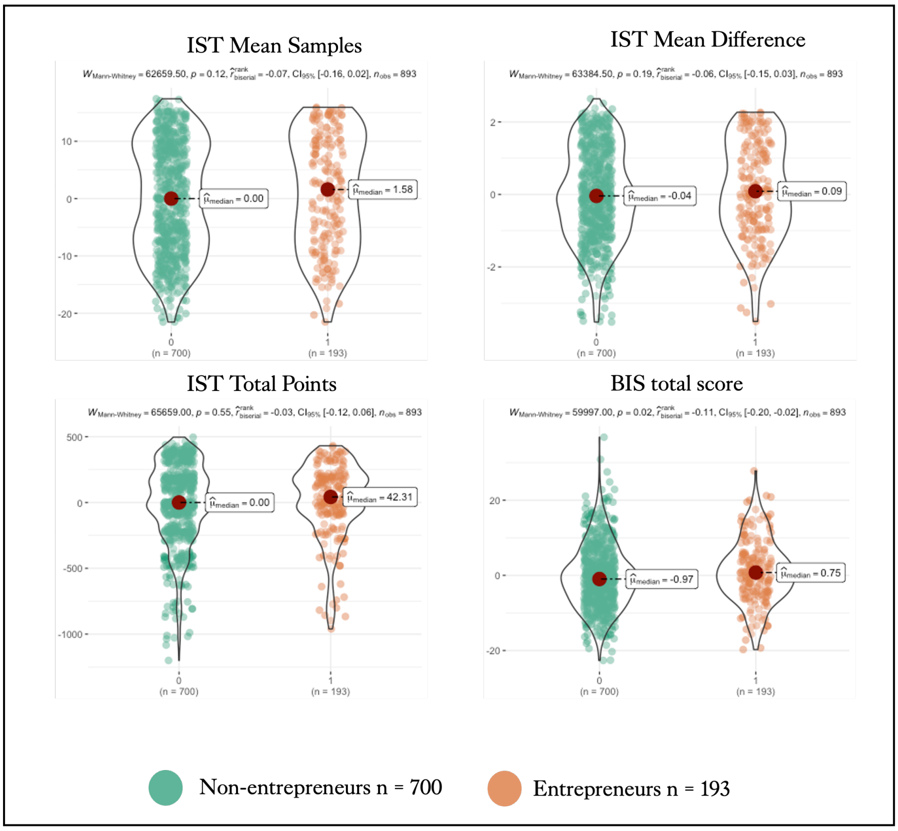

Figure 4.6: Neurocognitive impulsivity was tested in entrepreneurs with the information sampling (Bees) task. This figure shows results from kruskall-wallis tests with entrepreneurs (orange) and non-entrepreneurs (green) as the independent variables. Mean Samples (top-left), mean difference (top-right), total points (bottom-left) and overall Barrats Impulsivity Score (bottom-right) all show no significant differences at the Bonferroni-corrected alpha level of .0125 and examination of confidence intervals indicate no evidence to reject the null hypothesis.

(W = 65659.00, p = .55, CI = [-0.12, 0.06]). There were no significant group differences on the Barrett's Impulsivity Scale (BIS) total score (W=59997.00, p = 0.07, CI = [-0.20, -0.02]), with residual medians of -0.97 for non-entrepreneurs and 0.75 for entrepreneurs.

4.5.2 *Hypothesis 2: Entrepreneurs' perception of- and use of- uncertainty in decision-making differ from that of the general population.*

Dataset 2 consisted of n = 658 samples (507 non-entrepreneurs and 151 entrepreneurs). Descriptive statistics are shown in Table 13. Potential confounding effects of age, gender, education, language, ethnicity, handedness and device were removed from the parameter values obtained from the models before group-level analysis was performed. The median and SEMs for the raw and residual scores are shown in Table 13, and the violin plots show the spread of data in Figure 4.7

Group Differences in Uncertainty Processing

Fixed- and random-effect Bayesian model selection indicated that model 5 (the HGF 3 level model with soft-max volatility response model) was the winning model, the results of which are in Table 14. Moreover, the Bayes Omnibus Risk (BOR) value of 9.86e-304 indicated strong evidence that there was only one winning model in this data. Model 5 was therefore inverted and the parameters were compared between entrepreneurs and non-entrepreneurs.

Mann-Whitney-Wilcoxon tests with independent variables of group membership (entrepreneur vs non-entrepreneur) showed no significant differences between groups for any perceptual parameter values derived from the 3-level HGF model. The median (residual) score for $\omega 2$ was 0.63 in non-entrepreneurs and 0.30 in entrepreneurs (W =

Table 13: Entrepreneurial Brain Challenge Experiment 2: Demographics for the Dataset of the Probabilistic Learning Task Entrepreneurs n = 658

Demographics	Non-Entrepreneur	Entrepreneur		
n	507	151		
Age Mean (SD)	28 (9)	34 (12)		
Age Range	18-72	18-69		
Gender (ratio F:M)	157:350	73:78		
Business Information				
Number of Businesses Mean (SD)	–	2.00 (1.37)		
Number of Businesses Range	–	1-8		
Years of Business Running Mean (SD)	–	5.62 (5.71)		
Years of business Running Range	–	1-35		
Solo-founder n	–	74		
Co-founder n	–	76		
HGF estimation from Probabilistic Learning Task				
Raw Scores	Median (SEM)	Median (SEM)		
$\omega 2$	-2.23 (0.09)	-2.38 (0.17)		
$\omega 3$	2.70e-04 (6.70e-02)	-4.68e-02 (0.12)		
κ	1.43 (0.04)	1.41 (0.07)		
$\mu 3$	2.28 (0.02)	2.25 (0.05)		
Residual Scores - demographics modelled out			Mann-Whitney U	CI
$\omega 2$	0.63 (0.09)	0.30 (0.17)	p = .58	[-0.07, 0.14]
$\omega 3$	-0.34 (0.07)	-0.28 (0.12)	p = .98	[-0.10, 0.11]
κ	-0.05 (0.44)	-0.16 (0.07)	p =.58	[-0.05,0.16]
$\mu 3$	0.09 (0.02)	0.023 (0.05)	p = .58	[-0.06,0.15]
Intolerance to Uncertainty Scale				
Total Raw Score	18 (0.38)	13 (0.67)		
Total Residual Score, Median (SEM)	0.66 (0.38)	-3.37 (0.65)	p = 6.24e-05**	[0.13, 0.33]

Note: *FDR adjusted p-value at <.05, ** <.001 alpha level.

	Alpha	Fixed- Effect	Random-effect
Model 1	75.65	0	1.97 e-304
Model 2	4.55	0	1.97 e-304
Model 3	1.31	0	1.97 e-304
Model 4	7.35	0	1.97 e-304
Model 5	620.13	1	1

Table 14: Results from fixed and random-effect Bayesian model selection using $spm_B MS$

39767, $p = 0.58$, CI = [-0.07,0.14]). $\omega3$ was -0.34 in non-entrepreneurs and -0.28 in entrepreneurs(W = 38325, $p = 0.98$, CI = [-0.10,0.11]).κ median score were -0.05 for non-entrepreneurs and -0.16 for entrepreneurs (W = 40262, $p = 0.58$, CI = [-0.05, 016]). The median (residual) score for $\mu3$ in non-entrepreneurs was 0.09 and 0.02 in entrepreneurs (W = 40039, $p =0.58$, CI = [-0.06, 0.15]). However there was a significant difference between entrepreneurs and non-entrepreneurs in IUS scores, the median (residual) score was 0.13 in non-entrepreneurs and -3.37 in entrepreneurs (W = 47239, $p <.001$, CI = [0.13,0.33]). Showing entrepreneurs are less intolerant (more tolerant) of uncertainty.

4.5.3 *Hypothesis 3: Performance on standardised cognitive tasks and personality scores can predict entrepreneurship grouping.*

Dataset 3 comprised participants who completed all 12 cognitive tasks and the personality tests in part 2 of the EBC (n = 459). This sample comprises non-entrepreneurs (n=366) and entrepreneurs (n=93). Table 15 shows the descriptive statistics of the demographics for each group. Confounding factors (age, gender, languages, ethnicity, education, handedness) were removed through linear modelling to leave residual scores for every task and personality score. The 12 residual summary scores from the cognitive tasks were taken into the factor analysis.

Factor Analysis

The decision to adopt a five-factor solution for the summary scores was reached after a careful and comprehensive evaluation. We initially examined the scree plot, as illustrated in the supplementary material 4.10, Figure 4.11, although its interpretation was somewhat ambiguous, it seemed to suggest the retention of five components. Additionally, we conducted a parallel analysis, which provided an al-

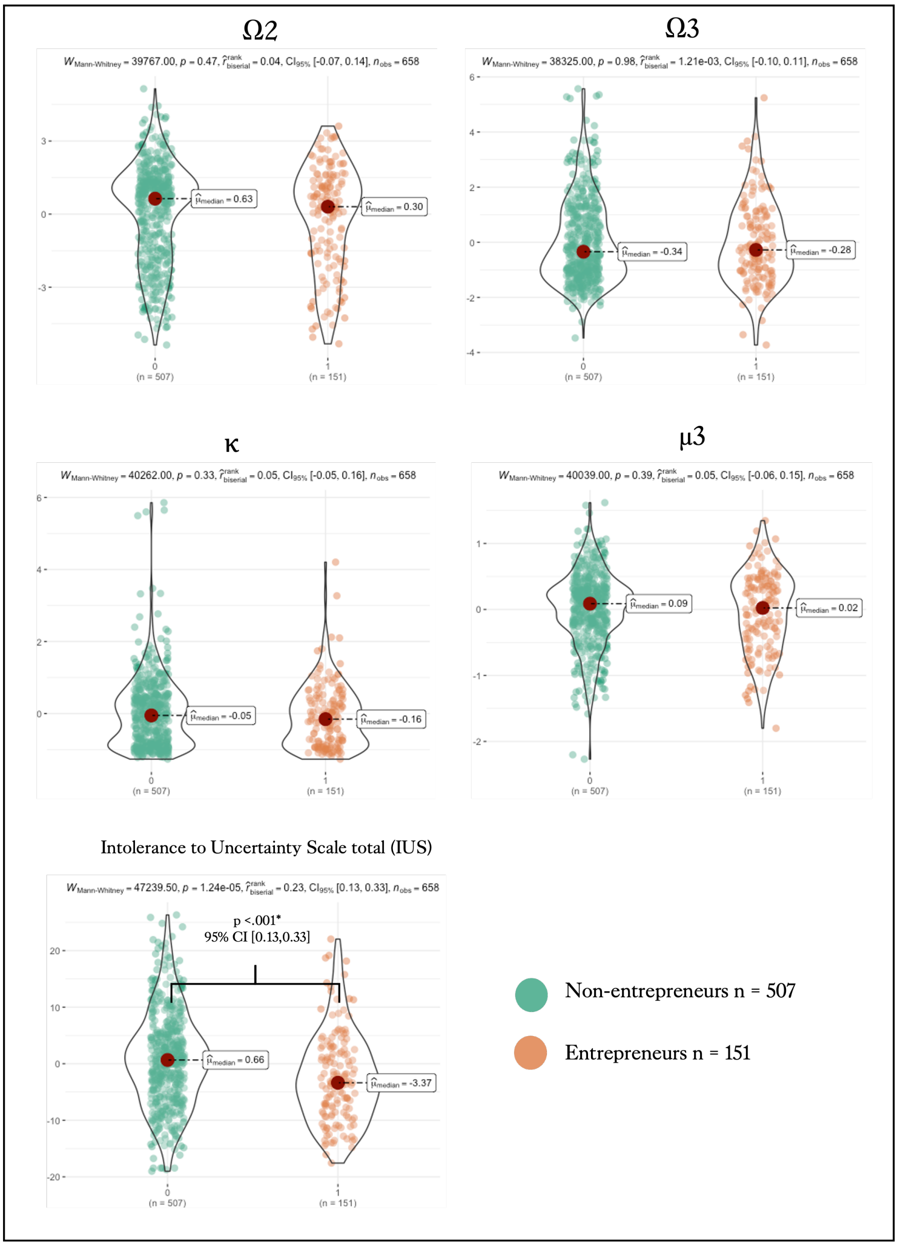

Figure 4.7: Uncertainty processing was tested in entrepreneurs with the probabilistic learning 2-arm bandit task. This figure shows results from separate Kruskall-Wallis tests with entrepreneurs (orange) and non-entrepreneurs (green) as the independent variables. ω2 ω3, κ and μ3 were derived from the inversion of the model 5, the 3-level HGF model combined with a volatility response model. No significant differences were found between the perceptual parameters and confidence intervals, indicating no evidence to reject the null hypothesis. However, self-reported Intolerance to Uncertainty Scale (bottom-left plot) was significantly different, such that entrepreneurs are more tolerant (less intolerant) than non-entrepreneurs of uncertainty. Starred items correspond to statistically significant differences at .05 alpha level.

Table 15: Entrepreneurial Brain Challenge Experiment 3: Demographics for the Dataset of the Cognitive and Personality Profiling n=459

Demographics	**Non-Entrepreneur**	**Entrepreneur**				
n	366	93				
Age Mean (SD)	26 (11)	34 (13)				
Age Range	18-72	18-69				
Gender (ratio F:M:N)	247:119	49:44				
Business Information						
Number of Businesses Mean (SD)	–	2.17 (1.64)				
Years of Business Running Mean (SD)	–	5.92 (5.53)				
Years of business Running Range	–	1-35				
Solo-founder n	–	37				
Co-founder n	–	56				
Binomial logistic regression (GLM)						
Factor Scores (residual)	Median (SEM)	Median (SEM)	p-adjusted (FDR)	CI (95%)	Odds Ratio	(95%)
Intercept			5.58e-30***			
F1 Episodic Memory	0.06 (0.05)	0.11 (0.11)	.043*	[0.04, 0.53]	1.33	[1.04,1.70]
F2 Mental Imagery	-0.03 (0.05)	0.14 (0.10)	.607	[-0.15, 0.34]	1.10	[0.86,1.41]
F3 Verbal Reasoning	0.04 (0.04)	-0.13 (0.09)	.021*	[-0.70, -0.10]	0.67	[0.49,0.90]
F4 Spatial Reasoning	0.03 (0.04)	-0.08 (0.07)	.803	[-0.42, 0.32]	0.95	[0.66,1.38]
F5 Working Memory	0.06 (0.04)	-0.11 (0.08)	.749	[-0.43, 0.28]	0.93	[0.65,1.33]
Big 5 Personality Scale (residual)						
Agreeableness	0.68 (0.32)	0.55 (0.58)	.607	[-0.06, 0.03]	0.98	[0.94,1.03]
Extroversion	-0.05 (0.44)	-0.16 (0.07)	.607	[-0.02, 0.04]	1.01	[0.98,1.04]
Conscientiousness	0.50 (0.37)	-0.001 (0.71)	.021*	[-0.08, -0.01]	0.95	[0.92,0.98]
Neuroticism	0.28 (0.41)	-2.64 (0.80)	.021*	[-0.08, -0.01]	0.96	[0.93,0.99]
Openness	-0.09 (0.31)	2.76 (0.50)	.002**	[0.04, 0.14]	1.10	[1.04,1.15]

Note: *FDR adjusted p-value at <.05, ** <.001 alpha levels

ternative perspective by indicating that all 12 factors could potentially be retained. However, in order to streamline the analysis and align it with our research objectives, we further investigated factor structures ranging from 2 to 7. In doing so, we also took into account the existing theoretical framework.

Ultimately, our choice of a five-factor structure was grounded in its alignment with prior research, notably supported by Hampshire's work (Hampshire, Highfield et al. 2012), and corroborated by the indications from the scree plot. It is crucial to underscore that each factor is composed of various tasks, each contributing to the underlying neurocognitive structure of these components. To illustrate this, consider the following factor loadings in Figure 4.8: Episodic memory exhibited a high loading from both immediate and delayed word recall tasks. Mental Imagery was predominantly influenced by the 2D manipulations task. Verbal Reasoning drew its strength from word definitions and verbal analogy tasks. Spatial reasoning was associated with the four towers, blocks, emotional discrimination, and tower of

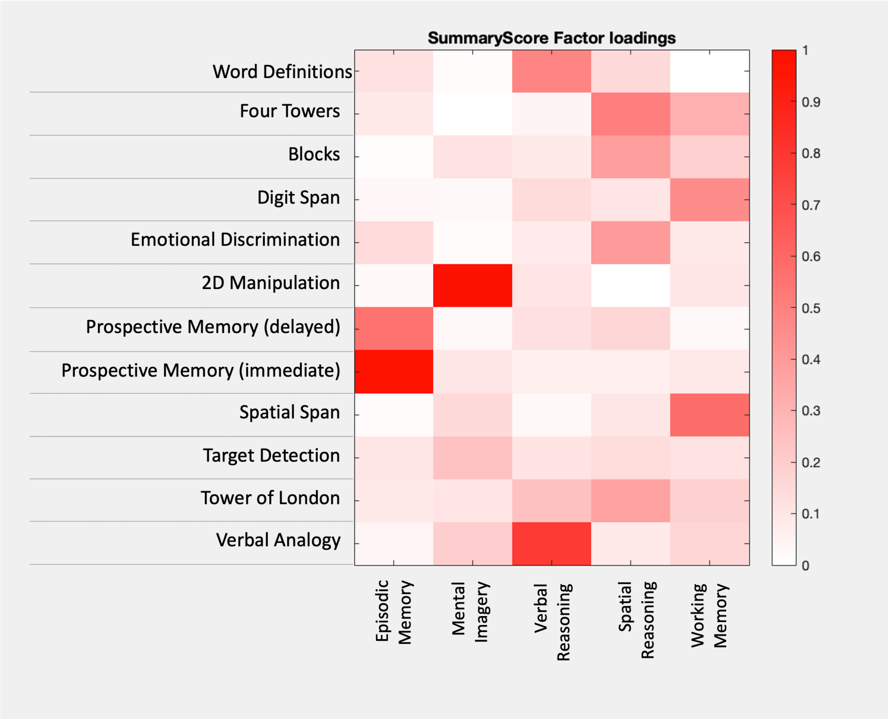

Figure 4.8: Heatmap of how each cognitive score from the 12 cognitive tests loads onto the five cognitive factors (left to right): (1) episodic memory, (2) mental imagery, (3) verbal reasoning, (4) spatial reasoning, and (5) working memory.

London tasks. Lastly, working memory was charactersed by strong loadings from digit span and spatial span tasks.

Logistic Regression Model

The five cognitive factor scores (episodic memory, mental imagery, verbal reasoning, spatial reasoning, and working memory) and five personality measures (agreeable, conscientiousness, extroversion, neuroticism and openness) were used as predictor variables in a GLM (binary logistic regression) analysis with entrepreneur (1) and non-entrepreneur (0) as the response variables, as shown in Table 15. Visualisation of data points between groups for the neurocognitive factors is shown in figure 4.9 and the summary of the neurocognitive and personality profiles together are shown in figure 4.10.

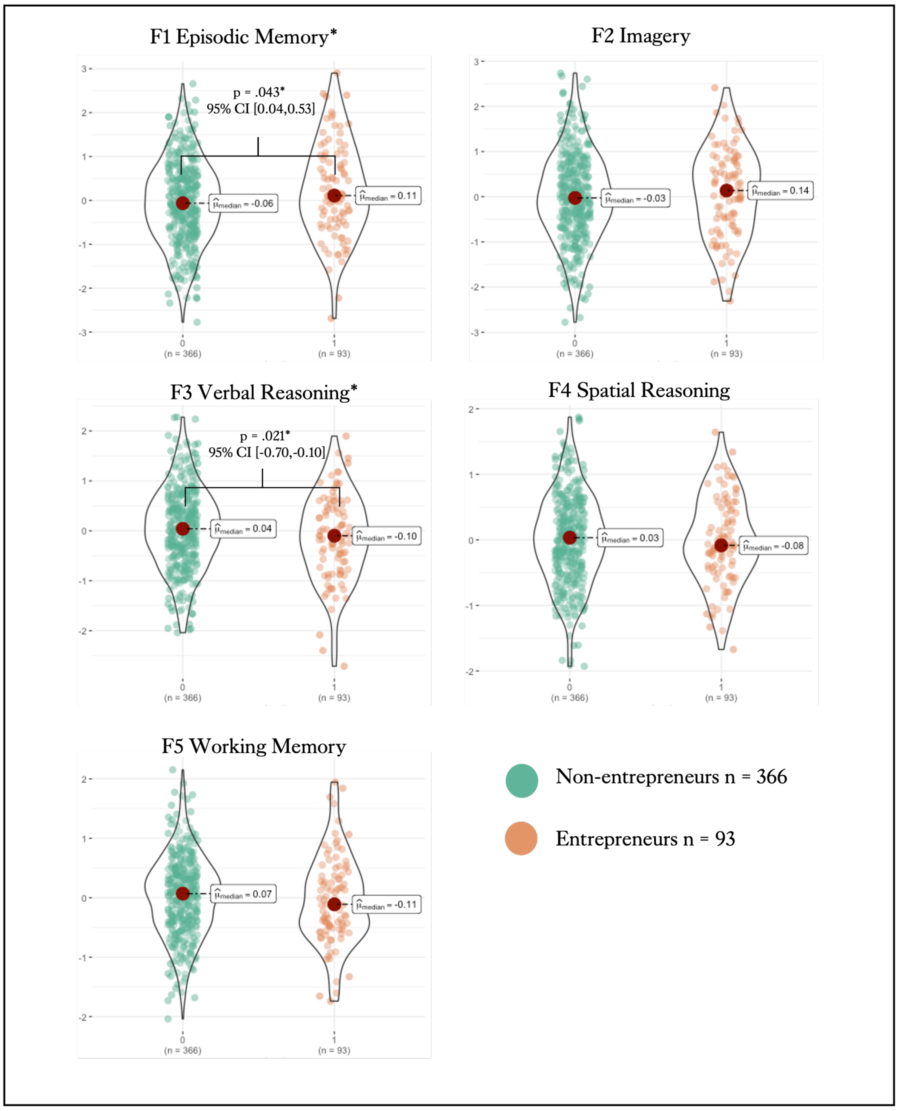

Figure 4.9: The five cognitive factor scores between non-entrepreneurs (green) and entrepreneurs (orange). Factor 1 episodic memory and F3 verbal reasoning are shown in a binomial logistic regression to associate with group membership significantly. Starred items correspond to statistically significant differences at .05 alpha level.

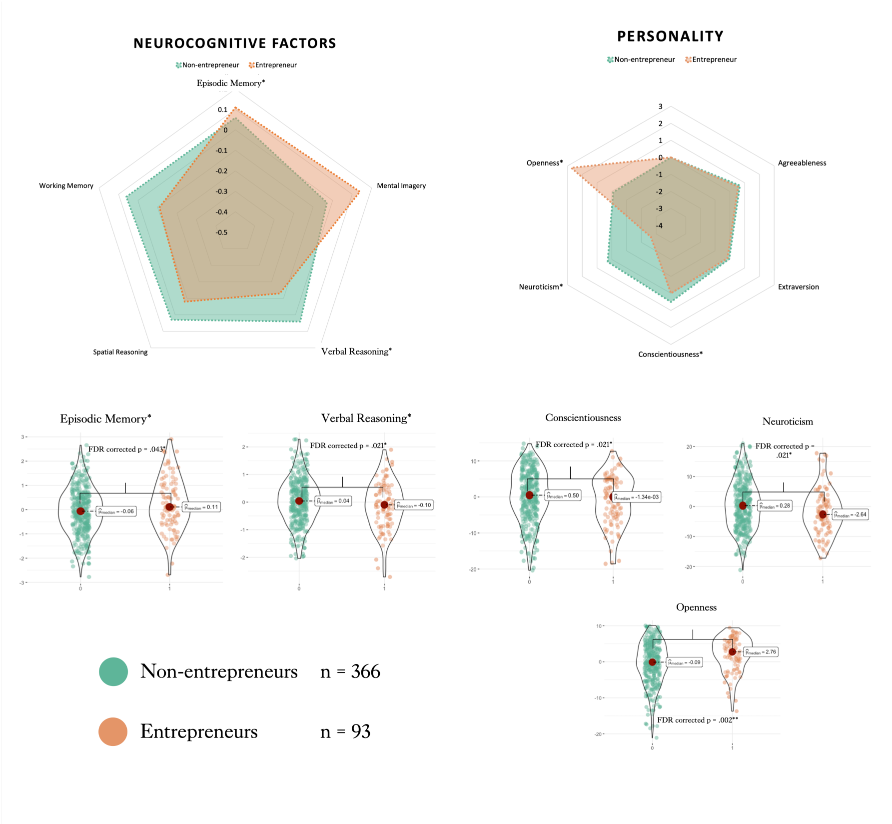

Figure 4.10: Spider plot of the median scores for neuro-cognitive scores (top-left) and personality scores (top-right). Plots show significant differences in episodic memory and verbal reasoning (bottom-left) and conscientiousness, neuroticism and openness (bottom-right). Starred items correspond to statistically significant differences at .05 alpha level.

Cognitive predictors

Episodic memory is higher in entrepreneurs (median = 0.11, SEM = 0.11) than in non-entrepreneurs (median = 0.06, SEM = 0.05). A binomial logistic regression shows this association to be significant. The odds ratio is 1.33 (95% CI of 1.04 to 1.70), indicating that those with a higher score on episodic memory had a 33% higher likelihood of being an entrepreneur than individuals with lower scores. This is further supported by a significant FDR-adjusted p-value = 0.043.

Verbal reasoning is lower in entrepreneurs (median = -0.13, SEM = 0.09) than in non-entrepreneurs (median = 0.04, SEM = 0.04). A binomial logistic regression shows a significant association between verbal reasoning and entrepreneurial status. The odds ratio is 0.67 (95% CI of 0.49 to 0.90), indicating that those with lower verbal reasoning skills have a 33% higher likelihood of being entrepreneurs. This is echoed by the significant FDR-adjusted p-value = 0.021 for verbal reasoning.

Whilst mental imagery is more significant in entrepreneurs (median = 0.14, SEM = 0.10) than non-entrepreneurs (median = -0.03, SEM 0.05), there is no indication of substantial associations from the binomial logistic regression, with an odds ratio of 1.10 (95% CI of 0.86 to 1.41) and FDR adjusted p-value = .607. Spatial reasoning is lower in entrepreneurs (median = -0.08, SEM = 0.07) than non-entrepreneurs (median = 0.03, SEM 0.04), with no significant association found, with an odds ratio of 0.95 (95% CI of 0.66 to 1.38) and FDR adjusted p-value = .803. Working memory is also lower in entrepreneurs (median = -0.11, SEM = 0.08) than non-entrepreneurs (median = 0.06, SEM = 0.04), but with no significant association, with an odds ratio of 0.93 (0.65-1.33) and FDR adjusted p-value = .749.

Personality predictors

Conscientiousness is lower in entrepreneurs (median = -0.001, SEM = 0.71) than non-entrepreneurs (median = 0.50, SEM = 0.37). A binomial logistic regression shows a significant association between conscientiousness and entrepreneurial status, with an odds ratio of 0.95 (95% CI of 0.92 to 0.98), indicating that those with lower conscientiousness are 5% more likely to be entrepreneurs. This is echoed by the significant FDR-adjusted p-value = .021.

Neuroticism is lower in entrepreneurs (median = -2.64, SEM = 0.80) than non-entrepreneurs (median = 0.28, SEM = 0.41). A binomial logistic regression shows a significant association between neuroticism and entrepreneurial status. The odds ratio is 0.96 (95% CI of 0.93 to 0.99), indicating that those with lower neuroticism are 4% more likely to be entrepreneurs. This is echoed by the FDR-adjusted p-value = .021 for neuroticism.

Openness is higher in entrepreneurs (median = 2.76, SEM = 0.50) than non-entrepreneurs (median = -0.09, SEM = 0.31). A binomial logistic regression shows a significant association between openness and entrepreneurial status. The odds ratio is 1.10 (95% CI of 1.04 to 1.15), indicating those with higher traits of openness are 10% more likely to be an entrepreneur. This is echoed by the FDR-adjusted p value = .002 for openness.

Agreeableness is lower in entrepreneurs (median = 0.55, SEM 0.58) than non-entrepreneurs (median = 0.68, SEM 0.32). However, the binomial logistic regression shows no significant associations, with an odds ratio of 0.98 (95% CI of 0.94 to 1.03) and FDR-adjusted p-value = .607. Extroversion is also lower in entrepreneurs (median = -0.16, SEM = 0.07) than in non-entrepreneurs (median = -0.05, SEM = 0.44). However, the binomial logistic regression shows no significant associations, with an odds ratio of 1.01 (95% CI of 0.98 to 1.04) and FDR-adjusted p-value = .607.

4.6 DISCUSSION

This extensive online study takes a novel approach to studying the entrepreneur using both hypothesis-driven and exploratory neurocognitive testing. Results showed that hypothesis-driven cognitive tests for information sampling (a proxy measure of impulsivity) and probabilistic learning (a proxy measure of uncertainty processing) yielded no difference between entrepreneurs and non-entrepreneurs. However, in our exploratory analyses, a binomial logistic regression model and odds ratios showed that those with a higher score on episodic memory or with lower verbal reasoning skills had a 33% higher likelihood of being an entrepreneur. In addition, out of the personality traits tested, those with lower traits of conscientiousness were 5% more likely to be entrepreneurs, lower neuroticism was associated with a 4% more likely chance of being an entrepreneur, and those with higher traits of openness were 10% more likely to be an entrepreneur. Taken together, this suggests that a subtle combination of cognitive and personality characteristics is associated with being an entrepreneur.

Overall, we argue that the cognitive testing methods shown here could provide novel approaches to understanding entrepreneurship, informing the design and focus of more advanced neuroscience experiments, e.g including neuroimaging, thus providing new insights into entrepreneurial neurocognition.

4.6.1 *Contributions of this research*

Hypothesis-driven testing

Hypothesis 1: Impulsivity in decision-making is higher in entrepreneurs than in the general population, and this difference can be identified via cognitive testing.

First, we tested impulsivity in entrepreneurs using the Barrat's Impulsivity Scale and Information Sampling task. As introduced in Chapter 2, interest in the topic of impulsivity and ADHD-like behaviour in entrepreneurs is growing. However, despite the increasing number of reviews and literature papers relating ADHD-like behaviour to entrepreneurship, there is little empirical evidence that tests for impulsivity in entrepreneurs. Moreover, the existing empirical studies contest a view of higher impulsivity in entrepreneurship. In our study of 700 non-entrepreneurs and 193 entrepreneurs, we do not show that entrepreneurs differ in the amount of information they require before making a decision, nor do we show higher trait impulsivity on the BIS. Prior research has employed neurocognitive tasks measuring motor impulsivity (Go/No-Go task and the Eriksen Flanker Task), conflict inhibition (Stroop task) and risk-taking (the Balloon Analogue Risk-Taking Task) (Fisch, Franken and Thurik 2021; Nejati and Shahidi 2013; Ortiz-Terán et al. 2013). In our study, we have used the IST to measure reflection impulsivity (Kagan 1966). Designed by Clark et al. (2006), the IST has reliably shown different behavioural results in individuals with more impulsivity, such as substance users and Alzheimer's patients (Tavares et al. 2007; Zamarian et al. 2015). APA defines reflection impulsivity as *"a dimension of cognitive style based on the observation that some people approach tasks impulsively, preferring to act immediately on their first thoughts or impressions, whereas others are* *more reflective, preferring to consider a range of alternatives before acting"* (Dictionary 2022).

Therefore, this task was particularly relevant to entrepreneurs in assessing whether they do make more impulsive decisions, acting on their first impressions with a lack of information. However, we found no evidence that entrepreneurs are more impulsive or make decisions without reflective thought. Interestingly, an empirical study performed by Ortiz-Terán et al. (2013) suggests that the opposite is the case and that entrepreneurs reflect more on their decisions. Using electroencephalogram (EEG) and the Stroop task, they found that entrepreneurs' N450 event-related potential was more significantly activated than non-entrepreneurs. The N450 is located in the anterior prefrontal region of the brain and these results suggest that entrepreneurs are slower and more cautious in evaluating their decisions after a response on the Stroop Task. Therefore, whilst the empirical evidence of impulsivity tasks in entrepreneurs is still somewhat limited, we feel that neurocognitive techniques cast new light upon and challenge existing theoretical assumptions. The empirical evidence here and in Chapter 2 does not provide a strong motivation for more research into impulsivity and risk-taking. Nor does it show neurocognitive support for theories of entrepreneurs that assert that they make decisions using overconfidence (overestimating the probability of being right) and over-representation (the tendency to overgeneralize from a few characteristics or observations) (Busenitz and Barney 1997).

Hypothesis 2: Entrepreneurs' perception of- and use of- uncertainty in decision-making differs from that of the general population.

As an alternative to impulsive decisions, we can instead consider the extent to which entrepreneurs make informed decision in uncertainty. We tested how entrepreneurs process uncertainty using a 2-arm bandit task. This task is a good reflection of volatility and uncertainty processing and makes it possible to study how entrepreneurs learn and adapt. However, we failed to find significant differences in any of the model parameters on this task in entrepreneurs. Examination of the median scores and plots in fig 4.7 also do not suggest a trend that warrants further investigation in this specific computational measure of uncertainty processing, as the spread of data and median scores seem well matched across both groups and the 95% confidence intervals of the difference between groups fall close to zero. This methodology for studying decision-making stems from work by Behrens et al. (2007), Andreea O. Diaconescu et al. (2017) and C. D. Mathys et al. (2014), who provided a novel way to measure how humans learn information in an uncertain world. The particular models used here were derived from Reed et al. (2020). Participants' beliefs on this task can be inferred from the 3-level HGF with a volatility response model (the model that most reflected participants' behaviour in this sample) (C. D. Mathys et al. 2014). From this, we gained objective measures of how much the participant: 1) updates which card they think is the most likely to be correct ($\omega 2$); 2) updates their estimate about how much the environment is changing ($\omega 3$ =); 3) uses their belief about how much it's changing to update which card they think is correct (κ); and 4) how volatile they thought the task would be when they began ($\mu 3$). As stated above, none of these belief parameters differed between entrepreneurs and non-entrepreneurs. The sample here is large enough (n = 658, 507 non-entrepreneurs and 151 entrepreneurs) that we should have been able to detect differences in this model parameters if there were any. Therefore, we feel the results suggest no core differences in how entrepreneurs perceive uncertainty in the environment, nor in how they learn about unexpected uncertainty and use it to update beliefs about the environment.

Interestingly, however, the Intolerance to Uncertainty scale did show a statistically significant difference, such that entrepreneurs were less intolerant (more tolerant) of uncertainty. This fits in with prior empirical and theoretical developments that have shown entrepreneurs to be more comfortable with ambiguity and uncertainty (McMullen and Dean A. Shepherd 2006; Sarasvathy 2001; Schere 1982). It may be that this trait of tolerance to uncertainty reflects entrepreneurs' attitudes and temperament towards environmental changes, as traits have been described as "motivational systems with an affective core" (MacDonald 1995). This suggests an emotional tendency towards being comfortable with uncertainty, as opposed to a computationally different way in which entrepreneurs perceive or learn about it (Baron 2008).

Despite the popularity of these theories in entrepreneurship research, we failed to show differences between entrepreneurs and non-entrepreneurs in neurocognitive impulsivity and uncertainty processing. Whilst there is good reason to doubt that entrepreneurial behaviour involves 'impulsive' decisions, we feel that tolerance and adaptation to uncertain choices is the cornerstone of entrepreneurial thinking (McMullen and Dean A. Shepherd 2006). However, the tasks we selected did not have an element of risk or reward , nor did they have any emotional contexts. Therefore, as termed by Lawrence et al. (2008), these measures likely reflect 'cold' cognition, and they previously only found differences in entrepreneurs' 'hot' cognition during the Cambridge gambling task where participants could win or lose money based on their performance. As shown in Chapter 2, entrepreneurs form emotional attachment to their ventures and ideas and this may affect decision-making. The difficulty in this study was the online context and the large sample sizes we aimed to recruit, making it difficult to provide emotional or monetary incentives. Therefore, future studies should design more ecologically valid tasks and motivate participants with a 'hot' element to the decisions made.

Exploratory Data-Driven Testing

Hypothesis 3: Performance on standardised cognitive tasks and personality scores can predict entrepreneurship grouping.

Despite the null findings in our hypothesis-driven experiments, the exploratory data-driven analysis revealed distinct neurocognitive and personality dimensions in entrepreneurs: higher episodic memory, lower verbal reasoning, higher openness, lower conscientiousness and lower neuroticism. An approach such as this has never been used to study entrepreneurs before, and thus we show here the unexpected insights we can gain from such methods, before discussing what these findings could mean in the context of entrepreneurial neurocognition.

The Factor Structure of Neurocognition Across All Participants

First, we showed that the 12 neurocognitive tasks in this battery could be reduced to five underlying factors: Episodic Memory, Imagery, Verbal Reasoning, Spatial Reasoning and Working Memory. The tasks and methods we used are similar to those discussed in Chapter 1 section 1.3.8, which previously mapped onto 3 distinct functional networks in the brain; Working Memory Multiple Demand component (wmMD), a Reasoning Multiple Demand component (rMD), and a Verbal Reasoning component (VR) (Hampshire, Highfield et al. 2012). Our results across all participants complement these findings, as we showed components of Working Memory (wmMD) and Reasoning (rMD) (although separated into two components in our factor analysis: Imagery and Spatial Reasoning) and Verbal Reasoning. However, we also found an additional Episodic Memory factor in our data. This factor was likely not present in (Hampshire, Highfield et al. 2012) who focused on the MDN, as episodic and autobiographical memory is more closely mapped to the default-mode network.

The strength of these standard cognitive tests and methods to study entrepreneurs comes from the ability to map such factors onto known functional networks in the brain. This may give an indication of the networks and regions to study in subsequent neuroimaging experiments. For example, working memory has been shown to be implicated in brain activity and functional connectivity in superior/ventral regions of the multiple demand network (MDN), such as the insula/frontal operculum (IFO), the superior frontal sulcus (SFS), and the ventral portion of the anterior cingulate cortex/pre-supplementary motor area (ACC/preSMA). Whilst reasoning has been associated with brain activity in the inferior/dorsal portions of the MDN, such as the frontal sulcus (IFS), inferior parietal cortex (IPC), and the dorsal portion of the ACC/preSMA (Hampshire, Highfield et al. 2012; Camilleri et al. 2018). Verbal reasoning has been linked to the left inferior frontal gyrus (IFG) and the bilateral temporal lobes, areas which overlap with both the MDN and default mode network (DMN) (Hampshire, Thompson et al. 2011; Krieger-Redwood et al. 2023; Davey et al. 2016). Finally, our additional component of episodic memory has often been associated with the DMN, which consists of the anterior and posterior midline cortex, the angular gyrus, and the medial temporal lobe (Kim 2010; Krieger-Redwood et al. 2023).

Therefore we argue that applying such neurocognitive tests can give an indication of the underlying brain networks and functioning that may differ in entrepreneurs, as the factor scores can then be compared between groups, as we did in the present study. As these tests can be delivered online, they provide pilot data to motivate the design of more complex neurognitive testing, such as costly and time-consuming neuroimaging experiments. Here we found differences in two factors: Episodic Memory was higher in entrepreneurs and Verbal Reasoning was lower.

Differences in Episodic Memory and Verbal Reasoning in Entrepreneurs

We found episodic memory to be higher in entrepreneurs, with an odds ratio indicating those with higher scores in this factor are 33% more likely to be entrepreneurs. This factor contained high loadings from the immediate and delayed word recall task, in which participants were presented with words, then after a short time (immediate) and half an hour (delayed) were asked to recall which words they saw. This encoding and retrieval of verbal information taps into measures of episodic memory, and as indicated by the factor analysis, is quite different to verbal reasoning using semantic memory, see figure 4.8, which shows low to no loadings from the word definition or verbal analogies task (components of verbal reasoning) onto the episodic memory component. Episodic memory is defined by (Tulving 2002) as a neurocognitive entity that 'makes mental time travel possible' due to the three core concepts of episodic memory; a sense of subjective time, an awareness a consciousness of the 'now' and the 'past' and a sense of 'self' which can think back to the past and relate it to the present. With episodic memory, people can consciously 're-live' a memory, associated with the DMN (Kim 2010; Krieger-Redwood et al. 2023). This finding therefore indicates that the default-mode network and episodic memory processes may be fruitful areas of neurocognitive research to pursue further in entrepreneurs.

In contrast, we found verbal reasoning to be lower in entrepreneurs, with a 33% odds ratio of belonging to the entrepreneur group with a lower score. This suggests an inverse relationship between episodic memory and verbal reasoning in entrepreneurs, which is backed by neuroimaging findings and theories in cognitive neuroscience asserting that episodic and semantic memory are related, yet distinct neurocognitive processes (Tulving 2002; Krieger-Redwood et al. 2023). In our work, the tasks that most highly loaded onto the verbal reasoning components were the verbal analogies (e.g. true or false answers to statements such as *soldier is to army as drummer is to band*) and the word definition task. This indicates that semantic memory (knowledge and understanding of concepts without an explicit memory) and thus verbal reasoning may be weaker in entrepreneurs. Moreover, this should be explored for a possible compensatory effect in entrepreneurs, whereby this lower verbal reasoning is balanced by the greater long-term memory and perhaps access to autobiographical and episodic memories, to aid creative responses and problem-solving.

More Open, Less Neurotic and Conscientious Entrepreneurs

Finally, we found that entrepreneurs in our sample demonstrated trait differences of higher openness, lower neuroticism and lower conscientiousness. No significant differences were found in extraversion or agreeableness. Our results are consistent with previous findings which consistently showed higher openness and low neuroticism when contrasting entrepreneurs versus managers, and when correlating these traits with entrepreneurial intention and performance (Zhao and Seibert 2006). Traits are often thought to include affect (emotions), behavioural and cognitive components. Openness is particularly relevant to study in entrepreneurship, due to its relationship to imagination and cognition (McCrae 1993; Zillig, Hemenover and Dienstbier 2002). Openness to experience reflects *individual differences in the ability and tendency to seek, detect, comprehend, utilise, and appreciate complex patterns of information, both sensory and abstract* (DeYoung 2015) and it has been previously been termed as intellect or imagination. However, fMRI has distinguished openness from intellect, with the latter correlating with working memory and activity in the left lateral anterior prefrontal cortex and posterior medial frontal cortex, while the former shows a high and reliable relation to creativity, divergent thinking, and implicit learning (Oleynick et al. 2017; Kaufman et al. 2010). Both openness and creativity are associated with increased connectivity in the DMN which activated when people are engaging in spontaneous thought and letting their mind wander (DeYoung 2015), as well as with with decreased white matter integrity in the frontal lobes. Openness was inversely related to white matter integrity within the right inferior frontal white matter, whilst creativity was inversely related to white matter integrity in the left inferior frontal matter (Jung et al. 2010). Therefore suggesting networks and connections within the frontal projections and default-mode networks may be interesting neural structures to study in entrepreneurs.

In addition, our finding of lower neuroticism echoes the point made earlier about the importance of the emotional nature of entrepreneurs, or indeed the controlling of emotions (Baron 2008). In particular, the low levels of neuroticism we show in entrepreneurship may be particularly useful in aiding an emotional tolerance to uncertainty. Therefore future studies may explore how low trait neuroticism in entrepreneurs relate to specific brain processes. Neuroticism has been consistently associated with deeper brain structures such as the limbic system and with the involvement of the amygdala to ventro-medial prefrontal connections implicated in emotional regulation (Hsu et al. 2018; Silverman et al. 2019). Emotional stability (low neuroticism) is thought to involve the control of emotional impulses and it may be interesting in future research to link back and contend with theories of impulsivity and ADHD-like behaviours in entrepreneurship (Wiklund et al. 2017; Fisch, Franken and Thurik 2021). An alternative to the idea of low neuroticism as a pre-requisite to entrepreneurship, is that entrepreneurs overall report to be happier and have better work-life satisfaction, so the autonomy of working on ones' passions may indeed be associated with the profile of someone seeming more emotionally stable (U. Stephan et al. 2020). Therefore future work on entrepreneurial traits may wish to explore how neuroticism changes when undergoing a transition from a working professional to self employment and how this potentially scales up with entrepreneurial experience and success.

As introduced in Chapter 1 there is often a high degree of heterogeneity in the Big 5 Personality traits of entrepreneurs, so it is not surprising that we find differing results in this sample to that of the meta-analysis of entrepreneurs personality which shows higher C, O, E, and lower N, A in entrepreneurs versus managers, correlations with entrepreneurial intention (higher C, O,E, and lower N), and higher entrepreneurial performance (higher C, O, E, and lower N) (Zhao and Seibert 2006). One finding in our sample was contradictory to that prior literature in that we found a lower level of conscientiousness in entrepreneurs. However, we do not think it unreasonable for entrepreneurs to be low in conscientiousness. Conscientiousness represents how much of a thought and planned-out approach someone takes with questions such as *I follow a schedule* and *I am always prepared*. Disruptive entrepreneurship, particular in the early-stages, does not seem to be conducive with a conscientious or casual planning approach (Read et al. 2009; Sarasvathy 2001). In our sample, entrepreneurs had on average two businesses, with an average time of running them for 6 years, therefore whilst not completely novice, it would be interesting the explore how conscientiousness changing with experience in future research, potentially with longitudinal studies.

Therefore whilst personality research has been somewhat dismissed by many entrepreneurial cognition researchers (Gartner 1988), we still believe that the evaluation of entrepreneurs' personality is relevant in neuroentrepreneurship. This is mainly due to the consistent findings of higher openness and low neuroticism, and to the wealth of literature relating traits to cognition and brain function/structures.

4.7 LIMITATIONS

There are limitations when applying such methods as we used here to studying entrepreneurs. One limitation relates to the online nature of this study. As noted in Chapter 3, the data was collected during the Covid-19 pandemic. Whilst this meant that many people were working from home, and so it is likely that we saw more interest in the research, it is more difficult to control for attention and engagement online, especially on cognitive tasks. However this was accounted for in the analysis, in which we followed a strict data cleaning procedure and remove participants who showed a significant amount of time off-screen. As mentioned earlier in regard to motivation and the lack of reward/risk in our study, we have identified that this could also potentially affect task performance. However previous research has shown similar performance when participants performed cognitive tasks with a real monetary incentive and without (Ličen et al. 2016). We feel confident that those who competed the task were motivated by the incentive to 'do well', further motivated by the report they received at the end detailing their performance against the rest of the population.

A further limitation to this type of testing in entrepreneurship is that any neurocognitive differences are expected to be very small, and therefore their detectability may be particularly sensitive to statistical choices and inference. Most often the methods we have used here have tested differences between healthy controls and patient groups, where we usually expect larger differences to be found that between two healthy groups of participants. Whilst for this study we kept statistical rigor and only reported statistically significant differences through corrected p-values and confidence intervals, we do feel future research in this area should take great care in considering the most appropriate statistics to answer questions of what may be subtle inter-individual differences in otherwise 'healthy' individuals.

A final limitation to consider is the composition of the sample groups in this study, both on the criteria they are grouped by and the nature of the online study, leading to dropout throughout.

Due to the online nature of the study, participant dropout occurred at various stages, resulting in differing sample sizes across the sub-studies. For instance, the first sub-study on impulsivity comprised 893 individuals (700 non-entrepreneurs and 193 entrepreneurs), while the second sub-study on uncertainty included 658 participants (507 non-entrepreneurs and 151 entrepreneurs). Finally, the third sub-study on the full cognitive battery consisted of 459 individuals (366 non-entrepreneurs and 93 entrepreneurs). This discrepancy in sample sizes introduces heterogeneity between the sub-studies, which in turn makes direct comparisons challenging. Participants in the final sub-study would have been part of both the first and second groups, further complicating the independence of the samples. To address this limitation, no correlations or comparisons were made between results from different sub-groupings, thus avoiding assumptions of independence. In the final analysis, only participants who completed all tests were included in the factor analysis on the cognitive battery and group comparisons.

However, it is essential to consider the generalisability of the results, particularly in the final sample. It is likely that in batteries of cognitive tests that participants who complete all tests may represent a biased sample, potentially finding the tests easier, enjoying them more, having better attention spans, or being more motivated to obtain their results. This highlights the challenge of participant retention in large batteries of tests. We anticipated this challenge and administered hypothesis-driven tests at the beginning to obtain larger sample sizes and statistical power for these groups, whilst including exploratory tests at the end. Future research may benefit from strategies to address retention issues in online protocols. This could include condensing testing time or introducing incentives to keep participants engaged throughout the study.

Finally, power calculations indicated a required sample of 244 for the first two hypothesis (122 in each group), for a 0.95 power. Meaning the first two hypothesis were fully powered. However the final group would have required a sample of 1299 people to achieve 0.95 power at the 0.05 level, predicting a 10% difference between groups. This highlights a further limitation of the dropout during this study as under-powering our final analysis.

4.8 CONCLUSION

In conclusion, our findings carry significant implications for both the understanding of entrepreneurship and the direction of future research in this field. Firstly, the observed link between lower verbal reasoning and entrepreneurship, alongside literature suggesting a potential higher prevalence of dyslexia among entrepreneurs, highlights a critical area of investigation that deserves more attention. This connection may shed light on the unique strengths and challenges faced by neurodiverse individuals in entrepreneurial endeavors.

Secondly, the intriguing disparities we uncovered between episodic memory and verbal reasoning in entrepreneurs suggest underlying neurocognitive distinctions in how they harness semantic and episodic memory processes during verbal tasks. Given the well-established role of episodic and semantic memory and trait openness in creativity, (Krieger-Redwood et al. 2023; DeYoung 2015), and the undeniable importance of creativity, especially verbal creativity, in entrepreneurship, our findings open up a promising avenue for further exploration. Future research should delve deeper into the intricate relationship between traits, memory processes and creativity within the entrepreneurial context, offering valuable insights into the cognitive mechanisms that drive innovation and success in this field. These discoveries have the potential to reshape our understanding of entrepreneurship and provide practical applications for fostering entrepreneurial skills and strategies.

Therefore, in relation to this thesis, we show how a unique cognitive and personality profile may drive entrepreneurs towards competencies of disruptive thinking and resourcing. In particular we highlight how a combination of traits such as tolerance to uncertainty, openness, and low conscientiousness, mixed with a cognitive profile of greater episodic memory and lower semantic reasoning may aid creative thinking. In the next chapter, I continue to delve even deeper into the competency of disruptive and creative thinking to explore what happens in an entrepreneur's brain when they combine the resources to hand to come up with new and innovative ideas, applying a neuroimaging to the study of effectual thinking.

4.9 REFERENCES

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4.10 SUPPLEMENTARY MATERIAL

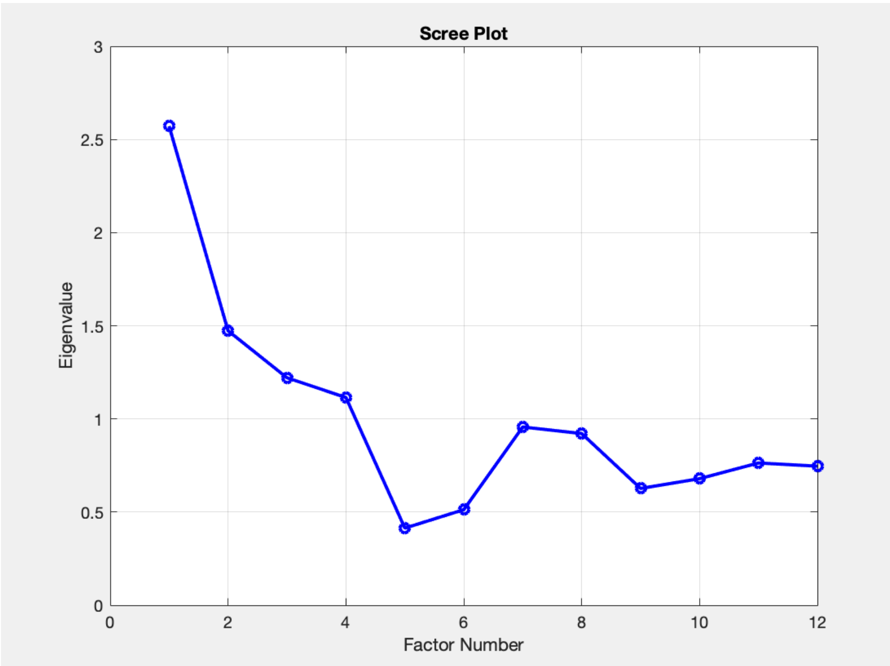

Figure 4.11: Scree plot from the factor-analysis on the 12 tasks cognitive battery shows each factor's Eigenvalues. There was an 'elbow' point at 5, indicating how many factors to retain.

Uncertainty stops me from having a firm opinion
Being uncertain means that a person is disorganized
Uncertainty makes life intolerable
It's unfair not having any guarantees in life
My mind can't be relaxed if I don't know what will happen tomorrow
Uncertainty makes me uneasy, anxious, or stressed
Unforeseen events upset me greatly
It frustrates me not having all the information I need
Uncertainty keeps me from living a full life
One should always look ahead so as to avoid surprises
A small unforeseen event can spoil everything, even with the best of planning
When it's time to act, uncertainty paralyses me
Being uncertain means that I am not first rate
When I am uncertain, I can't go forward
When I am uncertain I can't function very well
Unlike me, others always seem to know where they are going with their lives
Uncertainty makes me vulnerable, unhappy, or sad
I always want to know what the future has in store for me
I can't stand being taken by surprise
The smallest doubt can stop me from acting
I should be able to organize everything in advance
Being uncertain means that I lack confidence
I think it's unfair that other people seem sure about their future
Uncertainty keeps me from sleeping soundly
I must get away from all uncertain situations
The ambiguities in life stress me
I can't stand being undecided about my future

Table 16: Intolerance to Uncertainty Scale (IUS). Answered on a scale of (1-5): 1 = Not all characteristic of me; 2 = Not at all/Somewhat characteristic of me; 3 = Somewhat characteristic of me; 4 = Somewhat/Entirely characteristic of me; 5 = Entirely characteristic of me.

1. I plan tasks carefully
2. I do things without thinking
3. I make-up my mind quickly
4. I am happy-go-lucky
5. I don't "pay attention"
6. I have "racing" thoughts
7. I plan trips well ahead of time
8. I am self controlled
9. I concentrate easily
10. I save regularly
11. I "squirm" at plays or lectures
12. I am a careful thinker
13. I plan for job security
14. I say things without thinking
15. I like to think about complex problems
16. I change jobs
17. I act "on impulse"
18. I get easily bored when solving thought problems
19. I act on the spur of the moment
20. I am a steady thinker
21. I change residences
22. I buy things on impulse
23. I can only think about one thing at a time
24. I change hobbies
25. I spend or charge more than I earn
26. I often have extraneous thoughts when thinking
27. I am more interested in the present than the future
28. I am restless at the theater or lectures
29. I like puzzles
30. I am future oriented

Table 17: Barratt's Impulsivity Scale (BIS) (Patton, Stanford and Barratt 1995). Answered on a scale of (1-4): 1 = Rarely/Never; 2 = Occasionally; 3 = Often; 4 = Almost Always/Always. Reversed scores = 1,7,8,9,10,12,13,15,20,29,30.

Task / Questionnaire	Measure	Shapiro-Wilk's p
Information Sampling Task	mean samples	6.077e-15*
	mean difference	2.2e-16*
	total points	2.2e-16*
BIS	total score	1.517e-05*
Bandit Task	$\omega 2$	3.032e-12*
	$\omega 3$	3.855e-14*
	κ	2.2e-16*
	$\mu 3$	8.128e-07*
IUS	total score	7.979e-05*
Cognitive Factors	episodic memory	0.9723
	mental imagery	0.9378
	verbal reasoning	0.9551
	spatial reasoning	0.7776
	working memory	0.3558
Big 5 Personality	agreeableness	2.454e-12*
	conscientiousness	2.348e-06*
	extraversion	1.239e-05*
	openness	0.02273*
	neuroticism	1.832e-08*

Table 18: Shapiro-Wilk's scores of normality: whereby a significant *p-value (<.05) indicates the data significantly deviates from the normal distribution and thus non-parametric tests should be performed.

5

CHAPTER 5: THE ENTREPRENEUR'S BRAIN: UNRAVELING THE IMPACT OF TASK AND CONTEXT ON CREATIVITY WITH FMRI

> There is no doubt that creativity is the most important human resource of all. Without creativity, there would be no progress, and we would be forever repeating the same patterns.
>
> — Edward de Bono

5.1 PREFACE

Research into the neuroscience of entrepreneurship is novel, and as a consequence, knowing which tasks and facets of neurocognition to study with neuroimaging experiments is a challenge. However, this thesis has built up an approach to study the entrepreneur's brain in stages; from setting a theoretical standpoint rooted in mentalism and process-orientation, to understanding the minds and thinking of entrepreneurs, the context in which the thinking presents and how this develops. I have reviewed the existing work that uses cognitive neuroscience methodology to guide and refine the online study presented in chapters 3 and 4. Chapter 3, reaffirmed the view that creativity and resourcing were the core components of entrepreneurship, which fits with contemporary theories of effectuation, in which the entrepreneur's imagination and ability to *create* or design an answer come to the forefront. Chapter 4 delves into the underlying components of entrepreneurs' competencies, as the personality and cognitive profiles which guide this way of thinking. I showed a unique profile of an entrepreneur, with increased traits of tolerance to uncertainty, openness and emotional stability, married with a neurocognitive profile of lower verbal reasoning (semantic memory) and greater episodic memory. Fascinatingly, these traits (openness) and neurocognitive findings (episodic and semantic memory) are often linked to creative neurocognition (Krieger-Redwood et al. 2023).

In this chapter we explore what, if anything, is different in the brains of entrepreneurs that allow them to imagine up and create something new. I designed and ran a neuroimaging experiment which enabled us to see how entrepreneurs create new ideas, under time pressure, with the resources to hand. In addition, we manipulated the context to provide situations of low and high uncertainty. I show in this chapter that differences in the functional activity of entrepreneurs' brains can be found when considering both the task and context they are operating within. This provides neuroscience evidence to the complex interactions between why, when and how entrepreneurial cognition comes into play, as a sum of the mind and environment.

5.2 ABSTRACT

Verbal creativity is a core feature of entrepreneurship, the ability to link distant concepts to form new and useful ideas. This study examines the neural underpinnings of verbal creativity in entrepreneurs. We employ BOLD fMRI analysis to a word pairs task, with two conditions: familiar (semantically related word pairs) and unfamiliar conditions (semantically unrelated word pairs). We also tested for differences in resting-state networks in the brains of entrepreneurs versus working professionals, using Independent Component Analysis (ICA) and dual-regression. While behavioural measures were not significantly different between the groups, neuroimaging findings revealed distinct neural patterns depending on the condition. Entrepreneurs exhibited enhanced right hemisphere efficiency, particularly in the right middle frontal gyrus (MFG). They showed increased MFG and frontal pole activity in familiar conditions, possibly reflecting better attention-switching abilities between internal and external processes. Conversely, entrepreneurs displayed reduced MFG and frontal pole activity in unfamiliar conditions alongside more significant deactivation of the precuneus, the latter being a component of the brain's default-mode network. These results suggest that entrepreneurs may find greater cognitive ease in breaking free from learned associations, leading to more creative responses. However, no differences between groups were found in the core creative regions involved in verbal creativity, nor in the resting-state networks. This study challenges assumptions about entrepreneurs' innate creativity and highlights the importance of task-specific adaptability. Future research should explore the role of the right MFG and frontal pole in entrepreneurs' creativity, and also consider integrating emotional aspects of entrepreneurship-related creativity. Limitations of this research include the need to design objective creativity measures and the ecological validity of such neurocognitive tasks to entrepreneurship.

Nevertheless, this work contributes novel insights into neuroentrepreneurship by being the first to uncover differential activity in the brains of entrepreneurs during verbal creativity.

5.3 INTRODUCTION

Theoretical Background

The ability to create something original and effective is crucial in defining creativity and an essential factor for entrepreneurship. (Runco and Jaeger 2012). Entrepreneurs are the people who drive forward new ideas or offer new solutions to old problems, with *disruptive entrepreneurship* being the most extreme of its kind, whereby individuals create and introduce new products that fundamentally change a market or industry (Schumpeter 1943). It is no wonder that the academic literature has focused for a long time on what makes some people in society become such innovators and *entrepreneurs*. Yet, despite creativity being a necessary and essential component in any entrepreneurial endeavour, it is surprisingly overlooked. Many narratives instead focus on the elements of entrepreneurial cognition that proceed the creative process, such as the uncertainty that comes with being creative, or the perceived risk of taking an idea toward (McMullen and Shepherd 2006; L. W. Busenitz and Barney 1997). It is surprising that less interest has been given to the event that 'kicks off' such subsequent challenges in the mind. An idea or entrepreneurial endeavour could not appear risky, or be deemed uncertain to work, unless it was something that had never been done before, or a venture that was perceived disruptive. The theory of effectuation at its core, describes the creative logic of an entrepreneur to use their imagination and conjure up a new recipe of ideas and strategies never tried before (Sarasvathy 2001).

Effectuation places entrepreneurship and imagination in the same realm. An effectual approach to thinking is, as quoted by Denis A Grégoire and Cherchem (2020) "Given an uncertain world, what could I do with the means, resources, and capabilities I have or could readily mobilize?". The answer to such a question can only come from one's imagination and ability to *create* or design an answer. Yet, whilst there are established theories explaining what makes an entrepreneur *different* and able to navigate uncertainty (Sarasvathy 2001), there is a lack of empirical understanding. This is primarily due to the limits of previous self-report methods and the subjective experiences of individuals' thought processes (Denis A. Grégoire, Corbett and Mcmullen 2011), and in particular, the limits of self-report in capturing imagination.

As introduced in Chapter 1, the cognitive approach in entrepreneurship was positioned by scholars such as Denis A. Grégoire, Corbett and Mcmullen (2011) as the means to truly disentangle what the 'difference' is in entrepreneurs. This can be done in two ways; either we may see what the differences are in the cognitive resources of an individual that predate entrepreneurial actions (e.g. the dispositions, cognitive skills, and knowledge of an individual) or we may study the differences in the 'live' cognitive experience of individuals (e.g. how they perceive the process differently in the moment, due to interactions with the context and environment they find themselves in). Up until this point, this thesis has taken the former approach looking to the resources of the individual that may enable entrepreneurial and creative thinking; noting the competencies, traits and neurocognitive profiles of entrepreneurs. However with neuroimaging methods, we have the means to also test 'live' cognitive experiences.

The unique contribution of brain imaging is to provide insight into the entrepreneur's brain and the differences in idea generation that are unique to them, in real-time and in-vivo. By exploring the neural mechanisms associated with creative ideation in entrepreneurship, we aim in this chapter to assess the differences in an entrepreneur's brain live processing. Understanding how the brain produces creative ideas in different groups, such as entrepreneurs compared to other working professionals, enables us to study how experiences influence such cognitive skills and how we may create environments that foster creative thinking.

Neuroscience approaches to creativity

Often, creativity is seen as a subjective and elusive event that cannot be quantified, such as a spontaneous 'aha moment'. However, research on problem-solving and insights in cognitive neuroscience have challenged this view. Creativity is now understood as an integral part of a broad range of mental processes (Dietrich 2004; Beaty 2020; Chrysikou 2019). Creative cognition has been demonstrated to be associated with increased connectivity between fronto-parietal control regions (default mode network (DMN)) and the DMN (Ovando-Tellez et al. 2022). There is a balance in creative cognition between the involvement of core executive/control functions, such as inhibition, attention, working memory, and cognitive flexibility (Palmiero et al. 2022), and the default-mode networks of the brain have been shown to be involved in mind-wandering, memories and self-referential thoughts (Raichle et al. 2001).

Research on the cognitive neuroscience of creativity suggests that it results from searching for, reorganising, and combining semantic memories. (Ovando-Tellez et al. 2022). This means the 'glueing together' of concepts in our knowledge and memory into something novel. As a result, a growing corpus of work aims to integrate theoretical and neurological accounts of semantic memory and creative cognition. In particular, the default mode, multiple demand network (MDN) and semantic control network (SCN) have been implicated in

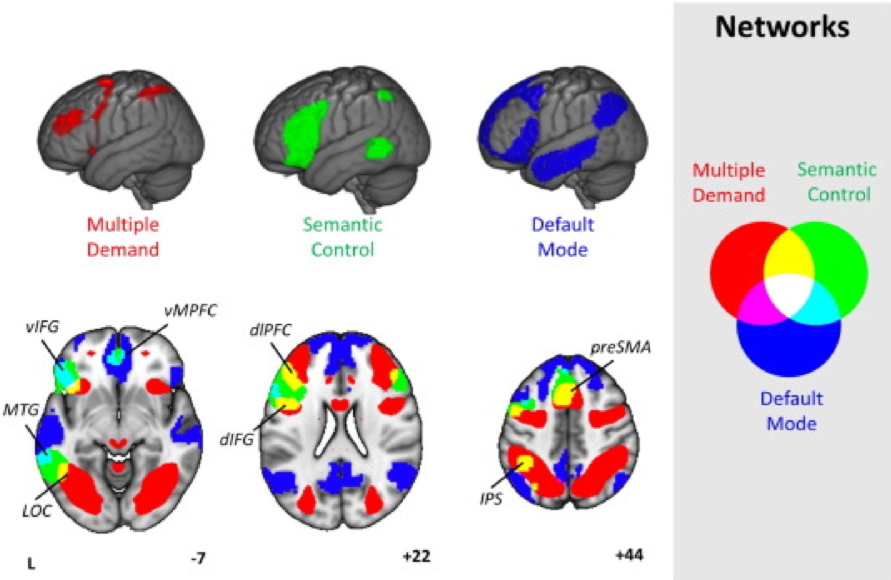

Figure 5.1: Figure from Davey et al. (2016), showing the MDN (red), DMN (blue) and Semantic Control Network (green) rendered on an MNI-152 standard template brain. The Colour key shows where areas overlap between these networks.

the automatic retrieval of semantic information in our memories, combined with the executive goal-orientated cognition of a task (Davey et al. 2016). These networks are depicted in Figure 5.1, which illustrates how areas of the Semantic Control Network overlap with the MDN in the dlPFC (dorsolateral prefrontal cortex), dorsal inferior frontal gyrus (IFG), pre-SMA, IPS (intraparietal sulcus) and LOC. Regions of the semantic control network overlapping with the DMN include the ventral IFG, VMPFC (ventral medial prefrontal cortex) and posterior medial temporal gyrus (MTG). The interplay of these networks and underlying brain regions are thought to be involved in how we make sense of the world, in the retrieval and integration of semantic information to suit the particular task at hand, and perhaps in facilitating the meshing together of new concepts for creative ideas (Krieger-Redwood et al. 2023; Orwig et al. 2021; Chiou et al. 2023).

Researchers can objectively score verbal creativity and study how semantically distant links form in the brain thanks to novel computational methods. Orwig et al. (2021) asked participants to undergo resting-state and fMRI and the Unusual Uses Task (UUT), in which participants had to come up with as many uses as they could for everyday objects, such as a brick, newspaper or a paperclip. The UUT is a classic divergent thinking task, which tests the ability of people to generate creative ideas; it is scored by measures of fluency, originality, flexibility and elaboration (Guilford 1967). Taking a different approach to standard scoring, responses in Orwig et al. (2021) were analysed using computational semantic models to measure the semantic distance between objects and responses. The authors showed that higher local connectivity at rest within visual regions was associated with higher semantic similarity in responses (e.g. low creative responses, such as linking a brick to a wall). In contrast, projections from the precuneus to the right inferior occipital and temporal cortex at rest were positively associated with lower semantic similarity in task responses (e.g. high creative responses, such as suggesting a brick could be hollowed out and used as a vase). This indicates that individuals who engage in more mind-wandering during rest (associated with DMN regions) and pay less attention to external visual inputs are more creative during divergent thinking tasks such as the UUT.

Objective measurements of 'semantic distance' for pairs of related and unrelated words can be used to design tasks that test creativity in different contexts, for example, by converging the concepts instead of creating many different solutions. Krieger-Redwood et al. (2023) designed a word-pairs task where the semantic distance of 2 words changed along a continuous scale from very unrelated (unfamiliar context) to very related words (familiar context), scored by the computational model Word2vec. Word2vec is a trained algorithm for natural language processing that uses neural networks to learn word associations (Google 2013). Word2vec was trained on a 100 billion-word Google News dataset (Mikolov et al. 2013) and can therefore be used to calculate objective scores for the semantic similarity between words, e.g. how often do they usually occur together? During that study, participants were asked to mentally create a link between two words shown on a screen while undergoing fMRI scanning. The authors were able to differentiate brain networks involved in creative responses between two experimental conditions. In familiar situations where the words were very related, e.g. 'farm' and 'sheep', participants used more episodic memory and engaged the core DMN.

Conversely in unfamiliar situations, e.g. forming links between 'seat' and 'grapefruit', more controlled retrieval was required from the semantic control network (IFG, and dorsomedial prefrontal cortex (dlPFC)) and an additional area outside this network temporal fusiform gyrus (TFG)), which overlaps with the MDN network and more dorsal portion of the DMN. These results show that, in different contexts, creativity may be produced by other brain processes. In particular, in familiar situations, past (episodic) memories may help form unique responses; in unfamiliar situations, more regions in the semantic control network are recruited to create unique and creative ideas. Creative cognition, therefore, is said to occur from an optimal balance between spontaneous processing and controlled processing (Mok 2014; Kenett 2018; Ovando-Tellez et al. 2022).

Research Gap

The methods and tools of cognitive neuroscience that are available to us today are ideal to enable us to study creativity and, at large, the biology and cognition of entrepreneurs (Nofal et al. 2018). Research in the cognitive neuroscience of creativity is particularly relevant to entrepreneurship for two reasons. Firstly, verbal creativity and integrating concepts into something new and useful are crucial to core theories in entrepreneurship. As introduced in chapter 1 and 2, creating or spotting opportunities is a defining feature of entrepreneurship. Opportunity alertness in entrepreneurs is described to involve three processes: (1) scanning and searching, (2) association and connection, and (3) evaluation and judgement (Tang, Kacmar and L. Busenitz 2012). This shows a robust conceptual link with the cognitive neuroscience definitions of creativity as the searching, reorganising and combining of semantic memories. It is highly relevant to study how such processes occur in the entrepreneur's brain to cast light on the age-old question, 'What is different about how an entrepreneur thinks?'.

Secondly, many recent theories in entrepreneurship converge on the importance of 'context' and, in particular, on the role uncertainty plays in entrepreneurship. Uncertainty is the cornerstone of all entrepreneurship theories, as entrepreneurs introduce new ideas into society despite the lack of predictability in doing so (McMullen and Shepherd 2006; Knight 1921; Sarasvathy 2001). The study by Krieger-Redwood et al. (2023) includes both a measure of creativity in the brain and how this differs in two contexts: familiar and unfamiliar situations. The controlled environment of fMRI study design allows us to create different contexts and then test the influence of these on neural activity. By studying how familiar and unfamiliar scenarios affect creativity, we better understand the environments that stimulate new ideas, matched with the ability to test how this differs between entrepreneurs and other professional groups.

We therefore argue that there is currently a notable gap in research that we aim to address here. First, for the neuroscience field, while verbal creativity has been studied in numerous studies, none has attempted to understand if the neural processes involved in creativity differ between professional groups. Second, for the entrepreneurship field, there is a lack of understanding about the neural mechanisms which underlie entrepreneurs' ability to *create through uncertainty*.

Objective

This neuroimaging study aimed to test creative processes in the brain between a group of established (disruptive) entrepreneurs and a control group of working professionals. Using an adapted version of the semantics word-pairs task from Krieger-Redwood et al. (2023), I manipulated the context for blocks of related and unrelated word pairs to measure and compare the neural mechanisms involved in generating new links between the words. In addition, I performed an exploratory ICA to analyse the resting-state networks of both groups to uncover any functional connectivity differences in the brain of entrepreneurs in networks such as the DMN, MDN, which overlap to form the Semantic Control Network (SCN).

Hypotheses

The study aimed to replicate findings in the cognitive neuroscience of creativity and expand upon them to uncover potential differences between entrepreneurs and working professionals. The hypotheses of this study were as follows:

1. Entrepreneurs are more creative and form unusual links than working professionals between unrelated concepts, as measured by frequency scores.

2. Increased creativity in entrepreneurs will correspond to differential activity in regions of interest associated with verbal creativity; the dmPFC, IFG and TFG.

3. Entrepreneurs' brains will show different functional connectivity in resting-state networks associated with creativity, such as the MDN and DMN.

5.4 METHODS

5.4.1 *Participants*

Ethical approval was obtained for this study (HR/DP-21/22-26710) by the Health Faculties (Blue) Research Ethics Subcommittee, Research Ethics Office, King's College London. Participants were recruited through two methods for the different groups: Entrepreneurs and working professionals. Entrepreneurs were recruited using targeted strategies facilitated by a gatekeeper, the Entrepreneurship Institute at King's College London, which has an extensive community and network of founders. Invitations were extended through letters from the lead researchers attached to emails and LinkedIn messages to potential participants from lead researchers and interns from the Entrepreneurship Institute. Working professionals were enlisted via adverts and recruitment newsletters on the King's Fortnightly Circular recruitment emails. For both groups, those displaying interest in joining the research were encouraged to read through the information sheet and criteria for the study before booking a screening call so that we could assess their eligibility. No monetary incentive was given for taking part in the study. Instead, participants could obtain a copy of their structural brain scans.

Entrepreneur Inclusion and Exclusion Criteria

Entrepreneurs were invited to participate to this study based on knowledge of their successful business, rather than through an open call for participants. Much of this recruitment was facilitated through the Entrepreneurship Institute at Kings College London, and their existing network. This targeted strategy was chosen to ensure that our entrepreneurs were experienced, disruptive, original founders and that their business was their sole focus. The inclusion criteria was checked via background checks on business(es) and verbal questioning during screening interviews. They had to have founded, managed, and maintained ownership of a business for at least three years. Their business needed to be actively generating revenue. Additionally, they were required to be the founders and to have played a pivotal role in establishing the business. Furthermore, we only recruited into this study 'disruptive entrepreneurs', where their business had to address a specific problem and provide a unique solution to an existing issue. This was assessed during a one-minute elevator pitch on the screening call in which they were asked 'can you tell me in one minute the specific problem your business addresses'. The first two criteria ensured that participants were actively engaged in entrepreneurial endeavours, deriving a substantial part of their livelihood from their businesses. The latter two criteria aimed to ensure that participants had a direct hand in conceptualising and creating their businesses, in line with the study's focus on how experience shapes brain-based creativity. Exclusion criteria encompassed individuals who had established a business based on conventional and repetitive models (e.g., accountancy) without a distinct selling point or problem-solving element. Additionally, those not deriving a livelihood or revenue from their businesses were excluded.

Working Professional Inclusion and Exclusion Criteria

Similarly, participants in the Working Professional group had to meet specific inclusion criteria. This included having a minimum of three years' experience in full-time employment. Job roles necessitating analytical and logical thinking, such as accountancy, administration, law, or roles following a structured progression, were included. Exclusion criteria entailed past involvement in starting a business, current freelance work, self-employment or intrapreneurship (where an individual acts like an entrepreneur within an organisation).

Further Exclusion Criteria

Moreover, additional exclusion criteria were implemented across all participant groups primarily for MRI safety and cognitive testing validity. These exclusion criteria included a history of psychiatric or psychological disorder likely to impact cognitive function on the day of testing significantly; neurological or neurodegenerative injuries or disorders affecting brain structure or function, including conditions like Parkinson's disease, multiple sclerosis, stroke, traumatic brain injury, and brain tumours; inability to provide information regarding MRI safety concerning metal implants, surgical records, or dental procedures; claustrophobia; pregnancy; and consumption of alcohol or drugs on the day of testing. Furthermore, individuals with full-time student status were also excluded, as we wished to have both entrepreneurs and working professionals with matched professional experience.

Screening and Sample

Fifty-two individuals were screened for participation, resulting in forty-two participants recruited for the study. Of these participants, 23 were entrepreneurs, and 19 were working professionals. Three screened entrepreneurs were not recruited; two due to medical grounds (traumatic brain injury and pregnancy) and one due to disclosure of claustrophobia. Seven screened working professionals were also excluded: one due to prior traumatic brain injury; one due to metal dental work that would interfere with the scanner; two due to being students and not having at least three years experience in full-time employment; and three due to previously owning a business, or currently undertaking freelance work of self-employment, in addition to their full-time job.

Two of the 42 individuals who entered the study did not complete the entire testing protocol and were excluded, leaving 40 participants: 22 entrepreneurs and 18 working professionals.

One entrepreneur's behavioural data file was irreversibly corrupted, so 39 participants' data were used in the final behavioural analysis: 21 entrepreneurs and 18 working professionals. Three participants had missing volumes from the fMRI scan at the start of the semantic task (one entrepreneur and two working professionals). FMRI data from 37 participants were included in the analysis, representing 21 entrepreneurs and 16 working professionals.

5.4.2 *Protocol*

Following a successful screening call, participants were booked in for an MRI scan and sent a storyboard of the protocol to help them prepare on arrival (Figure 5.2) and during the scan (Figure 5.3). Infographics were employed as an engaging way to give information about the study to participants and help them make an informed decision to participate. This method has increased the feeling of transparency and trust in participants (Kiernan et al. 2018; McCrorie, Donnelly and McGlade 2016).

Pre-visit Survey

Participants first undertook a shortened version of the Entrepreneurial Brain Challenge (see Chapters 3 and 4. This version included an initial page for them to consent, a demographic questionnaire, a brief questionnaire about their business(s) (years running, number of businesses

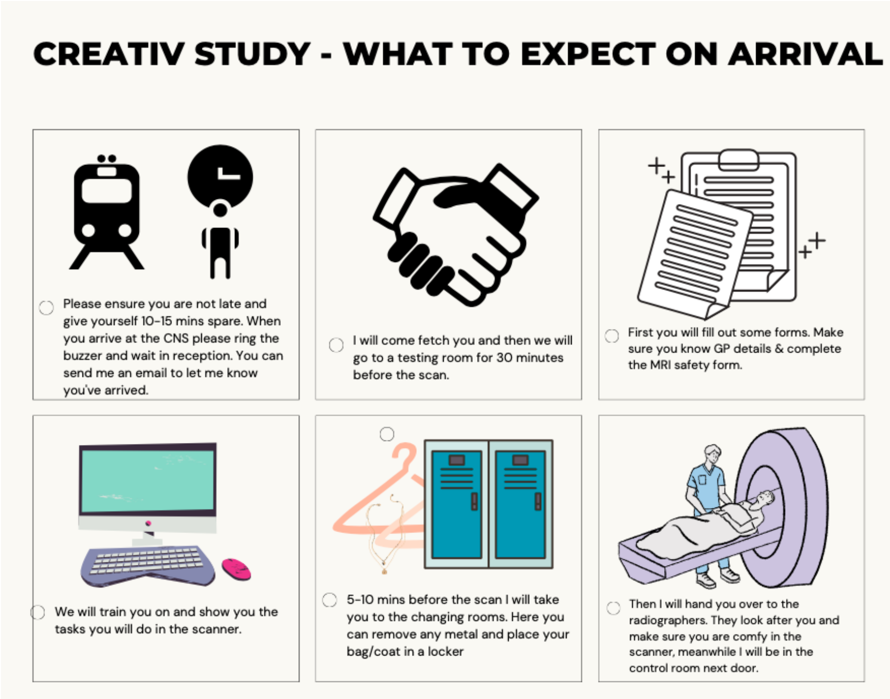

Figure 5.2: Page 1 of the storyboard sent to participants so they knew what to expect on arrival.

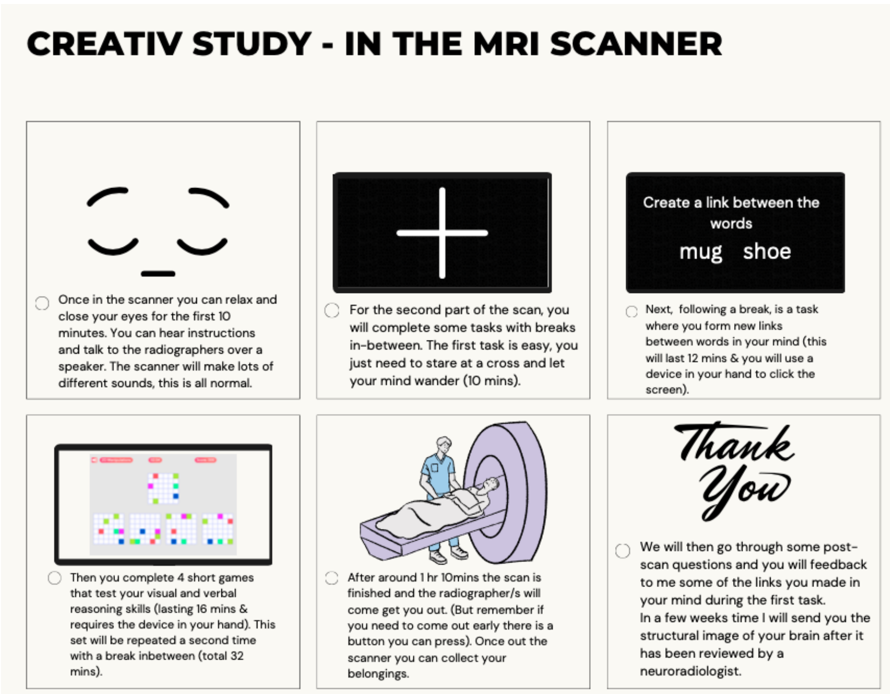

Figure 5.3: Page 2 of the storyboard sent to participants so they knew what to expect during the MRI scan.

created, etc), the Intolerance to Uncertainty questionnaire (see Chapter 4, Section 4.4.4) and the 50-item Big5 Personality Questionnaire (see Chapter 4, Section 4.4.5). This was so we could obtain descriptive and trait information about our sample and compare it to the model in the online study.

Pre-scan Protocol

During the in-person visit, participants were informed about the protocol using the storyboard to explain the procedure. They were given an information sheet and allowed time to read through it before consenting to the MRI study and MRI safety form, which an NHS radiographer then checked. Participants then practised the cognitive tasks they would perform in the scanner. Participants who were nervous about the MRI scan or had not had one before were allowed to experience the environment in a 'mock scanner' environment before their actual scan.

fMRI Task

Participants were scanned for a total of 75 minutes. They underwent structural scans, resting-state fMRI and two further fMRI scans while performing cognitive tasks: the semantics task detailed in this study and additional standardised cognitive testing, not analysed in the context of this PhD.

Design

In consultation with the authors of Krieger-Redwood et al. (2023), we adapted the semantic word-pairs paradigm to test verbal creativity from an event related to a block-design to ensure the greatest signal-to-noise, statistical power, and maximal time efficiency (Amaro Jr and Barker 2006). We reduced the time of the original task from 40 minutes down to only 12 minutes. In this task, word pairs were presented to participants who were asked to create a mental link between the two words. Following this, they rated the perceived creativity of their connection on a 1-4 scale. Participants were assured that there was no 'correct' or 'incorrect' response and were instructed to see 'whatever comes to mind'. In contrast to the original task in Krieger-Redwood et al. (2023) in which participants had to rate the 'uniqueness' of their responses, we asked them to rate 'how creative is your link?' to encourage creativity explicitly. In addition, as recommended by the authors of Krieger-Redwood et al. (2023), this self-rating is mainly to ensure engagement in the task (as the links are being formed in their head only and are not recorded) and for our purposes in the context of entrepreneurship, was to ensure that there is a degree of evaluation of ideas.

The word pairs varied in the degree of their pre-existing semantic link, as determined by Word2vec similarity scores (Google 2013; Mikolov et al. 2013). Figure 5.4 depicts how cosine similarity scores compute the strength of semantic association between two words. We obtained our word pairs from a list of 192-word pairs outlined in Gao et al. (2021). We chose this existing list for a few reasons. First, higher word2vec values (similarity) were associated with lower task demands. Second, weakly associated words (low word2vec) elicit more robust activation within the semantic control network (SCN). Third, these sets of words have been shown to have a high semantic decision consistency index, meaning people were likely to correctly rate these words as related when they had high word2vec values ($r = 0.773$, $p < 0.0001$) (Gao et al. 2021). Therefore, the word2vec scores reflect humans' interpretations of these word-pairs similarities.

To adapt the task design from an event-related design to a block design, we assigned 60 pairs with the highest similarity (high cosine scores) to our related block and 60 pairs with the lowest similarity (low

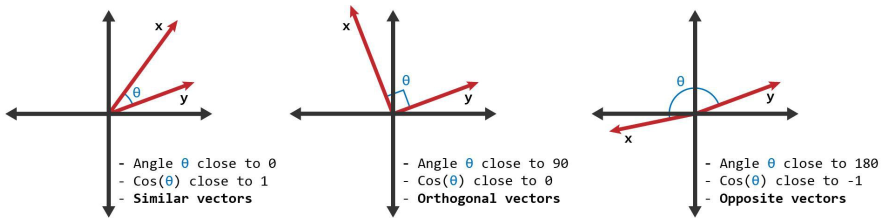

Figure 5.4: Visualisation of how the cosine similarity score between word-pairs can be computed, adapted from (Karabiber 2023). The similarity score can range between -1 and +1. It is computed by taking the cosine of the angle between vectors. Word2vec, utilised in this study, is a trained algorithm for natural language processing that uses neural networks to learn word associations (Google 2013). Word2vec was trained on a 100 billion-word Google News dataset and is a high-dimensional vector with 300 dimensions. This visualisation only shows the 2-dimensional angle between 2-word pairs. For example, 'spacecraft' and 'astronaut' are related (cosine similarity score of 0.55) and therefore would be represented by a more acute angle, closer to O. Alternatively, 'platform' and 'toothpaste' are unrelated and have a cosine similarity score of -0.05, represented by a bigger angle between vectors. In the word pairs used in this study, cosine scores ranged from -0.05 to 0.72: -0.05-0.14 for unrelated blocks and 0.32-0.72 for related blocks.

cosine scores) to our unrelated block. The word pairs and corresponding Word2vec similarity scores are in the supplementary material 5.8, for the related conditions in Table 23 and unrelated conditions in Table 24. The related blocks contained word pairs with similarity scores between 0.32-0.72. The unrelated block had word pairs with similarity scores between -0.05 and -0.14. Ten out of the 72-word pairs left over were used to create the demonstration version of the task to train participants on, thus ensuring that they were not primed during the demonstration, either by viewing the same stimuli or highly related or unrelated word pairs.

Presentation and timings

The design and timings of the task blocks and trials are shown in Figure 5.5. Each of the 40-second condition blocks, related (R) and unrelated (UR), were randomised into four different playlists with 6 UR and 6 R blocks. There were 12 rest periods in between blocks, lasting 20 seconds each. The total time of the task was 12 minutes long. There were a possible ten trials (word pairs) per block, depending on how quickly participants answered. The rest of the conditions displayed 'left left' and 'right right' on the screen, for which participants were instructed to click the left or right mouse button once, and this rest period aimed to provide baseline visual stimuli (two words on the screen) and a motor response from participants, which could then be used as a contrast during the analysis. Four different playlists were created, randomly allocating UR or R condition blocks, always keeping a rest block in between. This was to reduce expectancy effects (where they can predict the next block) and to balance whether individuals received UR or R conditions first. In addition, within each block, the order of presentation of word pairs was randomised by the cosine similarity scores.

Every experimental block began with the instruction 'Click when you've made a link' displayed for 1000ms. Trials lasted a maximum of

11 seconds. A fixation cross displayed for 250ms alerted the participant to a new trial, followed by the word pairs shown for up to 7000ms. When they clicked a button to indicate that they had made a mental link between the words, the screen would change to the rating page. If the participant made no response, the trial would time out after 7 seconds and skip to the rating screen. A 250ms fixation cross is first displayed to alert the participant that the rating phase of the trial is about to start, after which they have 2500ms to make a selection for 'How creative is your link?' from 1 (low) to 4 (high) using the left and right mouse buttons to adjust their rating. Participants were instructed that if they did not link, they should just let the rating screen also time out, and after 2.5 seconds, the subsequent trial would begin.

fMRI Resting-State

Participants were told to fixate on a white cross on a black screen for 10 minutes for the resting-state task. They were instructed during training and reminded just before the scan started that they should keep their eyes open to prevent them from falling asleep; they could blink and let their mind wander. We chose the fixated resting-state condition due to prior findings that show no significant effect of eyes-closed, eyes-open or eye-fixated conditions but greater internal reliability in the default-mode network during the fixated state (Patriat et al. 2013).

Post-scan Survey

Following a similar protocol as in Krieger-Redwood et al. (2023), participants were interviewed on the links they made during the semantics task straight after the MRI scan. Using the response files from the scanner computer, showing the word pairs they had responded to, they were asked to verbally describe the links they formed in their

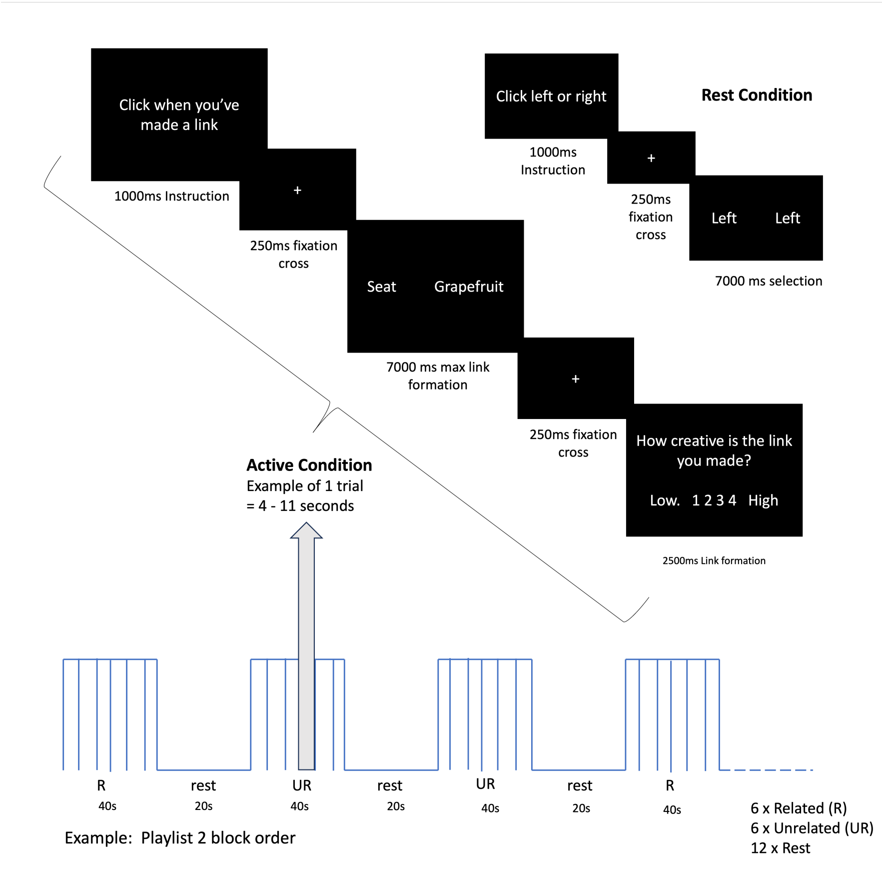

Figure 5.5: The timings of each trial (top) and each block in the semantics task (bottom). Top: Participants were instructed to form a mental link between the two words shown and click when this was done. They were then asked to rate how creative their link was from 1 (low) to 4 (high). The rest condition asked participants to click left when seeing 'left left' and right when seeing 'right right'. Bottom: Example of the running order of blocks. This shows the first few blocks from playlist 2 (out of 4 possible playlists). Each run contained six unrelated, six related and 12 conditions, previously randomized and inter-dispersed with 12 rest conditions. Every participant completed a single 12-minute run.

mind, with the experimenter recording their responses. In addition to recalling the link, we asked them to re-rate their creativity from 1 (low) to 4 (high), as the mouse in the scanner did not sometimes register their response. This was done to ensure that we could use the post-scan creativity ratings in the behavioural analysis and that the rating they gave was for the post-scan link they recalled. Therefore, we only used the post-scan creativity rating for all participants. Finally, as in Krieger-Redwood et al. (2023), we explained semantic memory and episodic memory to participants and asked, for each link, whether they thought they engaged in semantic memory (their understanding and meaning of the words/concepts) or whether they engaged episodic memory (they had a specific memory of something from their past that guided their response).

We asked for the links post-scan to make the in-scanner time more efficient, to avoid the movement artefacts that would have occurred from them verbalising their responses during the scan and due to the difficulty we would have had in recording responses over the scanner noise.

5.4.3 *fMRI*

fMRI procedure

Once set up in the scanner, participants repeated the same demonstration task as in the pre-scan testing to ensure they could use the fMRI Mouse System and to remind them how to respond. The MRI session lasted 75 minutes, including a localiser scan, structural T1 and T2 scans, a resting-state scan (10 mins) and three functional runs with cognitive tasks. The semantics task was the first of these, lasting 12 minutes.

Participants performed the task using a dedicated FOM-2B-10B fMRI Mouse System (Technologies 2023), which looks and performs like a regular computer mouse but is compatible with an MRI environment.

fMRI acquisition

Whole brain structural and functional MRI data were acquired using a General Electric MR750 3.0T MR scanner utilising a 32-channel head coil at the Centre for Neuroimaging Sciences, King's College London.

Structural T1-weighted images, used during the fMRI analysis pipeline, were acquired using an IR-SPGR sequence (TR= 7.31 ms, TE= 3.02 ms; TI=400 ms; voxel size= 1.05 × 1.05 × 1.2 mm; spatial locations 196, slice thickness of 1.2 mm (1.2 slice gap); flip angle=11○; FoV=270 mm; matrix = 256 x 256).

Resting-state fMRI were acquired using a multi-echo epiCNS sequence. (TR = 2000 ms; TE = 28 ms; voxel size 1.05 × 1.05 × 1.2 mm; slice thickness of 3 mm (4mm slice gap); FoV = 240 mm; flip angle = 80○; volumes 240; spatial locations 32; matrix = 64 x 64).

Whole brain functional runs were acquired using an epiRT sequence for the semantics task (TR = 2000 ms; TE = 30 ms; voxel size 1.05 × 1.05 × 1.2 mm; slice thickness of 3 mm (0.3mm slice gap); FoV = 211 mm; flip angle = 5○; volumes 363; spatial locations 41; matrix = 64 x 64).

5.4.4 *Analysis Plan*

Semantics Task

Behavioural analysis

Behavioural measures obtained from the word-pairs task were unusualness (frequency) scores, self-rated creativity, self-reported memory and reaction time (time between word-pair presentation and clicking to indicate the formation of a mental link). For each participant, the scores for each trial were averaged across each condition (related and unrelated).

Unusualness (frequency) scores were calculated in the same way as in Krieger-Redwood et al. (2023), as the proportion of the participants who gave a particular response to a trial. For example, take the word-pair *dove - trainer*. In our sample, there were 39 respondents, so if only one person gave a particular response, such as "dove, wearing trainers," they received a score of 1/39 = 0.03. Whereas if 15/39 people gave a response, such as "training a dove", they all received a score of 0.38 for that trial. Participants verbally recalled their links to the experimenter post-scan, who scored them once all the study data had been collected. Krieger-Redwood et al. (2023) discuss this, the 'relative frequency scoring' method being less problematic than other frequency-based scoring methods based on thresholds (e.g. 5% and 10% thresholds (Reiter-Palmon, Forthmann and Barbot 2019). However, they note a limitation with this approach related to smaller sample sizes and suggest that replication of their study is needed to ensure this is appropriate. Our study replicates their methods, albeit with a modified experimental task.

The average behavioural scores (frequency, self-rated creativity, self-rated memory and reaction time) were run through separate two-way ANOVA analyses on R (R Core Team 2023) with two factors: "Group" (N or WP) and "Condition" (unrelated or related), and with FDR correction for multiple comparisons.

fMRI analysis

All fMRI data pre-processing, first-level and higher-level analyses were carried out using FEAT (FMRI Expert Analysis Tool) Version 6.00, part of the FSL toolbox (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl).

Pre-processing and first-level fMRI Analysis

The following pre-statistics processing pipeline was applied to the fMRI data before statistical analysis: motion correction using MCFLIRT (Jenkinson et al. 2002); non-brain removal using BET (Smith 2002); spatial smoothing using a Gaussian kernel of FWHM 5mm; grand-mean intensity normalisation of the entire 4D dataset by a single multiplicative factor; highpass temporal filtering (Gaussian-weighted least-squares straight line fitting, with sigma=60.0s).

Time-series statistical analysis was carried out using FILM with local auto-correlation correction (M. W. Woolrich, Ripley et al. 2001). Separate first-level analyses were carried out for each participant, taking into account the playlist they had been assigned to, and we defined four contrasts of interest at the first level: related > rest, unrelated > rest, unrelated > related, and related > unrelated.

Pre-defined ROI Analysis

We performed a region of interest (ROI) analysis to investigate 1) whether the related and unrelated conditions across the whole group activate similar regions as in Krieger-Redwood et al. (2023), and 2) whether activity in these regions differed between our groups of entrepreneurs and working professionals.

Krieger-Redwood et al. (2023) revealed activation in the left Inferior Frontal Gyrus (lIFG), dorso-medial Prefrontal Cortex (dmPFC) (two regions in the semantic control network), and bilateral temporal fusiform cortex (temporal fusiform cortex (TFC)) for more unusual word-pair link formation. The lIFG has also been implicated in a meta-analysis of verbal divergent thinking (Cogdell-Brooke et al. 2020), and the lIFG and dmPFC are involved in semantic control in another meta-analysis (Jackson 2021). Our work defined the lIFG and bilateral fusiform cortex (anterior and posterior) using the Harvard-Oxford (H-O) cortical atlas in FSL. The dmPFC does not exist in this atlas, so we defined it based on the meta-analysis of semantic control: an ROI mask was created from seed region coordinates taken from the results from Jackson (2021) in the left dmPFC. This was expanded into a 5mm sphere.

Each of the four ROI activation contrasts was obtained from FSL featQuery. We obtained the mean estimates for each ROI from the first-level analysis statistical maps (copes) of the unrelated vs. related contrasts. First, to test whether our task conditions activate the same regions as in Krieger-Redwood et al. (2023), paired sample t-tests were performed between the mean activation in each ROI between the related and unrelated conditions. Two-way t-tests were then run on R (R Core Team 2023) to compare the differences between entrepreneurs and working professionals in each ROI, between unrelated/rest, related/rest and unrelated/related contrasts. The complete list of p-values was then corrected for multiple comparisons using FDR correction.

Exploratory Whole brain fMRI Analysis

We also performed a higher-level analysis using FLAME (FMRIB's Local Analysis of Mixed Effects) stages 1 and 2 (Beckmann, Jenkinson and Smith 2003; M. W. Woolrich, Behrens et al. 2004; M. Woolrich 2008). Z (Gaussianised T/F) statistic images were thresholded using clusters determined by $Z>2.3$ and a (corrected) cluster significance threshold of $P=0.05$ (Worsley 2001). First, a model implementing a paired-sample t-test was run to test the effects of the conditions defined in the first-level analysis (related > rest, unrelated > rest, unrelated > related, and related > unrelated) across the whole sample. Then, we defined four higher-level contrasts in a general linear model to complement our first-level contrasts and compare differences in whole-brain activation between the two groups: Entrepreneur group mean, Working Professional group mean, Entrepreneur > Working Professional and Working Professional > Entrepreneur. To help understand the interaction effects, data were extracted with FSL featQuery and plotted from masks created from clusters showing significant differences in the whole brain analysis.

Resting-State fMRI

Independent component analysis (ICA) is a computational multivariate statistical method that decomposes fMRI data into distinct spatiotemporal components, representing 'networks' of regions in the brain, where activity during the 10-minute scan is both spatially and temporally synchronised, i.e., the individual brain regions (nodes) of the network shown in the component map to fluctuate in a similar pattern (McKeown and Sejnowski 1998). At the subject level, ICA can help to separate activity from noise, and at the group level, this technique can reveal common brain networks between and across participant groups.

Here, we carried out our ICA analysis using Probabilistic Independent Component Analysis (Beckmann and Smith 2004), specifying 30 components, as implemented in MELODIC (Multivariate Exploratory Linear Decomposition into Independent Components) Version 3.15, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl).

The following data pre-processing pipeline was applied: masking of non-brain voxels, voxel-wise de-meaning of the data, and normalisation of the voxel-wise variance. The pre-processed data were whitened and projected into a 30-dimensional subspace using Principal Component Analysis (PCA). The whitened observations were decomposed into sets of vectors which describe signal variation across the temporal domain (time-courses), the session/subject domain and across the spatial domain (maps) by optimising for non-Gaussian spatial source distributions using a fixed-point iteration technique (Hyvarinen 1999). Estimated Component maps were divided by the standard deviation of the residual noise and thresholded by fitting a mixture model to the histogram of intensity values (Beckmann and Smith 2004).

The results from the individual ICA analyses were then run through a dual regression (Zuo et al. 2010). This technique identifies how each subject contributes to the group-level ICA components. The result is a subject-specific spatial map and time course for each of the 30 components. These maps and time course were then compared between our two groups using a group-level general linear model and the following contrasts: Entrepreneur group mean, Working Professional group mean, Entrepreneur > Working Professional and Working Professional > Entrepreneur.

5.5 RESULTS

5.5.1 *Demographics*

Our samples were well-matched. There were no significant differences between our groups of working professionals and entrepreneurs in age or gender, as shown in Table 19. Also shown in this table are further details about our entrepreneurs: the average and range of their number of businesses, years running their business (es), and proportion of solo to co-founders. We also include, for all participants, scores on the intolerance to uncertainty scale and Big 5 personality scores. Entrepreneurs in our sample show lower intolerance (high tolerance) to uncertainty than working professionals ($t(33.86) = -4.29$, $p < .001$), higher trait openness ($t(22.34) = 3.19$, FDR corrected $p = .018$) and higher trait extroversion ($t(30.67) = 2.87$, FDR corrected $p = .018$).

Table 19: Demographic features of participants in MRI study

Demographics	Non-Entrepreneur	Entrepreneur	
n	16	21	
Age Mean (SD)	40 (9)	35 (7)	p=.11
Age Range	27-54	27-60	
Gender (ratio F:M)	9:7	12:9	p=.05
Business Information			
Number of Businesses Mean (SD)	–	2.38 (1.75)	
Number of Businesses Range	–	1-7	
Years of Business Running Mean (SD)	–	8.00 (3.44)	
Years of business Running Range	–	3-16	
Solo-founder n	–	9	
Co-founder n	–	12	
Trait differences			
n	16	20	
Intolerance to Uncertainty Mean (SD)	10 (7.84)	20.38 (6.65)	p<.001*
n	15	19	
Agreeableness Mean (SD)	32.53 (5.31)	34.73 (4.22)	p(FDR)= .21
Conscientiousness (SD)	28.06 (7.39)	25.10 (6.06)	p(FDR)= .21
Extroversion (SD)	20.27 (7.41)	27.74 (7.69)	p(FDR)= .018*
Neuroticism (SD)	20.00 (7.05)	14.16 (8.67)	p(FDR)= .06
Openness (SD)	26.20 (7.66)	33.42 (4.80)	p(FDR)= .018*

1

Note: n of participants for the Intolerance to Uncertainty and Big-5 questionnaire differ to the final sample used in the fMRI analysis, due to some participants not completing the online questionnaire. *FDR adjusted p-value at <.05, ** <.001 alpha level.

Table 20: Summary of Behavioural Measures for Related and Unrelated Conditions. *FDR adjusted p-value at <.05, ** <.001 alpha levels

Measure	Related	Unrelated	p-Value	95% CI
Frequency (0-1)	0.37 (0.13)	0.21 (0.05)	.001*	[-0.21, -0.09]
Creativity (1-4)	1.46 (0.31)	2.17 (0.47)	.0001**	[0.59, 1.06]
Reaction Time (ms)	2698 (1223)	3594 (1218)	0.002**	[101.56, 1623.29]
Memory (1 semantic, 2 episodic, 1.5 both)	1.31 (0.18)	1.37 (0.19)	0.428	[-0.02, 0.20]

5.5.2 *Hypotheses 1 and 2: Semantics Task*

Behavioural Results

The results of the two-way analysis of variance (ANOVA) conducted on the behavioural scores (Frequency, Creativity) demonstrated that the task had the expected effect on behaviour, whereby unrelated conditions produced more creative ($F(1,74)=67.301$, $p<.0001$) and unusual (lower frequency) ($F(1,74)= 49.8159$, $p < .001$) links between and the word-pairs. These more unique and creative responses took longer to create, as indicated by slower reaction times ($F(1,74)=10.242$, $p=0.002$), as shown in Table 20. However, there were no significant differences between groups (entrepreneur versus working professionals) and no interaction effects between the group and condition on any of the behavioural measures (frequency, creativity, memory, reaction times). Furthermore, no significant effects on self-rated memory existed for the factors examined.

The specific test results were as follows. For the variable *frequency*, the analysis indicated a significant main effect of condition ($F(1,74)= 49.8159$, $p < .001$), indicating frequency decreased for the unrelated compared to related (indicating more unusual responses). However, there were no significant main effects of group ($F(1,74)= 0.1703$, $p=0.68$) nor a group x condition interaction ($F(1,74)=0.0774$, $p=0.78$). For the variable *creativity*, the analysis revealed a significant main effect of condition ($F(1,74)=67.301$, $p<.0001$), signifying creativity increased for the unrelated compared to related condition. There was no significant main effect of group on creativity (F(1,74)=0.920, p=0.341), and no significant group x condition interaction (F(1,74)=1.847 p=0.1. For the variable *reaction times (RT)*, a significant main effect of condition was observed (F(1,74)=10.242, p=0.002), such that reaction times increased for the unrelated conditions (responses were slower). There was no significant main effects of group (F(1,74)=0.005, p=0.95) and no significant group x condition interaction (F(1,74)=0.017, p=0.90). Finally, for the variable *memory*, the analysis revealed no significant main effect of group (F(1,74)=0.635, p=0.428), condition (F(1,74)=2.133, p=0.148), and no interaction of group x condition (F(1,74)=0.395, p=0.532).

Region of Interest Analysis

First, we aimed to replicate the results from Krieger-Redwood et al. (2023); we showed that, when both groups are pulled together, the experimental conditions resulted in differing activation in two of our regions of interest (ROI), the left IFG and dmPFC, but not in the anterior or posterior TFC. Results are shown in Table 21 and Figure 5.6. We showed increased related activity compared to unrelated blocks in the IFG and dmPFC. The IFC activity was greater in the unrelated condition (Mean = 22.46, SD = 26.94) than in the related condition (Mean = 17.64, SD = 23.22), t(36) = 2.61, p = 0.01 (FDR corrected, p = 0.03), 95 % CI [1.08,8.58], Cohen's d of -0.19. The dmPFC activity was also greater in the Unrelated condition (Mean = 44.1, SD = 35.7) than in the related condition (Mean = 33.7, SD = 31.3), t(36) = 3.90, p < 0.001 (FDR corrected, p < 0.001), 95 % CI [4.98, 15.8], Cohen's d of -0.31. However no significant differences were found in the anterior TFC (t(36) = -0.70, p = 0.49 (FDR corrected, p = 0.64)), or posterior TFC (t(36) = 0.47, p = 0.64 (FDR corrected, p = 0.64)).

Note: *FDR adjusted p-value at <.05, ** <.001 alpha levels

Table 21: Summary of ROI Data between Conditions

ROI	Related > Rest Mean (SD)	Unrelated > Rest Mean (SD)	Cohen's d	p-value (paired-sample t-test)	FDR corrected	CI
IFG	17.64 (23.22)	22.47 (26.94)	0.19	0.01*	0.03*	[1.08, 8.58]
TFCant	-0.11 (7.07)	-0.72 (6.87)	0.09	0.49	0.64	[-2.36, 1.15]
TFCpost	-2.01 (7.57)	-1.59 (8.17)	0.05	0.64	0.64	[-1.08, 1.92]
dmPFC	33.72 (35.74)	44.09 (35.74)	0.31	0.0004**	0.0001**	[4.98, 15.8]

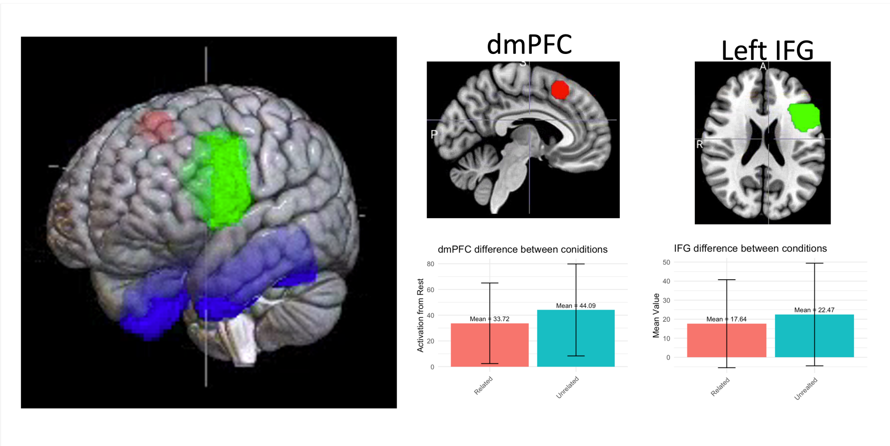

Figure 5.6: Pre-defined regions of interest for this study. Left shows the ROIs on a 3D standard template brain, the dmPFC 5mm sphere (red), left IFG (green) and TFC (blue). Right shows two ROIs where a significant difference was found between related and unrelated conditions. Activity in the dmPFC and left IFG increased in the unrelated condition, corresponding to behavioural results of more creative and unusual responses, in line with prior literature (Krieger-Redwood et al. 2023). However, no differences were found when comparing entrepreneurs and working professionals, neither between activity in the pre-defined ROIs nor in behavioural results.

Table 22: Summary of Pre-defined ROI Data compared between Entrepreneurs and Working Professionals

Pre-defined ROI	Contrast	Working Professionals Mean (SD)	Entrepreneurs Mean (SD)	Cohens d	p-value	FDR corrected p-value	CI
IFG	R-rest	17.1	18.06	0.04	0.12	0.82	[-0.62, 0.70]
	UR-rest	24.52	20.91	-0.13	0.69	0.82	[-0.78, 0.52]
	UR-R	7.16	2.85	-0.4	0.22	0.82	[-1.03, 0.24]
TFCant	R-rest	-0.43	0.13	0.08	0.82	0.82	[-0.57, 0.72]
	UR-rest	-1.37	-0.23	0.16	0.64	0.82	[-0.51, 0.83]
	UR-R	-0.94	-0.35	0.11	0.74	0.82	[-0.54, 0.76]
TFCpost	R-rest	-2.36	-1.74	0.08	0.81	0.82	[-0.57, 0.73]
	UR-rest	-1.11	-1.96	-0.1	0.76	0.82	[-0.75, 0.55]
	UR-R	1.25	-0.22	-0.27	0.41		[-0.92, 0.38]
dmPFC	R-rest	40.88	28.26	-0.41	0.22	0.82	[-1.06, 0.25]
	UR-rest	49.52	39.96	-0.27	0.42	0.82	[-0.91, 0.38]
	UR-R	8.63	11.7	0.19	0.58	0.82	[-0.45, 0.83]

Contrary to our initial hypotheses and expectations, the ROI analysis showed no statistically significant differences between the related and unrelated conditions when comparing our two groups (E v WP). We failed to demonstrate differential activation within the entrepreneur's IFG, dmPFC (two regions in the semantic control network), and bilateral temporal fusiform cortex (TFC). The results and statistics for the group analysis are presented in Table 22.

Whole Brain Exploratory Analysis

Effect of Related and Unrelated Conditions

When considering the effect of condition across all participants in the study, we show distinct brain regions involved in related and unrelated conditions.

In the related > unrelated contrast, when looking across all participants, we show five activation clusters in areas primarily associated with the Default-Mode and Semantic networks. First, a cluster peaking in the right angular gyrus and spanning the right superior parietal lobule and right superior occcipital cortex (MNI peak coordinates: [54,-54,44]) with a peak Z-score of [4.83] ($p < 0.05$, corrected). Second, a cluster in the left angular gyrus, also spanning the left superior parietal lobule and left superior lateral occipital cortex (MNI peak coordinates: [-50,-64,40]) with a peak Z-score of [4.62] ($p < 0.05$, corrected). Third, a cluster in the right and left precuneus cortex and left posterior cingulate gyrus (MNI peak coordinates: [-4,-72,34]) with a peak Z-score of [4.25] ($p < 0.05$, corrected). Fourth, a cluster in the bilateral frontal medial cortex and anterior cingulate gyrus and paracingulate gyrus (MNI peak coordinates: [2,44,-14]) with a peak Z-score of [4.81] ($p < 0.05$, corrected). And finally, a cluster in the left fusiform and lingual gyrus (MNI peak coordinates: [-14,-88,-10]) with a peak Z-score of [3.87] ($p < 0.05$, corrected). A spatial map of these clusters is shown in Figure 5.7.

In the unrelated > related contrast, we show six activation clusters in areas primarily associated with the MDN, Default Mode and left-lateralised language processing. First, a cluster peaking in the left Superior Frontal Gyrus, extending to the middle frontal gyrus and also to the left and right paracingulate gyrus (MNI peak coordinates: [-8,14,52]) with a peak Z-score of [4.84] ($p < 0.05$, corrected). Second, a cluster peaking in the left inferior frontal gyrus (MNI peak coordinates: [-52,20,24]) with a peak Z-score of [4.59] ($p < 0.05$, corrected). Third, a cluster peaking in the right lingual gyrus and extending to the right cerebellum (MNI peak coordinates: [4,-78,-16]) with a peak Z-score of [3.97] ($p < 0.05$, corrected). Fourth, a cluster in the left cerebellum (MNI peak coordinates: [-42,-54,-34]) with a peak Z-score of [3.86] ($p < 0.05$, corrected). Fifth, a cluster in the left rostral superior occipital cortex (MNI peak coordinates: [-18,-58,48]) with a peak Z-score of [3.74] ($p < 0.05$, corrected). Finally, a cluster in the left caudate (MNI peak coordinates: [-8,12,8]) with a peak Z-score of [3.71] ($p < 0.05$, corrected). A spatial map of these clusters is shown in Figure 5.8.

Interaction Effect of Group x Related and Unrelated Conditions

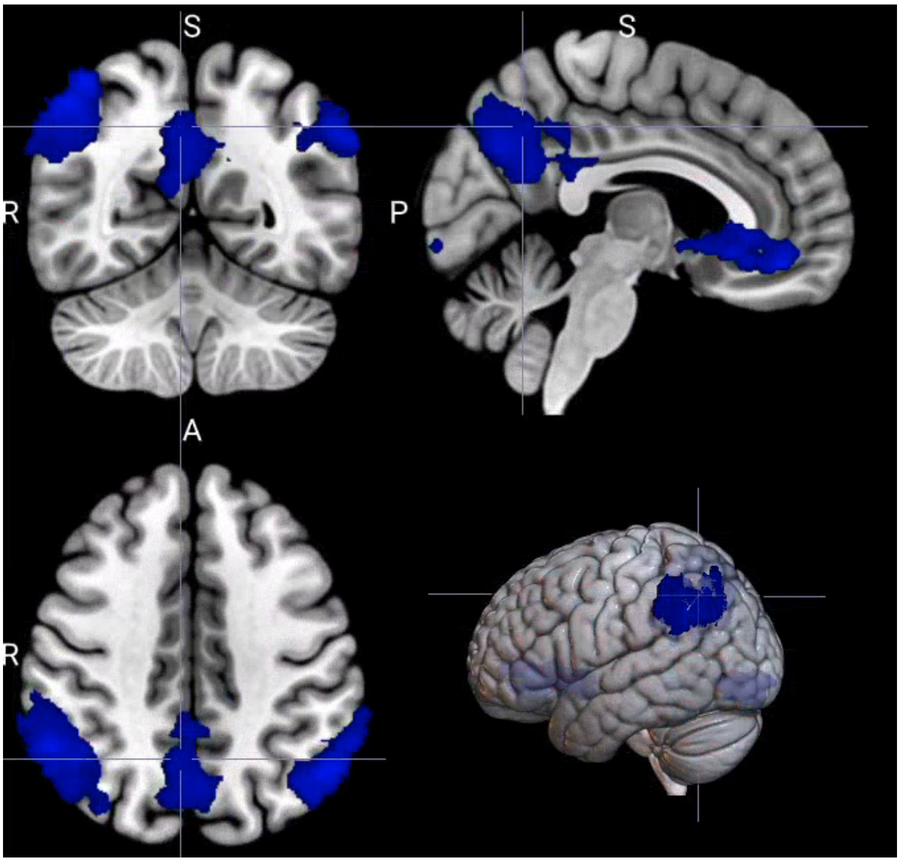

Figure 5.7: Whole-brain analysis of related > unrelated contrast of the semantics (word-pairs) task. In the Related condition, task difficulty is decreased, and we found increased activation in regions of the DMN. Five clusters were found in the left and right angular gyrus and precuneus cortex, the frontal medial cortex and anterior cingulate cortex (ACC), and the left fusiform lingual gyrus, which plays a role in the recognition of words.

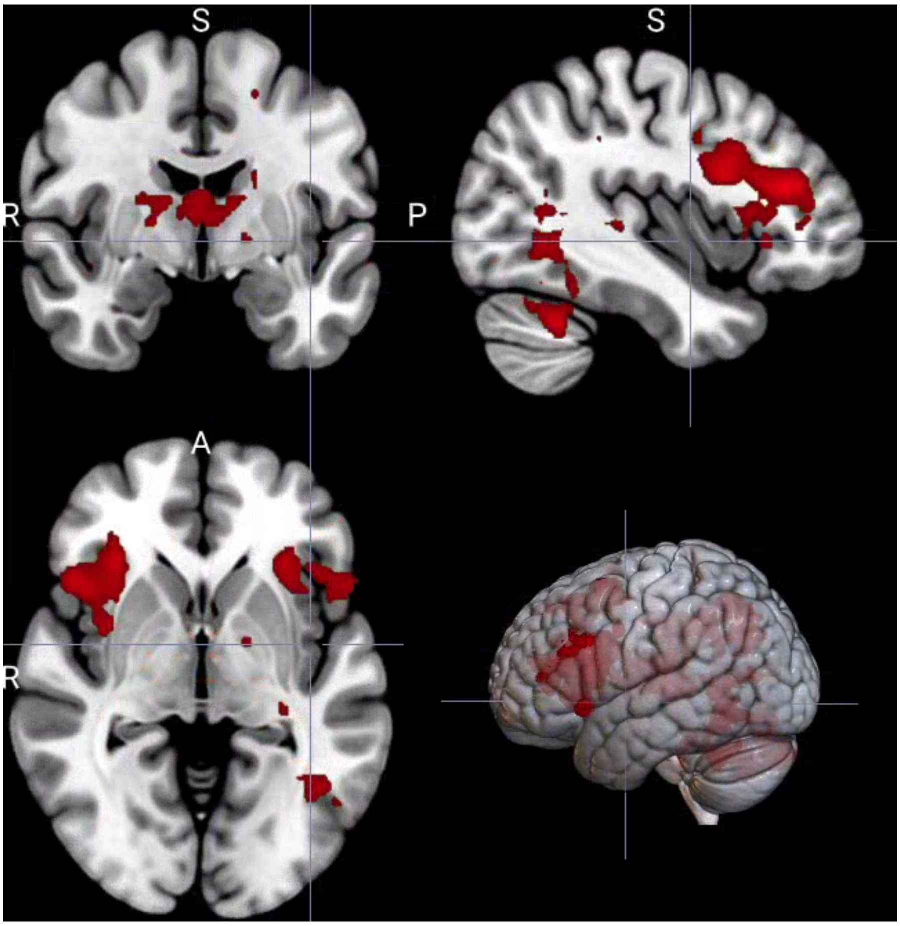

Figure 5.8: Whole-brain analysis of unrelated > related contrast of the semantics (word-pairs) task. During the Unrelated condition, task difficulty increases, and we found increased activation in areas associated with the MDN/ task-positive networks, language processing, and visual processing: the left superior frontal gyrus, extending to the MFG) and also to the left and right paracingulate gyrus; the left IFG; right lingual gyrus extending to the right cerebellum; left cerebellum; 5) left rostral superior occipital cortex; 6) left caudate.

The analysis of whole-brain fMRI data revealed significant activation across various brain regions in response to the condition by group interaction.

Three activation clusters were detected in the related > unrelated conditions when comparing entrepreneurs to working professionals. First, in the H-O Atlas right Precuneus Cortex (rPC) (MNI peak coordinates: [16, -70, 34]), with a peak Z-score [3.31] ($p < 0.05$, corrected). Second, in the left cerebellum, extending to parts of the right cerebellum (MNI peak coordinates: [-10, 88, -28]), with a peak Z-score [4.19] ($p < 0.05$, corrected). Third in the right MFG, extending to the right frontal pole (MNI peak coordinates: [36, 36, 48]), with a peak Z-score [3.82] ($p < 0.05$, corrected). Visual representations of these findings are presented in Figure 5.10.

When comparing working professionals to entrepreneurs in the unrelated > related conditions, we observed a robust significant cluster of activation, which on the Harvard-Oxford Cortical Structural Atlas spans the right MFG, extending to the right frontal Pole (MNI peak coordinates: [36, 36, 48]) with a peak Z-score of [3.81] ($p < 0.05$, corrected). Visual representations of these findings are presented in Figure 5.9.

5.5.3 *Hypothesis 3: Resting-State Networks*

We conducted an independent component analysis (ICA) with 30 components to extract resting state networks (RSNs) from all participants. These were compared against publications of ICA RSNs previously identified (Veer et al. 2010; Smith et al. 2009) and H-O atlases (Desikan et al. 2006) to determine resting state networks in the Default-Mode Network and MDN Networks, as well as Fronto-parietal and Fronto-temporal networks as shown in Figure 5.11. Other networks identified

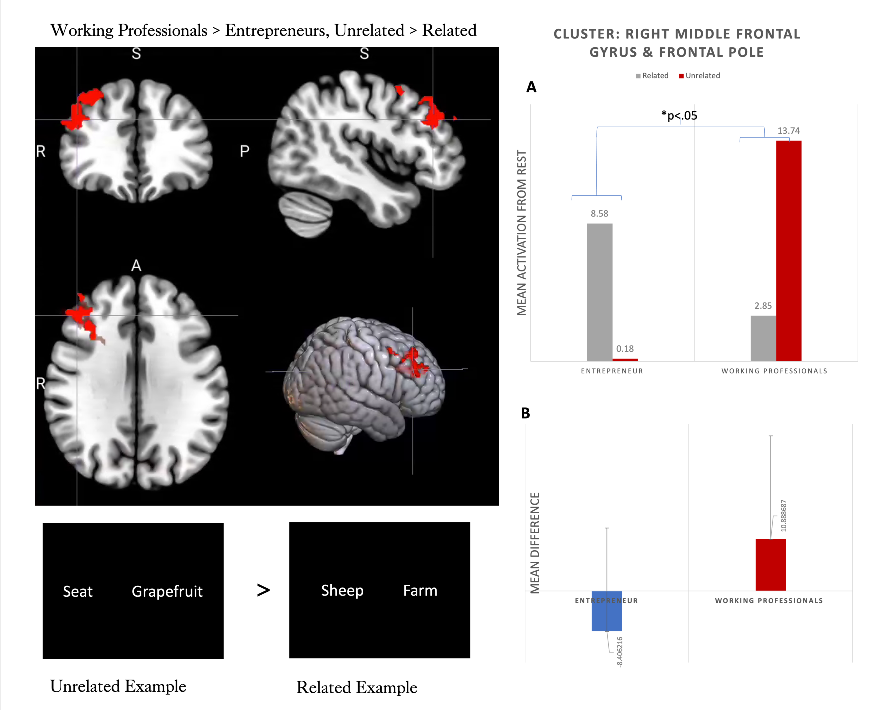

Figure 5.9: Activation differences between working professionals and entrepreneurs in the unrelated > related conditions in the semantics task; an example of each condition is shown on the bottom-left. A prominent cluster of activation was observed, spanning the right MFG and extending to the right frontal pole on the Harvard-Oxford Cortical Structural Atlas (top-left). The peak activation coordinates were located at [36, 36, 48], with a peak Z-score of [3.81] ($p < 0.05$, corrected). Of particular note, the activation pattern within this cluster exhibited opposing effects for the two distinct groups: Entrepreneurs displayed a decrease in activation from related to unrelated conditions. At the same time, working professionals demonstrated an increase in activation during the same transition. This stark divergence is illustrated in graph A, showing the mean activation compared to the rest of the related and unrelated blocks within each group. In contrast, graph B concisely represents each group's mean activation difference.

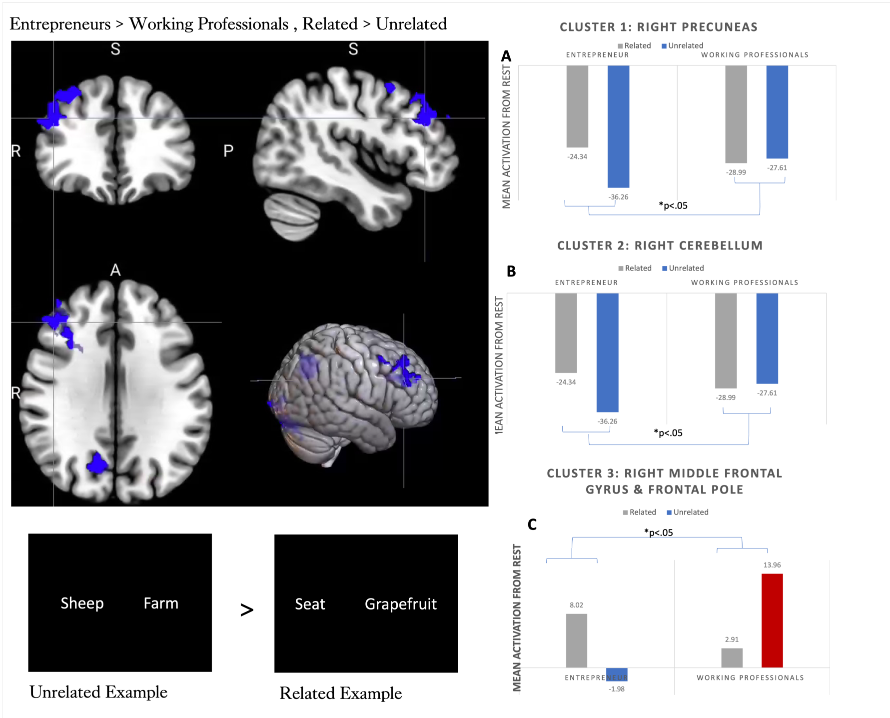

Figure 5.10: Activation differences between entrepreneurs and working professionals in the related > unrelated conditions in the semantics task; an example of each condition is shown on the bottom-left. We identified three distinct clusters of neural activation. The first cluster, located in the right precuneus cortex of the Harvard-Oxford Cortical Structural Atlas, exhibited peak activation at MNI coordinates [16, -70, 34] and a peak Z-score of [3.31] ($p < 0.05$, corrected). The second cluster spanned the left cerebellum, extending to parts of the right cerebellum, with peak activation observed at MNI coordinates [-10, 88, -28] and a peak Z-score of [4.19] ($p < 0.05$, corrected). The third activation cluster also encompassed the right MFG. It extended to the right frontal pole, with peak activation coordinates at [36, 36, 48] and a peak Z-score of [3.82] ($p < 0.05$, corrected). Graphs A, B, and C visually represent these findings, demonstrating that the observed differences in the precuneus and cerebellum were primarily due to changes in relative deactivation within these regions between conditions. Specifically, the right precuneus (A), an area associated with the DMN, and the left cerebellum (B) exhibited reduced deactivation during the related conditions, indicating increased activation in response to the related > unrelated conditions. In contrast, the right MFG (C) showed a significant difference with increased activity in entrepreneurs during the related > unrelated condition.

are shown in the Supplementary Material 5.8: Frontal, Temporal, Parietal, Fronto-temporal and Frontal-Parietal Networks shown in Figure 5.12 and precuneus, visual and cerebellum networks as shown in Figure 5.13. Some components were identified as noise or movement artefacts where activation was shown in white matter or ventricle space.

Subsequently, we performed dual regression to compare the functional connectivity patterns of RSNs between the two groups, Entrepreneurs and working professionals. The analysis did not reveal any statistically significant differences between these groups' spatial maps of RSNs. These findings suggest that, at the level of large-scale functional connectivity, there are no discernible distinctions in brain connectivity at rest between entrepreneurs and working professionals in our sample.

5.6 DISCUSSION

5.6.1 *Summary of Main Findings*

In this study, we aimed to uncover if entrepreneurs differ in their neurocognition involved in verbal creativity. We aimed to test this within two contexts/conditions: familiar (related word pairs) and unfamiliar (unrelated word pairs). Our results show that, despite the similarity in the behaviour and creativity of entrepreneurs compared to working professionals (i.e., higher creativity and unusual responses for the unrelated condition in all participants), more efficient neurocognitive mechanisms in the right hemisphere may serve this creativity in entrepreneurs. The right MFG, frontal pole, right precuneus and cerebellum activate differently in entrepreneurs when forming new links for word pairs. When the word pairs are familiar, entrepreneurs

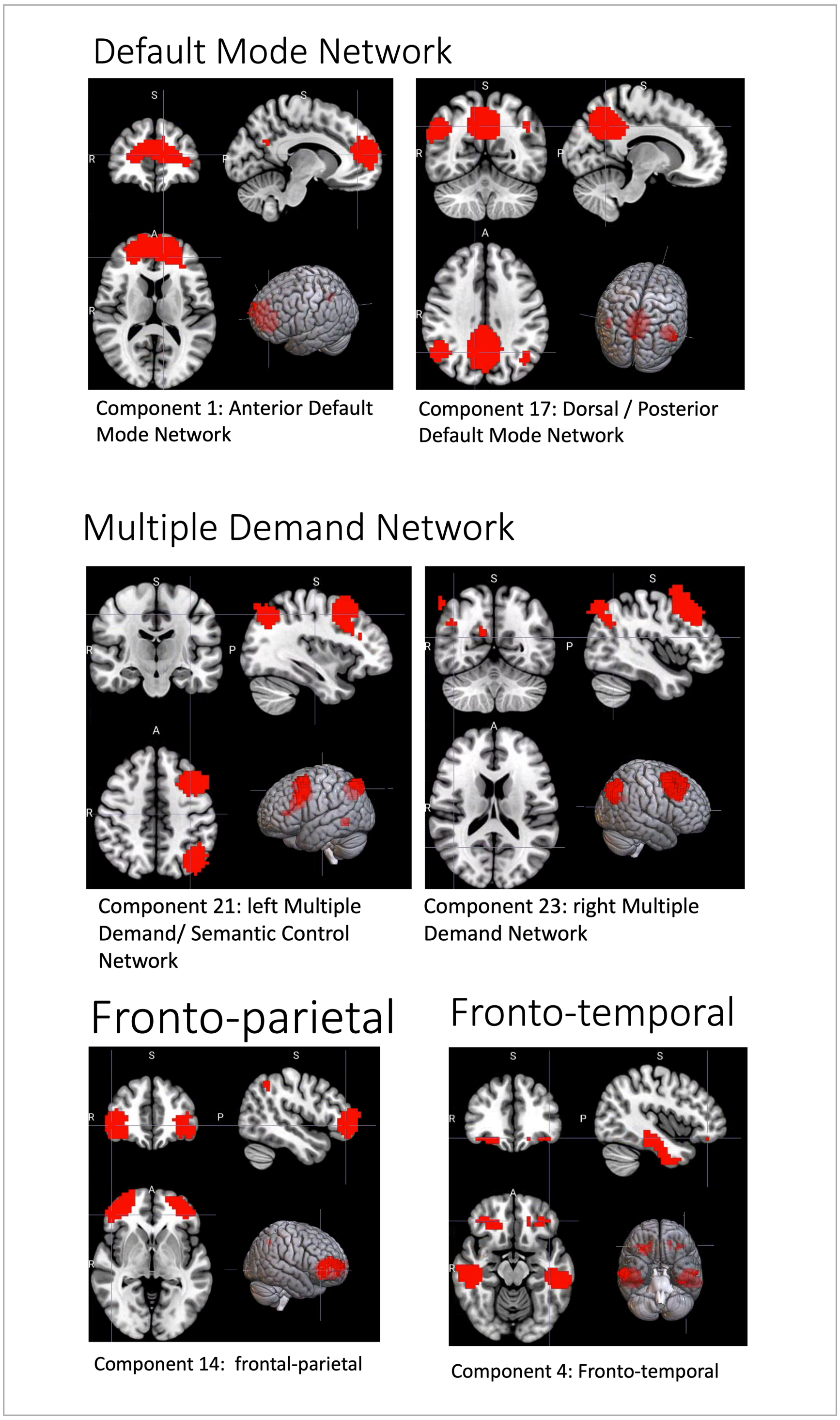

Figure 5.11: Spatial maps of the RSNs identified from the ICA across all participants. This figure shows (Top) the anterior and posterior portions of the Default-Mode Network; (Middle) left and right MDN Networks, sometimes termed Task Positive Networks; and (bottom) the Fronto-parietal and Fronto-temporal networks. No differences were found in any of the RSNs between entrepreneurs and working professionals when performing a dual regression.

engage the MFG and frontal pole more than working professionals. In unfamiliar conditions, there is a deactivation of the MFG and frontal pole, coupled with a more significant deactivation of the precuneus, a core component of the DMN. However, there are no differences in the resting-state connectivity between networks in the brains of entrepreneurs, indicating that difference in brain activity is only seen when considering task and context.

Adapting to task demands requires an optimal balance between different neurocognitive processes. Past literature has shown that the DMN (the resting state network of the brain involving the precuneus) deactivates as task difficulty increases. The MFG is an area of overlap between the semantic control network and DMN (Krieger-Redwood et al. 2023; Orwig et al. 2021; Chiou et al. 2023). Moreover, the MFG is a region thought to be involved in the re-orientating and switching attention between dorsal and ventral attention streams (Japee et al. 2015). Prior literature has shown the importance of a de-focus and re-focus of attention for creative responses (Chrysikou 2019). Therefore, it is interesting that the MFG, a site previously implicated in this de-focusing and re-focusing of attention (Japee et al. 2015), was found here to differ in entrepreneurs during a creativity task. We discuss later some possible explanations for the neurocognitive strategies discovered in entrepreneurs and working professionals, how these initial findings could be explored further in future research and present some further limitations of our study.

5.6.2 *Interpreting the Findings*

1. No Differences in the Behavioural Measures of Creativity or Regions of Interest in Entrepreneurs

We hypothesised that we would find entrepreneurs to be more creative in both related and unrelated conditions than working professionals. In our recruitment, we even selected working professionals with less typical 'creative' roles such as accounting, finance, admin, and law. We excluded those who had highly creative, autonomous or freelance roles from screening. In contrast, the entrepreneurs were selected for their ability to demonstrate creative disruption, having been involved in creating the business idea and working full-time on producing a unique solution to a problem they had identified. However, despite different neurocognitive findings, there were no differences between the frequency (unusualness) of entrepreneurs' responses and self-rated creativity. These findings could be for a few reasons I expand on further: 1) entrepreneurs are not 'more creative' in general, and when posed with a task and given 'permission' to be creative, working professionals show similar behaviour and ability; 2) the measures we employed did not capture other elements of creativity important for entrepreneurship such as elaboration, usefulness; 3) this task may not reflect the ecological validity of the differences we would see in entrepreneur behaviour in real-life scenarios, as there was no element of affect or 'risk'.

Explanation 1) Entrepreneurs Are Not More Creative; Creativity Is a Brain State That All Can Engage

To expand on the first point, the most apparent explanation is that it may be the case that entrepreneurs are not actually 'more creative' as a trait. In this regard, thinking of creativity as a 'state' rather than an attribute or skill is interesting (Weinberger et al. 2018). All humans have the potential to enter a creative state, which this task and experimental design primed and permitted individuals to do. Our whole brain findings show that different brain states exist when individuals, regardless of group, are more creative when forming more unusual links. The behavioural, ROI and whole-brain results show significant differences between the conditions across all the participants. More activity was observed in two of the pre-defined regions of interest (ROI): the dmPFC and the left IFG for the unrelated condition. The dmPFC is an area in the prefrontal cortex (PFC) involved in decision-making and working memory. This region has previously been shown to correlate with creative performance on the AUT (Chen et al. 2023). The left IFG is a crucial node in language (semantic and phonological processing, verbal fluency) and working memory, as shown in multiple studies and confirmed by meta-analysis (Costafreda et al. 2006; Liakakis, Nickel and Seitz 2011). In addition, dmPFC- IFG co-activation was shown to be involved in both the production of creative metaphors and creative uses for objects; this has been attributed as *a core creative network related to remote semantic association-making and conceptual integration* (Chen et al. 2023). Our findings, therefore, complement prior work in creative associations and the involvement of the dmPFC and IFG. However, we found no differences in the ROIs for entrepreneurs compared to managers, suggesting no neurocognitive differences in core regions of verbal creativity.

The whole brain exploratory analysis revealed the activation of additional regions involved in verbal creativity across all participants in our task, regardless of group. In the unrelated condition where there was greater creativity, we saw engagement of the left superior frontal gyrus, middle frontal gyrus, and left and right paracingulate gyrus, representing areas of the MDN and central executive network involved in working memory, attention and switching (Duncan and Owen 2000; Duncan 2010). This demonstrates the increased cognitive control required for unique link formation. The lingual gyrus is an area in the visual cortex that responds to decoding letters. It is involved in the recognition of words and, in particular, in encoding complex images (Machielsen et al. 2000), such as may have been produced when we asked participants to form links between *seat* and *grapefruit* or *printer* and *trumpet*. Therefore, activity in this area showed the increased demand for language and alternative visualisation encoding in the brain needed to link distant and unusual word pairs semantically. Finally, the occipital, cerebellum and caudate activations likely are associated with this increased cognitive effort and load. The cerebellum's involvement in higher-order cognitive functions is not well understood. The consensus often limits the cerebellum's role to fine-tuning motor control (Sullivan 2010). However, it has been found that this cauliflower-like 'little brain' at the base of the brain is involved in creativity (Saggar, Quintin, Kienitz et al. 2015; Saggar, Quintin, Bott et al. 2017; Patil, Madathil and Huang 2021). In addition, the caudate is a deeper brain structure associated with many functions, including reward processing, learning, and memory (Nakamura and Hikosaka 2006). We thus showed widespread activation in areas of the MDN, DMN, language processing, visualisation areas of the SCN, as well as reward-mechanisms, corresponding to more unique responses to obscure word pairs. The unique aspect of our task is that we primed participants to be creative and evaluate their ideas after forming the word pair. Therefore, this brain activation demonstrates the construction and evaluation of creative verbal ideas.

In contrast, due to the highly existing semantic link between the word pairs, the related conditions prompted more usual responses. Indeed, our behavioural results showed that the links produced were more frequent (less unusual) and self-rated as less creative by participants. In addition, the whole brain analysis demonstrated more activation of the default-mode network as shown in Figure 5.7 and echoes findings from Krieger-Redwood et al. (2023). This may be associated with greater ease in these conditions and the integration of autobiographical memory in link formation.

Therefore, due to the consistency with prior literature and the brain 'states' that engage in related (less creative) and unrelated (more creative) scenarios, we could conclude that there is no difference in the *core* brain networks that produce verbal creativity in entrepreneurs.

Explanation 2) Our Measures Do Not Capture Elaboration or Usefulness of Responses.

We may also consider that our behavioural measures of creativity may not have been valid in this context. We did not show greater creativity in entrepreneurs despite differences in brain function in the right MFG, frontal pole, precuneus and cerebellum. However, this could indicate problems with our behavioural scores. First, classic creativity tasks measure more than just the uniqueness of ideas, such as in the Alternative Uses Task (AUT), they often measure fluency (overall number of generated uses), originality (statistical frequency similar to our measure), flexibility (number of conceptual categories), elaboration (degree of detail in the response) and in recent studies: novelty and usefulness (subjective scoring from experimenters on a scale of 0-100) (Guilford 1967; Vartanian et al. 2020). Vartanian et al. (2020) showed a negative correlation in the left inferior temporal gyrus with the novelty and usefulness scores but no correlation with the standard AUT creative scores. In this task, we only measure originality (as the statistical frequency of these responses in our sample). Moreover, due to time and resource constraints, no second rating was carried out on frequency scores in our study. Although I was blinded to group membership during this scoring, further blinded scorers (at least two others) would have been helpful for multiple evaluations and to compute an average. Therefore, we suggest that future studies on entrepreneurs consider the measurements taken and explore the possibility of alternative ways to score creative responses.

Explanation 3) This Measure of Creativity May Not Be Ecologically Valid to Entrepreneurship

Finally, this task may not have been optimal for capturing behavioural differences in the creative potential of entrepreneurs specifically. The real-life contexts in which entrepreneurs employ creative problem-solving are much more nuanced and complex than the semantic task we used and may involve a more significant element of risk and reward. The study employed here could be considered a 'cold' measure of cognition. As shown in prior research in entrepreneurs and managers (Lawrence et al. 2008), differences in entrepreneurs' behaviour may only arise in 'hot' cognitive tasks, where there is a possible reward or loss to their decisions. The word-pairs task we employed does not incorporate any degree of compensation or loss. Other imaging studies have shown the importance of emotions and their effect on entrepreneurs' decision-making, as they view ventures similar to a parental-child relationship. Using fMRI, Halko et al. (2017) showed that similar brain areas involved in parent-child bonding, particularly the caudate nucleus often associated with rewards, come into play when entrepreneurs assess their ventures. This study showed that this attachment to their venture reduced decision efficiency. Therefore, the interaction of more emotional decisions must be considered in future studies in entrepreneurial neurocognition.

2. Differences in the Whole-Brain Analysis Findings for Entrepreneurs: in the Right MFG, Frontal pole, Precuneus and Cerebellum

Whilst the behavioural and ROI analysis did not yield significant differences between entrepreneurs and working professionals, the whole-brain analysis revealed an interaction effect. Specifically, we did not show any differences in the hypothesised ROIs (IFG, dmPFC and TFC) from the left hemisphere from (Krieger-Redwood et al. 2023) 's paper. However, we found differences between our groups in the right hemisphere, in the MFG, precuneus and cerebellum. Therefore, this suggests that any differences in entrepreneurs' creative cognition may not be associated with the standard left-lateralised networks involved in verbal creativity but with the additional recruitment of the right MFG and a differing deactivation of the DMN. We believe that more investigation into these regions is needed to determine what these findings mean, and we wish to avoid making reverse inferences about the function of these regions. However, here, we hypothesise what these different findings could indicate about creativity in the entrepreneur's brain in the context of prior literature involving imaging studies of these regions and the networks they are involved in. To contextualise and offer some theories and explanations for the results. We describe the role of these regions and suggest future studies and analyses which could be performed to test these hypotheses and assumptions further.

Entrepreneurs Brains Adapt Better to the Task Demands

In the familiar experimental condition, which favours the DMN and autobiographical memory as shown previously in Krieger-Redwood et al. (2023), we found less deactivation (more activation) of the right precuneus and cerebellum and increased activation of the MFG in entrepreneurs. This may facilitate autobiographical, creative and visualisation strategies into link formations. Conversely, entrepreneurs reduce the interference of the precuneus and cerebellum (linked to the DMN and self-referential thoughts) during the unrelated experimental condition, which may allow more controlled semantic retrieval, with less re-orientating of attention required by the MFG.

In contrast, in working professionals, we see increased activity in the right MFG and frontal pole in the unrelated experimental condition 5.9, whilst it decreases in entrepreneurs during this condition. As more controlled semantic retrieval and linking are required for unusual responses (Krieger-Redwood et al. 2023) during unrelated and unfamiliar contexts, this increased activity in the MFG could suggest working professionals need greater re-orientation of attention than entrepreneurs between the dorsal and ventral attention streams to produce creative responses.

The role of the MFG and Frontal Pole in Familiar Links

The MFG is a core region in the MDN (Duncan and Owen 2000; Duncan 2010; Fedorenko, Duncan and Kanwisher 2013). It has previously been implicated in attention, working memory and language-processing (Japee et al. 2015). The MFG is also an area of overlap between the semantic control network and DMN (Krieger-Redwood et al. 2023; Orwig et al. 2021; Chiou et al. 2023). Prior work has suggested that the left MFG is involved in literacy and the right MFG in numeracy. Moreover, activity in the right MFG has been associated with negative functional connectivity coupling with the DMN (Koyama et al. 2017). Interestingly, reduced activity in the MFG has previously been found in children with dyslexia, along with hyper-activation in regions of the IFG and left orbitofrontal cortex (Molfese et al. 2010). It is not entirely clear why we see this differing pattern of activation in entrepreneurs in the right MFG, such that activity in this region increases for related (cognitively less demanding tasks) yet decreases for unrelated (cognitively more demanding tasks) trials, which should engage the MDN more. We did not find differences in the left MFG, which the literature suggests is involved in literacy. Therefore, our data suggests that the right MFG is recruited in entrepreneurs to assist in the familiar semantic conditions.

A further explanation for these results may lie in the role of the MFG in attention. The right MFG, in particular, has been implicated as a region at which the dorsal and ventral attention streams are thought to converge, i.e. switching between top-down (internally goal-driven stimulated thought) and bottom-up (evoked by stimulus) attention (Japee et al. 2015). The study demonstrated that the right MFG shifts attention from external stimuli to internal thoughts and back, as evidenced by a patient with a right MFG resection struggling to revert to top-down attention control after the effect of an external cue dissipates. Additionally, resting-state fMRI data suggests compensatory mechanisms in other brain regions in response to the loss of function in the right MFG. In terms of episodic memory, it has previously been proposed that *Left prefrontal cortex is differentially more involved than right in encoding information into episodic memory, whereas right prefrontal cortex is differential more involved than left in episodic memory retrieval* (Tulving 2002). Therefore, increased activation in the right hemisphere in the related experimental condition for entrepreneurs may suggest greater attention switching to internal thoughts.

The role of MFG, frontal pole, precuneus and cerebellum in Unrelated links

In the unrelated experimental condition, we see decreased brain activity in the right MFG in entrepreneurs. This is counter-intuitive as we would expect to see an increase in the MDN or semantic control network as task difficulty increases (which we do see in working professionals). This suggests that 1) this area is not recruited to help create links between obscure word pairs in entrepreneurs but is in working professionals or that 2) less control over competing top-down and bottom-up attention streams and less episodic memory is needed for the unrelated word pairs in entrepreneurs.

The second explanation is better supported by our other findings that activation in the precuneus, a core component of the DMN, differs in entrepreneurs. For both experimental conditions, activity in the precuneus decreases compared to rest, a pattern consistent with accounts showing that DMN activity reduces when someone engages in a task (Raichle et al. 2001). The extent of this deactivation is similar for both conditions in working professionals. However, for entrepreneurs, this deactivation is more significant for unrelated trials. It is coupled with a deactivation of the MFG, likely because it does not need to work as much to inhibit the competing DMN internally-driven thoughts. Overall, these results could suggest better brain efficiency in entrepreneurs for unusual and creative scenarios that, in this case, cannot rely on past episodic processes to form links between word pairs.

Therefore, while the entrepreneur's brain may exert more control over related semantic associations, it shows greater ease and efficiency for unusual semantic associations and creative processes.

Creativity in the Right Hemisphere?

There is a popularised pseudo-science view that people are 'right-brained' and creative or 'left-brained' and logical. In particular, whilst the left side of the brain has long been attributed to language processes, the right or 'silent brain' is attributed to face recognition and, thus, spatial reasoning. From this, a non-empirical theory was formed that the right brain must be the hemisphere for art and visualisation processes (Sperry 1961; Zaidel 2013). Whilst we show that activity in the right PFC differs in entrepreneurs, we believe the story is more complicated and nuanced than the split-brain hypothesis. Neurocognition is more complex than this; this study shows that many regions in both the left and right hemispheres contribute to semantic and creative processes, as shown in Figure 5.8. That being said, there is a body of evidence suggesting that creativity, the combination of remote concepts into novel and practical ideas, is an ability which depends on the right hemisphere, whilst the left hemisphere processes close associations (Beeman et al. 1994; Jung-Beeman 2005; Chiarello et al. 2003; Hutchison 2003). However, as opposed to increased activation in the right hemisphere, a recent study showed that reduced activity in the associative areas of the right hemisphere released constraining effects on remote associations, thus aiding greater creativity (Aberg, Doell and Schwartz 2017). Rather than positing 'more creativity' in the right hemisphere, this may explain why we saw reduced MFG activity in the unrelated condition in entrepreneurs: their brain may demonstrate a better ability to 'release' the constraining effect of learnt or usual semantic associations.

3. No differences in Resting-State Networks in Entrepreneurs

Our resting-state findings fit in with the assumption we draw from our results that entrepreneurs' differential brain activation and neurocognition are only seen when considering both the task at hand and the context in which it is being performed. Our ICA results show the standard, well-known functional resting state network (RSN) maps across our whole group, but we do not see any difference when comparing entrepreneurs and working professionals. We think it is unlikely that differences between two healthy group participants would be detected (if they exist) in such networks without some brain pathology to disrupt them, as such resting-state networks are often spatially consistent accross healthy controls, however it is worth recognising here that this study is under-powered, and therefore would require much larger sample sizes to confirm this beyond our pilot study. Moreover, the ICA approach does not allow measures between how the networks may interact with one another, such as the activation/deactivation that occurs between the DMN and sub-networks within the MDN (Cole, Smith and Beckmann 2010; Zuo et al. 2010). This does present a weakness of the ICA method of analysis in that it is likely only to capture common variance in the spatial maps of RSN and, therefore, may miss subtle differences in functional connectivity.

Consequently, we suggest two methods which may better uncover if differences seen in task-based fMRI might also be present in resting-state data. First, more sensitive measures of FC could be employed, such as seed-based analysis, which may be better suited to uncover potential differences in the switching or interaction between networks of entrepreneurs (Joel et al. 2011). For example, the could be specified as a seed region to investigate with other regions and networks in co-activate with differentially in entrepreneurs. Second, FC analysis could be applied to the task data to see how the functional connectivity differs between rest and task-active states. In fact, some research has suggested that FC analysis on task data better predicts behavioural differences than resting-state (Zhao et al. 2023). Thereby FC on task data would give us a better ability to see how the DMN and MDN couple or decouple to produce creative responses.

5.6.3 *Additional Limitations*

We have mentioned many limitations throughout this discussion, such as the validity of the task used and the limits of the measures of creativity we gained. Performing objective research in creativity will likely always be a double-edged sword, as elements of creativity always feel subjective and are thus difficult to quantify. However, we do not believe this should discourage researchers from exploring creativity in cognitive neuroscience or entrepreneurship studies. We are entering an era of technology, AI and imaging methods, which are evolving quickly and can better aid us in researching the hard questions. For example, we have used a trained algorithm for natural language processing based on neural networks that learn word associations (Word2vec). This can be used to design tasks that consistently evoke creativity through distantly related semantic association like we did here and as was done in Krieger-Redwood et al. (2023) and Gao et al. (2021). This approach is most beneficial for neuroentrepreneurship research as it provides mutual benefit and insights for entrepreneurship and cognitive neuroscience.

Some design-based limitations exist in our study. Decisions were made to optimise the power and efficiency of the MRI study whilst limiting the cognitive load for participants as much as possible. One such decision was to adapt the original event-related design into a block design in consultation with the authors in Krieger-Redwood et al. (2023), reducing task time from over 40 minutes to only 12 minutes. During each trial, participants went through a sequence of stimuli as shown in fig 5.5; the strength of an event-related design would have been in the ability to distinguish between these events and even to separate the neurocognitive processes involved in the formation of the link and the post-evaluation rating of how creative they believed the link to be. Whilst we cannot separate this in our block-design analysis, we agree that 'creativity' arises from the entire cognitive processes involved rather than with a particular spontaneous event (Chrysikou 2019). As an essential component of useful creativity, we believe this stage of rating the link and thus evaluating their idea is necessary for true creativity in entrepreneurship.

Another practical limitation occurred due to the equipment used. During the MRI scans, we had recurring problems with the MR mouse system used for participants to register their responses. Therefore, some of the 'in-scanner' creativity ratings may have been inaccurate as participants sometimes struggled to select along the scale. Consequently, we discounted this rating in the final analysis and instead used the recorded rating given to the experimenter after the scan as the self-rated creativity score. Ideally, if we were to perform this study again, we would use both measures and see how the self-rating of creativity differs on a second evaluation, post-hoc.

Statistical power was also a limitation, and thus, the reliability of these findings. Estimating statistical power in fMRI studies is exceedingly complex, and it is difficult to predict how strong should the level of activation be, or how large should a cluster extent be. In addition, there is ongoing realisation that most fMRI studies are under-powered, and thus meta-analyses and the accumulations of many studies are needed to achieve the required sample size that avoids Type II and Type I errors (findings effects where there isn't any, and finding no effect where there is) (Button et al. 2013). Calculating the sample size using traditional measures on G*Power to achieve a 0.95 power, at the 0.05 alpha threshold and a medium effect size, led to 174 participants being required, 88 within each group . This shows that this present study is significantly under-powered (with 16 working professionals and 21 entrepreneurs). However, it is common for sample sizes in neuroimaging studies to be small and under-powered: for example 96% of the most influential neuroimaging papers had a median of 12 participants within a single group (Szucs and Ioannidis 2020). This is most likely due to the cost and time constraints associated to recruiting large groups for neuroimaging studies. Therefore, this imaging paper should be treated as a pilot study, to test if there are any observable differences in entrepreneurs' neural activity (BOLD response) during a verbal creativity task. It must also be considered that both groups here come from a healthy population, so effect sizes are likely to be small and thus even larger sample sizes would be required to detect reliable statistical differences. Future studies would need to replicate these findings with much greater sample sizes, to ensure that results are more reliable and generalizable.

Finally, an important limitation of our research is the overall ecological validity of neuroimaging studies. We know that the noisy, cramped environment of an MRI scanner is quite distinct from the scenarios most people, and indeed entrepreneurs, find themselves in day-to-day. Moreover, the environment of the scanner and the experimenters themselves add a degree of stress to the tasks, which could undoubtedly affect performance. This is where some wearable technology such as EEG, whilst less sensitive and more 'noisy' in terms of data output, may be preferred in future studies to complement and corroborate the findings from lab-based experiments. Nevertheless, even in this case the variability in the environments outside of a lab setting should be carefully considered when designing more naturalistic field-based experiments.

5.6.4 *Conclusion*

This is the first study to explore creativity in the brains of entrepreneurs and to understand the neural processing behind effectual reasoning, as a way of imagining new ends given a set of means. This underlies the prerequisite to any entrepreneurial endeavour, that is to come up with a unique idea. Therefore the findings from this study have important applications, despite their limitations, in 1) future theoretical and empirical enquiries, 2) methodological approaches to neuroentrepreneurship and 3) the practical application of this knowledge.

First we bring to light the importance of creative thinking for entrepreneurship and show via neuroimaging findings that an entrepreneur's brain may be more suited and efficient in creative, divergent and effectual approaches to thinking. Our results show task-specific adaptability of the entrepreneur's brain, leading to a situated view of entrepreneurial cognition, which emphasises that it is not solely a function of traits or cognitive processes, but that it is also shaped by the immediate situational context. Entrepreneurs demonstrated reduced MFG and frontal pole activity in unfamiliar situations, suggesting that they may use less neurocognitive resources overall in the unfamiliar conditions and may be better at releasing constraints of learned associations to produce creative responses. This is very fitting with a prior study by Japardi et al. (2018), who also showed reduced activity in the right frontal pole during divergent thinking for successful and creative professionals such as artists and scientists, which they termed the Big-C group, compared to a matched control group who lacked a creative element to their role. This prompts future questions of; how does this efficiency towards creativity develop, is it inherent or learnt? Moreover, does an efficiency towards creative thinking enable more flexibility and adaptability in the uncertain environment entrepreneurs often navigate? (McMullen and Shepherd 2006; Sarasvathy 2001).

Not only do we here provoke deeper theoretical inquiries, but we also prompt a call to action for the thoughtful design of future neuroimaging studies on the topic. Subsequent research should aim to study the nuanced variations in an entrepreneur's brain, recognising that these differences may arise from the interplay of context and task manipulation. This challenges the simplistic approach of seeking global connectivity or structural differences in entrepreneurs' brains, highlighting the necessity of uncovering insights from context-specific behaviors.

Finally, this study offers the initial evidence linking a crucial competency in entrepreneurship, disruptive thinking, to its neurological underpinnings. Disruptive thinking appears to intensify with entrepreneurial expertise as show in chapter 3, yet the factors driving entrepreneurs' enhanced competency or confidence in generating ideas and crafting visions have remained elusive. Our findings suggest preliminary evidence that greater expertise enables entrepreneurs to enter creative states more readily. This implies that individuals aspiring to pursue an entrepreneurial path, or seeking to cultivate entrepreneurial skills, should prioritise experiences and practices that foster disruption and creativity in their learning and training.

Overall, our findings contribute a significant empirical, methodological and practical contribution to the neuroentrepreneurship literature, as the first to show neurological evidence of the agent-context interaction in entrepreneurial thinking, in this case in the disruptive, creative and effectual logic that entrepreneurs use to imagine a new end.

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5.8 SUPPLEMENTARY MATERIAL

Table 23: Example of Word2Vec Similarity Scores for Related Condition

Probe	Target	Word2Vec
lorry	highway	0.324990738
belt	vest	0.33815705
jug	water	0.351800067
vet	animal	0.397178875
farm	sheep	0.474503282
melody	flute	0.539265683
spacecraft	astronaut	0.550899548
garden	flower	0.594903923
rabbi	synagogue	0.724205782

Table 24: Example of Word2Vec Similarity Scores for Unrelated Condition

Probe	Target	Word2Vec
platform	toothpaste	-0.051348295
seat	grapefruit	-0.01374512
prune	poker	-0.00044977
blazer	foal	0.025396759
kiwi	locker	0.056608185
kangaroo	aerial	0.080986859
bracelet	flea	0.109759561
vinegar	bone	0.129882703
mop	skin	0.135836061

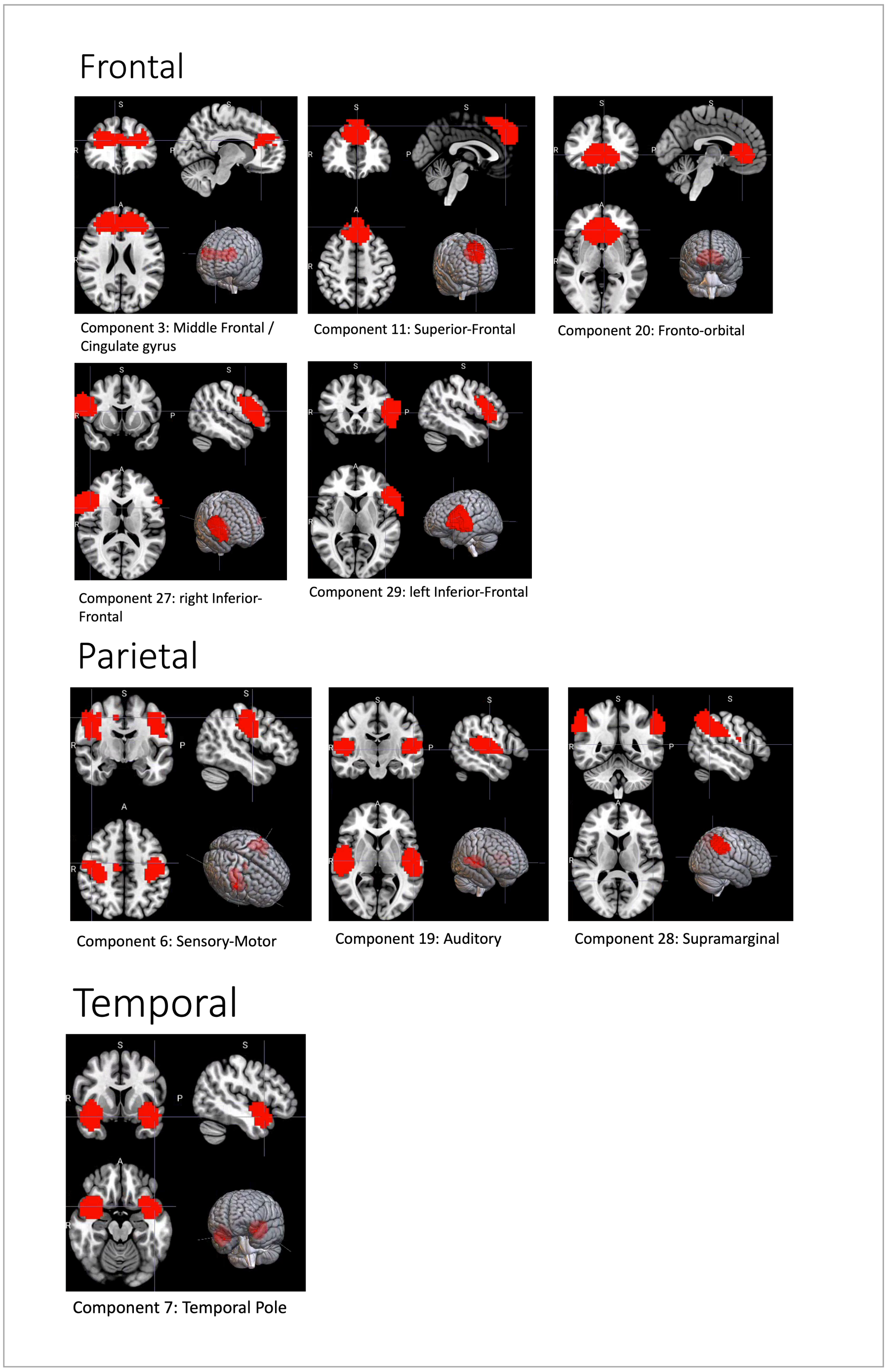

Figure 5.12: Additional RSNs identified from the ICA analysis. This figure shows (Top) Frontal Networks; (Middle) Parietal Networks such as sensory-motor, auditory and submarginal; and (Bottom) a network in the Temporal Pole.

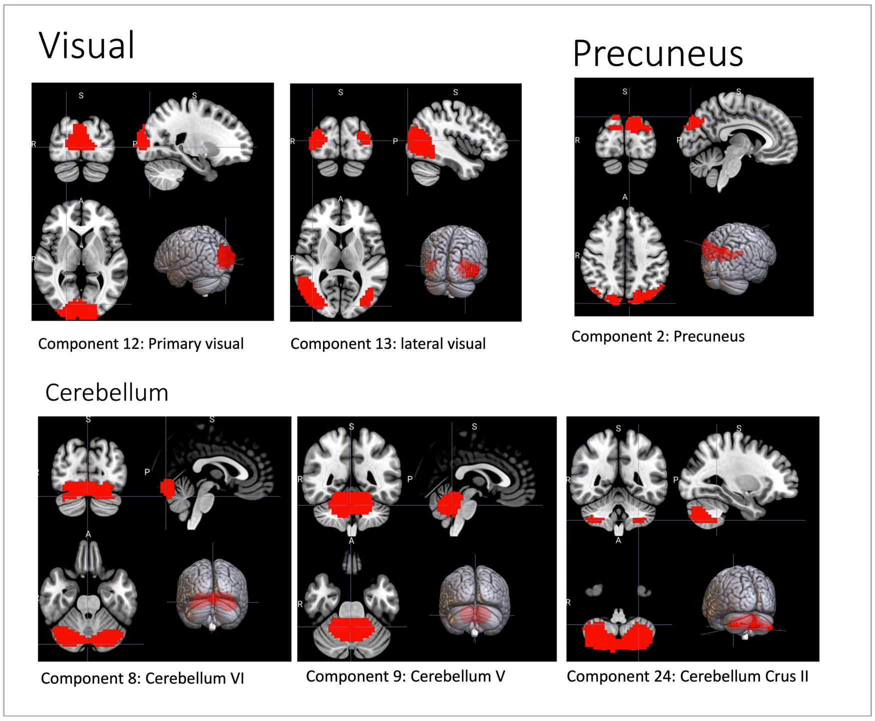

Figure 5.13: Additional RSNs identified from the ICA analysis. This figure shows (Top) visual and precuneus networks; (Bottom) RSNs in the cerebellum.

6

CHAPTER 6: GENERAL DISCUSSION

> If at first the idea is not absurd, then there will be no hope for it.
>
> — Albert Einstein

This thesis represents a significant contribution to the field of neuroentrepreneurship, aiming to illuminate what constitutes entrepreneurial thinking and whether specific neurological differences play a role. While the age-old debate of nature versus nurture in entrepreneurship marks the biggest unanswered question, this study takes a more modest yet novel approach to add data to the discussion. It marks the first comprehensive exploration of the neuroscience of entrepreneurship, blending insights from entrepreneurship cognition theory of mentalism and process-orientation, with methods and perspectives from cognitive neuroscience. Specifically, this research introduces the concept of entrepreneurial neurocognition, deciphering the neural structures and processes underlying the identification, evaluation, creation, and exploitation of opportunities.

This approach enabled us to find key differences in the brain and neurocognition of entrepreneurs, and we also to discovered that these are not due to global and consistent differences in brain activity. Instead, they are nuanced and context-specific. The differences in neurocognitive profile found in Chapter 4, particularly the findings of lower verbal reasoning, married with the compensatory effect found in Chapter 5, whereby entrepreneurs' brains appear more efficient for creative processing, suggest entrepreneurial and disruptive thinking a more suitable path for some, while supporting the notion that creativity is a brain state that anyone can access.

Through this thesis, I challenge popular assumptions of entrepreneurs. Entrepreneurs in our work do not appear to be impulsive, nor do they possess characteristics typical of someone with ADHD. Instead, it seems that they have a unique ability to find ease in disruptive thinking and resourcing and show efficiency in their ideas and decisions. Entrepreneurs are open to new opportunities and keen to explore uncertain territory, and they possess the emotional stability to tolerate such environments. This personality and neurocognitive profile may enable entrepreneurs to enter states that allow them to best use effectual logic, engage their imagination and conjure up ideas never previously seen.

Importantly, I position creativity as a brain 'state' that any individual can access rather than as a trait. However it is through the agent-context interactions that differences can be seen in the brain. We argue that this explains why we did not find differences in resting-state networks of the entrepreneur's brain, but found differences in neurocognitive functioning only when the task and context are considered. These findings fit in with theories of entrepreneurship which position entrepreneurship as the ability to create and imagine up new ideas with the resources to hand, despite the inevitable uncertainty that comes with doing so (Sarasvathy 2001).

We acknowledge the progress made as we distil the findings within each chapter and contextualise them within the evolving research landscape. However, we also emphasise the complexity of the field and the need for further investigations to comprehensively unravel the interplay between neurocognition and entrepreneurship. This research provides a valuable starting point, but the journey ahead into neuroentrepreneurship is filled with questions awaiting exploration.

6.1 SUMMARY OF MAIN FINDINGS

We have comprehensively interpreted and discussed the results in each original research chapter. Here, I summarise these findings and then critically analyse how the evidence presented best fits with that in the current literature.

In Chapter 1, I delved into the historical context of entrepreneurship, shedding light on how foundational Schumpeterian and Knighterian theories continue to shape our contemporary understanding of entrepreneurship as the art of identifying and seizing opportunities amid uncertainty. In particular I examined how the field has moved towards looking at the judgements and decisions of entrepreneurs, and the importance of the context and environment, and how this interacts with their thinking. I highlighted the shift in focus within the field, from probing "who entrepreneurs are" to examining "what entrepreneurs do." Nevertheless, despite significant theoretical advancements such as in effectuation, Sarasvathy (2001), I contend that the current approach falls short, as it confines itself to examining theorised mental processes and behavioural expressions, neglecting the exploration of the underlying neural substrates. This limitation sets the stage for integrating cognitive neuroscience in entrepreneurship research, which offers the unique ability to investigate the neural mechanisms underpinning cognitive processes within the brain, thus defining a new entrepreneurial neurocognition.

In Chapter 2, I identified the critical themes that bind neuroscience and entrepreneurship. My exploration uncovered themes such as (1) impulsivity and risk-taking, (2) decision-making efficiency in exploration and uncertainty, (3) emotional judgments, and (4) interpersonal trust and social cognition. Furthermore, I touched upon emerging empirical research in (5) opportunity alertness and (6) creativity, applying stringent search criteria to ensure the inclusion of only empirical studies employing cognitive neuroscience methods to study entrepreneurship.

The vast scope of possibilities meant that I needed to narrow down our focus, which prompted the inception of "The Entrepreneurial Brain Challenge," an online study designed to pinpoint differences in entrepreneurs' cognition, that was then used to guide the design of experimental paradigms for subsequent MRI studies using a data-driven approach. Chapters 3 and 4 present the pivotal findings derived from this online study.

In Chapter 3, I identified the competencies most relevant to studying entrepreneurship. My aim extended beyond popular stereotypes of entrepreneurship as mere risk-taking, seeking to offer fresh insights that could directly inform the practice, teaching, and training of entrepreneurship. Competencies, encompass an intricate interplay of behaviour, traits, and cognition within specific situations, prompting me to ask: What competencies should be assessed? Which ones do expert entrepreneurs exhibit in the real world? This led to using a self-report survey to determine a comprehensive list of competencies, followed by machine learning techniques to identify the key underlying competency factors. This analysis revealed that expert entrepreneurs excel in disruptive thinking (i.e., idea creation, validating ideas, vision) and resourcing (i.e., getting, learning, and managing resources, including tax, legal and financial resources, estimating costs and initiating and acting independently). This fits in with the theoretical take built up in Chapter 1.

In parallel, Chapter 4 delved into evaluating the entrepreneurs' personality and neurocognitive attributes that underlie disruptive and resourcing capability. Employing both hypothesis-driven tests and data-driven exploratory approaches, I investigated neurocognitive impulsivity and uncertainty processing among entrepreneurs. I used 12 standard cognitive tests and the Big 5 personality questionnaire to explore entrepreneurs' neurocognitive profiles. The hypothesis-driven tests did not yield significant differences between entrepreneurs and non-entrepreneurs, except for the former reporting higher tolerance for uncertainty. However, the exploratory approach unveiled intriguing differences, including a distinct neurocognitive profile for entrepreneurs, marked by greater long-term memory and lower verbal reasoning abilities. Variations in the Big 5 personality traits were identified, with entrepreneurs exhibiting lower conscientiousness, higher openness, and lower neuroticism.

The cumulative insights from Chapters 2, 3, and 4 guided the fine-tuning of our next research questions. These adjustments were driven by the core theories of entrepreneurship, the burgeoning theme of creativity research, and the discovery that disruption competencies increase with entrepreneurial expertise. The revelation of higher long-term memory and lower semantic reasoning led us to a stream of literature exploring verbal creativity and its association with the brain's default mode and semantic networks.

Consequently, Chapter 5 details our MRI study, which adapted an existing task from Krieger-Redwood et al. (2023), that identified differences in brain regions associated with semantic control during creativity tasks. In our sample, we uncovered distinct neurocognitive patterns in entrepreneurs despite observing no behavioural differences. For instance, while entrepreneurs did not produce more unconventional or creative responses than working professionals, fMRI analysis revealed divergent brain activation patterns. Working professionals' activity in the medial frontal gyrus (mFG) and frontal pole increased when transitioning from familiar to unfamiliar conditions, indicating increased cognitive effort in linking unusual word pairs. In contrast, entrepreneurs decreased mFG and frontal pole activity in unfamiliar conditions, suggesting a different cognitive processing strategy, and perhaps more cognitive ease in unfamiliar scenarios. We showed that these neural differences are only present when a task and context are manipulated: in resting state fMRI network analysis (i.e., with no task or context manipulation), we found no differences between entrepreneurs and working professionals in the default-mode network and multiple demand network. These findings are particularly relevant to highlight two key contributions neuroscience makes to entrepreneurship research: 1) uncovering differences in cognitive/neurocognitive processes that are not otherwise observed in behaviour and 2) demonstrating differences in entrepreneurs' cognition/neurocognition that are highly intertwined with the context and task at hand.

6.2 Interpretation and Generalisability of the Results

Going back to the core aim of this research - to offer fresh insights into how entrepreneurship is taught, I aim to explore whether there are distinct differences in the way entrepreneurs think, and if so, what these differences entail—are they innate traits or skills that can be developed? This inquiry is essential because current methods for training entrepreneurs lack clarity on which aspects of entrepreneurial thinking are inherent to individuals and which can be nurtured through the right environment and interventions. This thesis enabled the means to test what the entrepreneur *does*, not just what they say they do, particularly in the context of creative thinking and effectual logic, exploring both the stable and changeable aspects of cognition. I provide unique insights that contribute to our understanding of entrepreneurial cognition at the neural level (Denis A Grégoire et al. 2015; Sarasvathy 2001). Moreover, in terms of Amabile (1998)'s domains of competency, this thesis has explored the *thinking skills* of entrepreneurial competency, in terms of the cognitive and personality profiles conducive to disruptive thinking.

First we demonstrated the more stable traits and neurocognitive skills entrepreneurs possess in Chapter 4. This could be considered as the antecedents to entrepreneurial cognition, and the internal resources individuals possess that allow them to engage in the thought processes required for entrepreneurship (Denis A Grégoire et al. 2015; Penrose 2009). Second, we studied the 'live' neurocognitive processes which make up disruptive thinking in Chapter 5. Our MRI study enabled the means to study the operation of entrepreneurship neurocognition, in the form of the brain processes involved in creative associations. We show for the first time the nuanced differences in the level of brain activity required for entrepreneurs to produce creative responses.

6.2.1 *In the Context of the Current Literature in Neuroentrepreneurship*

This thesis makes a significant contribution to the emerging field of neuroentrepreneurship by presenting new empirical findings. Our initial literature review highlighted the scarcity of empirical work in this area. In Chapter 2 (dated November 2022), we revealed only nine studies that successfully integrated cognitive neuroscience and entrepreneurship. These encompassed EEG, fMRI, and neurocognitive testing, as summarised in Table 5. These investigations primarily explored entrepreneurial neurocognition in the domains of impulsivity and risk-taking (Fisch, Franken and Thurik 2021; Nejati and Shahidi 2013; Ortiz-Terán, Turrero et al. 2013), decision efficiency, exploration, and uncertainty (Laureiro-Martínez et al. 2014), emotional judgments (Halko et al. 2017; Lahti et al. 2019; Lawrence et al. 2008), interpersonal trust, and social cognition (S. Shane et al. 2020; Yang and Li 2017). Additionally, we identified two emerging themes, namely opportunity recognition and creativity (Rahmati et al. 2014; Saggar et al. 2017; Zaro et al. 2016), that were either pilot studies lacking fully developed methods or did not pivot their theoretical foundations to entrepreneurship, emphasising the need for further empirical work.

Re-doing this literature search in February 2024, revealed a further 153 papers, of which only one study met our search criteria of an empirical papers that successfully integrates cognitive neuroscience and entrepreneurship. This paper is by Ooms et al. (2023), who performed a functional connectivity analysis on MRI data, to explore if there were connectivity differences in entrepreneurs' brains. They found increased connectivity between the insula and two regions: the right anterior frontal cortex and the right precuneus, which I discuss more in section 6.4.1. This paper is methodological rather than fitting into the themes explored in Chapter 2 as this study did not perform any behavioural or cognitive tasks, however it highlights the increasing use of neuroscience methods in the study of entrepreneurs, albeit slowly.

While grounded in entrepreneurship research theories, this thesis adopts a data-driven approach to explore entrepreneurial neurocognition. For instance, two of the themes identified in Chapter 2, impulsivity and uncertainty, formed the basis of our hypothesis-driven neurocognitive tests discussed in Chapter 4. Surprisingly, we found no significant differences in neurocognitive performance regarding impulsivity and uncertainty processing among entrepreneurs. But we uncovered novel insights through our exploratory approach, where a comprehensive neurocognitive battery was administered to our study participants. Specifically, our findings highlighted differences in the verbal reasoning and episodic memory of entrepreneurs, prompting us to delve into verbal creativity for our fMRI study. This exploratory approach demonstrates the importance of embracing data-driven methodologies to enhance new research insights.

In the broader context of neuroentrepreneurship literature, this study marks the first endeavour to investigate creativity within the brain of entrepreneurs. It provides empirical data for an explanation of how the entrepreneur's brain may form effectual logic, to create something new out of their current resources. In Chapter 2, we identified creativity as an emerging avenue of inquiry in neuroentrepreneurship research, posing questions such as:

1. Do entrepreneurs exhibit higher creativity levels than non-entrepreneurs in lab-based objective cognitive neuroscience creativity tasks?

2. Are the brain networks involved in creative processes, such as the default mode and semantic control networks, more robustly connected in entrepreneurs, and do they correlate with increased creative insights?

Regarding the first question, our study does not support that entrepreneurs outperform working professionals in lab-based cognitive neuroscience creativity tasks. However, in response to the second question, we observed differential activity in brain regions associated with creative processes. Specifically, we identified reduced activity in a core component of the default mode network (DMN), the precuneus, and decreased activity in the multiple demand network (MDN), specifically in the right medial frontal gyrus (MFG). These findings suggest more efficient neurocognitive mechanisms in the brains of entrepreneurs when engaged in creative tasks. This efficiency may be attributed to the practice-based effect, where these mechanisms become more streamlined with experience. This allows for more flexible and less constrained ideation, particularly in associating semantic concepts.

A relevant study demonstrating the impact of practice-based effects is presented in Saggar et al. (2017), which we introduced in Chapter 2, Section 4b. This study revealed that a 5-week design-thinking intervention enhanced participants' creative abilities, associated with reduced task-related activity in the right dorsolateral prefrontal cortex (dlPFC), ACC, and SM, alongside increased cerebellar-cerebral connectivity.

This suggests that increased creativity is linked to reduced engagement of executive functioning regions and heightened involvement of spontaneous implicit processing. Our findings of reduced activity in the right MFG and frontal pole in entrepreneurs align with this concept of experience-dependent reduced engagement of executive higher-order functioning during verbal creativity. This could be attributed to experience and practice in creative problem-solving, which requires less cognitive exertion for more experienced entrepreneurs.

Notably, the concept of more 'efficient' cognition in entrepreneurs is consistent with the work of (Laureiro-Martínez et al. 2014). Their research demonstrated the involvement of the right frontal pole in the efficient switching between exploitative and explorative choices in entrepreneurs. They found that right frontal pole activity correlated with efficiency scores in entrepreneurs. In this PhD work, we reinforce these findings of differential activation in the frontal poles of entrepreneurs and relate them to task efficiency. The differential activation of the right MFG and frontal pole in entrepreneurs may enhance efficiency, allowing for more structured responses during specific tasks while enabling a more unrestricted flow of creativity when dealing with unrelated and uncertain scenarios.

6.2.2 *Positioning Entrepreneurial and Creative Thinking as a State Rather Than Trait*

In the introduction, we introduced the focus shift from what an entrepreneur 'is', using a trait approach, to what an entrepreneur 'does', using the cognitive approach (Baron 1998; Denis A. Grégoire, Corbett and Mcmullen 2011). However, this shift is still very much focused on what is 'different' about an entrepreneur's cognition, and the narrative seems to focus onto what an entrepreneur consistently does over and above a so-called 'non-entrepreneur'. Indeed, while at first I myself thought that this could be the aim of my PhD research, I now feel that the research presented is better positioned to answer questions such as those posed by Krueger Jr and Day (2010): "What is the nature of entrepreneurial thinking?" and "What cognitive phenomena are associated with seeing and acting on opportunities?". While we may consider the influence of traits on the likelihood of observing certain behaviours, we are most interested in studying the nature of thinking and (neuro)cognitive phenomena and the context in which they occur.

Whilst we found traits associated with entrepreneurship, these are heterogeneous, both in the past literature and within our findings. For example, in Chapter 4, I showed significantly higher openness, lower neuroticism and low conscientiousness when comparing non-entrepreneurs (n=366) and entrepreneurs (n=93). In Chapter 5, the entrepreneurs in the MRI study who also took the personality test (15 non-entrepreneurs, 19 entrepreneurs) showed significantly greater Extroversion and Openness. Prior research positions traits as the 'cause' of behaviour and mental processes (John, Naumann and Soto (2008) in Brandstätter (2011). I do not entirely agree with this statement and think that they represent phenomena measurable by self-report that may capture some consistent behaviour or attitudes within an individual. Therefore, I argue that the trait approach is somewhat limited in what it can tell us about an entrepreneur. Traits ultimately represent a characteristic associated with or 'more likely' to produce a specific behaviour. As described by Brandstätter (2011), the understanding of what the Big 5 traits are is still 'fuzzy', and they are attributed to include *characteristics of temperament as the overarching style of a person's experiences and actions*. Therefore, when asking to self-report such traits, there is an undeniable influence and bias on how people think and feel about their behaviour. As shown in our results, differences in traits do not directly correspond to differences in expected behaviour. For example, I did not show any correlation between self-reported and behavioural findings in 4 and 5.

In many ways, the concept of entrepreneurial competencies adopted by entrepreneurial education scholars better integrates such traits and characteristics with the skills (cognition) and knowledge that form certain observable behaviours. Competency, by definition, represents the skills, knowledge, and characteristics/attitudes that contribute to effective performance and behaviour in a given role or situation (Dictionary n.d.). As defined by Mitchelmore and Rowley (1995), entrepreneurial competencies comprise underlying characteristics such as specific knowledge, motives, traits, self-images, social roles, and skills that lead to venture creation, survival, and growth. The importance of differentiating them in relevant factors is that competencies can be acquired (whilst traits by definition are seen as static) (Mitchelmore and Rowley 2010). Therefore, studying entrepreneurship as the competencies of disruptive thinking or resourcing through uncertainty may be preferable. Competencies are driven by multiple factors, from one's attitudes, skills and knowledge, yet they also depend on the context they are operating within.

For example, we discuss in Chapter 3 how disruptive thinking increases with expertise in entrepreneurship and yet it can be curbed by power influences in an organisation. Márquez and Ortiz (2021) describes *The Fiction of Applicability* - whereby those with greater power find it easier to apply and assert their ideas, whilst 'base personal' with less power feel less empowered to do so. In this respect, 'permission' to be creative and disruptive may be required. Indeed, the findings from our MRI study support the importance of considering the task and conditions that individuals operate within. Every participant in our research was given specific instructions to be creative and was thus primed by the context of the particular word pair association task. Given this instruction, all participants in our study were able to form more creative responses in the unfamiliar conditions, and entrepreneurs were not more unique in their responses than working professionals. In addition, all participants showed increased brain activity in regions consistent with the literature on verbal creativity, such as the dmPFC and left inferior frontal gyrus (IFG), as well as widespread activation in regions of the MDN, when creating links in unfamiliar contexts, as compared to more cognitive ease during the familiar word pairs and greater engagement of the DMN (Krieger-Redwood et al. 2023; Ortiz-Terán, Agustın Turrero et al. 2013; Davey et al. 2016; Ovando-Tellez et al. 2022; Chiou et al. 2023). The difference is that entrepreneurs required less right middle frontal gyrus (MFG) activity in these creative and unfamiliar conditions. This suggests more ease for entrepreneurs to enter a creative state and produce the same results.

We are not the first to position creativity in entrepreneurs as a state. Weinberger et al. (2018) suggested that the view of creativity as a trait in entrepreneurship was flawed and proposed that the ability to engage in creative thinking may change daily; in that study, 77% of the creativity variation was within people over time, rather than differences between different subject. In particular, the researchers showed the critical role of rest and recovery during non-work hours for creative thinking, suggesting that the brain requires 'downtime' outside of work to best perform creative problem-solving on subsequent days. The widespread engagement of the MDN and cognitive control mechanisms needed for creativity, as shown in our study and in prior work, may provide a neural basis for why a lack of rest or recovery may lead to cognitive fatigue and more difficulty engaging a creative 'state' (Krieger-Redwood et al. 2023). Indeed, this fits in with a prior neuroscience theory on creativity that positions the importance of both focused attention (MDN) and defocused attention (DMN) (Chrysikou 2019). Psychology and behavioural studies have shown the effect that a short break and the chance for the mind to wander has on increasing creative performance, thus positing how the environment can impact these creative states in the brain.

For example, Baird et al. (2012) showed scientific evidence to support the anecdotal experiences that many people have where they come up with better solutions upon 'stepping away' from the problem, for example, by going for a walk, taking a shower, or sleeping on an issue. In their controlled experiments, participants performed the AUT then went into one of 3 groups. The first group rested for 12 minutes, the second group were given an 'undemanding' task, and the third group was assigned a 'demanding' task. After the intervention, they all performed the AUT again. The authors demonstrated that the optimal intervention to increase creativity was the second condition, i.e., engaging in an undemanding task, which provoked the highest degree of mind wandering due to its ease and the ability of participants to go into autopilot. Further studies have shown how environments, such as dim lighting and darkness, walking outside or listening to music may 'free constraints' and allow for creative states (McCoy and Evans 2002; Steidle and Werth 2013; Ritter and Ferguson 2017; Oppezzo and Schwartz 2014). An fMRI study has shown how creativity can be facilitated by exposing people to other creative ideas, linking this to increased activity in the right temporoparietal systems (Fink et al. 2012). A handful of research studies have even used transcranial direct current stimulation (tDCS) to attempt to increase excitability in neurons in areas of the brain associated with creativity, such as the IFG and TFG (Hertenstein et al. 2019; Lifshitz-Ben-Basat and Mashal 2021) see also Lucchiari, Sala and Vanutelli (2018) for a critical review. tDCS studies are built based on state views of creativity. For example Lucchiari, Sala and Vanutelli (2018) describes state creativity as *a transient property of the cognitive system, a mental configuration we may call a "creativity-on" state, which may be spontaneously activated and evoked by external conditions (e.g., by a task that asks individuals to find creative semantic connections between words).* tDCS thus aims to switch the brain to a "creativity-on" state.

This thereby highlights the effect that task demands, environment and even direct stimulation can have on inducing a creative 'state', as opposed to it being a set trait that specific individuals do or do not possess. We previously set out that neuroscience provides a set of complementary tools to 1) directly manipulate the task environment, 2) measure hidden processes of the mind in response, and 3) measure dynamic actions and performance of the participant (i.e., the entrepreneur in our case) and thus the relationship between the environment and the mind. Our results show that verbal creativity (an essential prerequisite to disruptive thinking) may be present as competency in individuals to varying degrees. Creative thinking is a fluctuating 'state' that all human brains can achieve.

6.2.3 *Using Task-Based and Resting-State fMRI Approaches*

As introduced in Chapter 1, there are many design and analysis approaches to MRI studies (Amaro Jr and Barker 2006). We introduced the concept of task-based fMRI, based on cognitive subtraction methods, that we used to study associations between related and unrelated word pairs (Donders 1868; Ulrich, Mattes and Miller 1999). With this approach, we can compare brain states between different conditions and distil down the neurocognitive processes to only those involved in the more creative links between obscure word pairs. While task-based approaches allow a specific investigation into particular brain processes, it is however well known that the brain is a dynamic system, with many areas and networks working together to carry out specific functions. Therefore, functional connectivity analysis is an alternative approach to understanding the more dynamic nature of brain networks.

Since the review in Chapter 2 was carried out in November 2022, I re-ran the literature search for this discussion (Oct 2023). This returned an additional paper, a methodological brief in *Entrepreneurship Theory and Practice*, focusing on resting-state fMRI in entrepreneurs versus managers (Ooms et al. 2023). In this paper, the authors took a different approach to resting-state analysis than the ICA method in Chapter 5: they performed a seed-based functional connectivity analysis. Their hypothesis-driven approach defined the right insula as seed region, due to its involvement in flexible behaviour and decision-making under uncertainty. Comparing entrepreneurs to managers, they found increased connectivity between the insula and two regions: the right anterior frontal cortex and the right precuneus. The strength of this approach is that it makes it possible to assess cross-network connectivity, whilst, as discussed previously, the ICA analysis that we performed in Chapter 5 only allows us to test and compare connectivity within networks, for which we did not find any differences. Therefore, future work may re-analyse our resting-state fMRI data by defining a seed region in the insula to see if we can reproduce and echo the recent findings from Ooms et al. (2023). Further analyses could also use as seed region a key brain area related to verbal creativity, such as the left IFG, or indeed the region we showed to differ in the entrepreneurs, the right MFG.

We find it particularly interesting that Ooms et al. (2023) also show a pattern of activity that represents an increase in the right frontal lobe and a decrease in connections to the precuneus, as this relates to our task-based findings. Our results expand theirs to show how activity in these regions (the right frontal lobe and precuneus) changes depending on the context. We showed in Chapter 5 how activity in the right MFG varies depending on the task (creating links between word pairs) and the conditions (related word pairs and unrelated word pairs). For non-entrepreneurs (working professionals), activity in the right MFG is related to task difficulty, increasing as the word pairs became more distant. In entrepreneurs, the opposite effect is seen whereby activity is more significant in the MFG regions during the related trials and decreases (even from baseline) for the unrelated trials. This opposite activation pattern in entrepreneurs is coupled with more significant deactivation in the right precuneus and cerebellum for the unrelated word pairs. We suggested that this may be due to the brain's efficiency in reducing interference from the precuneus (thereby reducing interference of episodic memory) to form creative links in uncertain and unfamiliar conditions. Ooms et al. (2023) did not provide a possible explanation for the anti-correlation seen between the precuneus and insula. However, previous work has shown that the insula and precuneus together are critical regions in attributions states (e.g. how one relates experience to oneself or external events) and also that the insula is implicated in interoceptive (i.e., bodily) states into conscious feelings and in relating experience to internal (oneself) (Xue et al. 2010; Cabanis et al. 2013). Therefore, these empirical findings may suggest altered attribution states in entrepreneurs, meaning differences in how they relate incoming information to themselves.

Altogether, this shows that resting-state differences in integrating internal/external information may persist from seed-based FC to task-based conditional fMRI. Our results, in particular, showcase how task-based fMRI can better understand how the brain responds to tasks and context than resting-state fMRI alone. However, more research should be performed to understand the nuanced relationship between regions of the insula, right frontal regions and precuneus, and their coupling and decoupling during resting-state scans and tasks-based fMRI.

6.2.4 *Neurodiversity in Entrepreneurship*

Finally, as it represents a growing stream of work in neuroentrepreneurship, I wish to address how these findings fit in with views of neurodiversity in entrepreneurship. Prior research introduced in 1 indicated that entrepreneurs show a greater prevalence of ADHD-like and dyslexia behaviours and symptoms (Logan 2009; Wiklund, Yu, Tucker and Louis D Marino 2017a). However, while research linking ADHD-like behaviours and entrepreneurship is becoming more popular (Gunia, Gish and Mensmann 2020; Moore, McIntyre and Lanivich 2019; Verheul et al. 2015; Wiklund, Yu, Tucker and Louis D. Marino 2017b; Yu, Wiklund and Pérez-Luño 2021), I casted a critical eye on the empirical evidence for greater impulsivity in entrepreneurs in Chapter 2 , having found no strong evidence for this differential behaviour. As per Chapter 4, we did not find greater impulsivity in entrepreneurs in our study, neither in the information sampling task, nor on the well-validated BIS. Moreover, I am unaware of any empirical work showing higher incidences of diagnosed ADHD in entrepreneurs. While the jury may still be out, I feel that the research incorporated in this thesis and the prior empirical work do not enough support views of more significant ADHD or ADHD-like behaviour in entrepreneurs.

Instead, this thesis's empirical and data-driven insights may warrant further investigation of dyslexia in entrepreneurs. The unexpected increased activity in the right MFG for the 'easier' related word-pairs condition in Chapter 5 and the lower verbal reasoning in entrepreneurs in Chapter 4, may be suggestive that simple semantic associations and semantic reasoning may be weaker in entrepreneurs, thus requiring more cognitive and neural effort on their part. This might point to unusual language processing in entrepreneurs' brains. Whilst there is an emerging belief amongst theorists that there may be a higher incidence of dyslexia in entrepreneurs, there is currently little empirical evidence to support this assumption (Nicolaou, Phan and Stephan 2021; Logan 2009). These results may provide the first neurological evidence for differential language processing in this expert population. It is indeed expected that people with dyslexia compensate for their language processing deficiency by recruiting brain areas not usually involved in such processes (Temple et al. 2003; Rasamimanana et al.

2020; Viersen, Bree and Jong 2019). Could it be the case that the right MFG is being incorporated into verbal processing in the brain of entrepreneurs during what should be simple semantic associations to produce the same behavioural results? The evidence here is not strong enough to assert such a theory but may provide preliminary evidence that warrants further investigation.

6.3 LIMITATIONS

As in most experimental scenarios, the research presented here has limitations. In each of the empirical chapters, such as Chapters 3, 4 and 5, I discussed the specific limitations relating to each piece of work. Therefore, in this section, I will list and discuss the setbacks of our overall approach. In addition, I will consider potential solutions to overcome these limitations in future research.

6.3.1 *Defining an Entrepreneur Group*

The challenge of defining 'groups' in entrepreneurship research is a central concern that we introduced in Chapter 1 as a persistent question throughout my PhD. Like many research endeavours, it appears that there is no perfect solution to obtain statistically sound results (typically better achieved through having clear-cut defined groups) while simultaneously satisfying a theoretical process-based account of entrepreneurial thinking or advocating, as I do, that entrepreneurial thinking likely exists in all of us. Consequently, defining groups as entrepreneurs and non-entrepreneurs can be seen as a problematic task. As such, whilst we tried to maintain the best grouping for our research questions, the limitations in this thesis include a lack of measurement of success in entrepreneurs and a control group that deviates from the norm in the rest of the literature.

First, I still maintain that the initial grouping I proposed at the outset of this thesis is valid, especially when we consider entrepreneurship as a process intertwined with experience-dependent expertise (Sarasvathy 2001; R. K. Mitchell, B. T. Mitchell and J. R. Mitchell 2017). As I previously argued in Chapter 1, Section 1.5, *I position that both definitions could be relevant to neuroentrepreneurship research. We can define entrepreneurs as those who identify, create and/or exploit opportunities whilst also representing groups of entrepreneurs who show real-life evidence of this identifying, creating and exploiting, which, in most cases, is likely to be in the form of starting a business.* The crux of the matter is that we can assess individuals' levels of experience in entrepreneurial pursuits, as demonstrated in Chapter 3 and Chapter 4, where we categorise groups based on those who have "founded, managed, and owned a business" in contrast to those who have not. It is important to note that the data presented in these chapters is therefore only limited to revealing disparities between those who have taken the entrepreneurial leap and those who have not, without delving into the success of these businesses or individuals.

Second, in Chapter 5, the criteria for our groups were more stringent. This allowed us to draw more nuanced conclusions. Given our focus on creativity, we sought participants who displayed creative disruption by creating solutions to problems and initiating and developing ideas behind their businesses (Schumpeter 1943). This underlines how group categorisation can be dependent on the specific research question. As for our control group, we chose to recruit working professionals for comparison. Although it is common in entrepreneurship literature to use managers as controls (Laureiro-Martínez et al. 2014; Lawrence et al. 2008; Ooms et al. 2023), we deviated from this practice. Therefore, a further limitation is that our results are not directly translatable to these studies and add a degree of variability to the field.

6.3.2 *Confounding Effect of Recruitment and Timing*

As is always the case with experimental research studies, the sample and data presented here are a 'sample' of the wider population. As discussed previously, regarding the different personality findings in the online sample in Chapter 4 and in the neuroimaging sample in Chapter 5, the means of recruitment, the adverts, the mailing lists, the nature of the study and how it is described will always enable some form of 'self-selection' into the research. It is also essential to consider when the research was conducted, the current climate through which the data were collected. The online data collection began in the summer of 2020 during the height of the COVID-19 global pandemic. Most importantly, the same neurocognitive battery and methods we used to study entrepreneurs in Chapter 4 were used by our collaborators to study the effect of COVID-19 on cognition. They found global cognitive deficits in those who had contracted COVID-19 (Hampshire et al. 2021). Therefore, we know that this period in time and COVID-19 may have confounded our results.

Moreover, concerning the trait differences we found, it is essential to note that the samples in this thesis are small compared to those of previous meta-analyses that show that, in comparison to managers, entrepreneurs have higher C, O, E, and lower N, A (Brandstätter 2011). However, the difference may also be present due to the types of entrepreneurs that may self-select for this particular online testing. The online testing in Chapter 4 lasted an hour, with the Big 5 personality test at the end. Therefore, we only capture the personality of those willing to sit through the entire testing. Moreover, more extroverted and confident entrepreneurs might be self-selecting for in-person research studies in entrepreneurship, which could explain why we find higher extroversion in the MRI sample but not in the online sample, nor in the prior meta-analysis by Brandstätter (2011).

Finally, the entrepreneurs in Chapter 4 had an average number of businesses of 2.17, and the average number of years running said businesses was 5.92. In comparison, in Chapter 5, the average number of businesses was 2.38, and the average number of years running the businesses was 8.00 years. Therefore, our second sample contained a sample of entrepreneurs with slightly more entrepreneurial experience. It is known that the approaches required during the stages of business creation differs from those needed for the growth and sustainability of a business (S. A. Shane 2003; Baron and Scott Shane 2007; Anderson and Jack 2002). S. A. Shane (2003) sets out these stages to be: (1) emergence of opportunities, (2) recognition of these opportunities by specific people, (3) evaluation of these with an active decision to pursue them, (4) assembly of required resources and (5) development of a strategy for using these resources to exploit the opportunity and (6) actual exploitation. The differential nature of these stages may therefore help to explain the differences we see in self-reported conscientiousness. This is further demonstrated by findings in technology-based ventures, where effectual logic is more dominant in the early stages. In contrast, casual logic and more planned-out approaches are required later on (Reymen et al. 2017). This highlights one of the critical issues with trait approaches: whilst traits attempt to define stable characteristics of individuals and even claim genetic causes, traits can and do actually change through experience and lifetime. For example, data from 132,515 adults, ages 21-60, has shown that the Big 5 personality traits are unstable and change throughout one's lifetime (Srivastava et al. 2003).

6.3.3 *Limitation of MRI for Studying Neurocognition*

Here we discuss the limitations of using MRI in studying entrepreneurs' brains, considering what the measures mean, the constraints of the BOLD response, and the practical aspects of this neuroimaging research, including the limits of the methods, interpretation of results, accessibility, the expertise required and costs.

First, we encounter a limitation when interpreting fMRI results. MRI is a powerful technique for examining brain function with a high spatial resolution down to 2mm specificity, but it has limitations. It is not an absolute quantitative measure of brain activity as it primarily measures changes in blood flow, an indirect measure of neuronal activity (Glover 2011; Hillman 2014). While we understand the haemodynamic response function well and its relationship to neuronal activity, it lacks temporal precision: with fMRI, we only acquire a snapshot of brain activity every 1-2 seconds. Other functional neuroimaging techniques, like EEG, provide better temporal information (but with poorer spatial resolution), and could complement fMRI in future multi-modal research to comprehensively understand neurocognition.

Second, we must consider the constraints posed by the task design and analysis methods we employed. Our data analysis used a block design, which offers the best statistical power with smaller sample sizes (Amaro Jr and Barker 2006). However, it does not allow the separation of distinct neural events; instead, it measures the average activity over a 20 30-second block (Logothetis 2008). In future work, it may be valuable to reanalyse the data with a finer-grained approach, treating the 'event' as forming a link and subsequently rating that link. This could offer more detailed insights into the role of the right MFG and regions in the DMN for verbal creativity in entrepreneurs. Additionally, seed-based functional connectivity (FC) analysis approaches for the task and resting-state data within these regions could provide a deeper understanding of the interactions between networks and regions involved in verbal creativity.

Third, a common issue in neuroimaging is that of reverse inference (Poldrack 2006). While we aimed to avoid this in Chapter 5, we also wanted to provide some interpretability of the fMRI differences we found in the context of the broader neuroscience literature and of the known roles of the brain networks and regions. It is important to emphasise that brain activity, whether positive or negative, does not confirm or deny the presence of a mental process or thought. Instead, considering the regions activated in the *context of the task* can offer predictive validity for the cognitive processes involved (Hutzler 2014). Furthermore, the direction of activation or deactivation in the brain doesn't necessarily indicate more or less of a mental process, as the neural efficiency hypothesis suggests that experts may show lower brain activation when performing a skill (Dunst et al. 2014). In our study, the lower activation in the right MFG for more demanding conditions may be due to practice-based effects on creativity or a deficit in verbal functioning. Without further testing, implying any causation or correlation between such brain states and experiences is difficult.

Finally, there is a significant practical limitation to MRI research related to scanner accessibility and costs. The price can vary depending on whether the research is conducted in a commercial or university-based department, but it often amounts to £500+ per hour. This cost includes not only scanner time but also the presence of radiographers to ensure participant safety and data quality. Additionally, task-based assessments require expertise in task design and specialised equipment, such as button boxes or an MRI-compatible mouse as we used. We concur with the points made by Ooms et al. (2023) regarding the need for expertise in these areas for successful MRI task-based research. While resting-state scans are an alternative, they are not a one-size-fits-all replacement for task-based assessments, as the latter offers a more nuanced and context-based understanding of cognition. We recommend that researchers looking to use MRI collaborate with institutions with the necessary resources and expertise. Alternatively, other neuroimaging methods, such as EEG, are more accessible, cost-effective, and safer for implementation.

6.3.4 *Hot Neurocognition and Considering Emotions*

As indicated in the limitations outlined in our empirical chapters, emotions play a significant role in understanding entrepreneurship. One limitation of this thesis is the omission of emotional aspects in the design and analysis of our empirical studies. Much of our research can be categorised as 'cold cognition' (Lawrence et al. 2008), as it lacks a direct link to rewards associated with specific behaviours or emotional motivations. This limitation may impact the generalisability of our findings, as the neurocognitive tasks we employed may not directly align with the real-life decisions entrepreneurs routinely make. As previously discussed, this limitation might help explain the null findings in Chapter 4 concerning impulsivity and risk-taking.

In Chapter 2, we introduced the concept of emotional attachment and bonding to ventures, emphasising their potential impact on an entrepreneur's judgment and decision-making (Halko et al. 2017; Lahti et al. 2019). It is essential to recognise that the effects observed in our MRI study may differ or become confounded when emotional factors like rewards or risks are introduced into the creative link-making process. Future research should delve deeper into the bi-directional relationship between judgment decisions and the emotions that entrepreneurs experience regarding their ideas. In practice, it is not uncommon for a strong emotional attachment to one's ideas to cloud an entrepreneur's judgment, which can be a common pitfall.

Such emotional attachment may hinder seeking objective feedback and adapting when an idea fails to validate (Toivonen et al. 2023).

6.4 FUTURE DIRECTIONS

6.4.1 *How to Further this Research*

Based on the interpretation and limitations of the findings in this thesis, I make some recommendations for how this research could be continued to test the theorised explanations of results, corroborate them with other recent findings, and dig deeper into the neural mechanisms behind entrepreneurial thinking.

Defining Groups

First is a recommendation for study and group design. We noted defining groups in entrepreneurship as a limitation. In particular, we mentioned deviating from the "norm" of selecting managers as a control group for entrepreneurs (Lawrence et al. 2008; Laureiro-Martínez et al. 2014; Ooms et al. 2023). However, there were carefully thought out reasons for our grouping that we think are important to consider for future research in the field. First, we aimed to align our working professionals with our entrepreneurs; both groups required at least three years of experience running a business (for entrepreneurs) or working in their respective fields (for controls). Some of our entrepreneurs lacked managerial experience, so managers would not have been an ideal professional match for them. Second, given our interest in creative processes, particularly in the ideation of a business, we selected entrepreneurs who demonstrated problem-focused disruptive innovation.

In contrast, we chose working professionals who engaged in structured professions with clear protocols, training, and procedures (such as accounting and law) and, crucially, ensured during the screening process that they had no experience in starting a business, did not engage in freelance work, and had no intention of starting a business in the future. We excluded three potential participants during screening because they had undertaken freelance work or had previously established a business. Therefore, we argue that comparing our entrepreneurs to managers, as the "default" control group in entrepreneurship research, is not always the most suitable approach for early-stage entrepreneurs or when studying disruptive creation.

For the reasons outlined throughout this thesis, entrepreneurs are unlikely to constitute a homogeneous group with a secret set of traits or a universal formula for the perfect definition. Consequently, defining criteria for grouping will always pose challenges, and each approach has strengths and limitations. Additionally, demographic features, such as age, gender, language, education, culture, and life experiences, introduce variability into the groups and results. In this thesis, I proposed two methods to mitigate this variability that could be used in future research. In Chapter 4, which involved a large online sample, we took great care to remove the effects of demographic features from our analysis by subjecting the scores to linear models with all potential confounding variables. Alternatively, in Chapter 5, where we worked with a smaller sample and conducted in-person testing, we were diligent during recruitment to ensure well-matched groups regarding age, gender, and professional experiences. I recommend that future research carefully considers the specific expertise or neurocognition they intend to investigate and use this to work towards defining their groups, ideally also examining the interactive effects of variables like age and gender on entrepreneurial thinking. Alternatively, research could follow a process-based entrepreneurship orientation, using individuals as their own controls. Using within-subject study designs and longitudinal studies, examining how neurocognitive changes develop over time and how best to foster them should be possible.

Future Neuroimaging Approaches in Entrepreneurs

Neuroimaging approaches in entrepreneurs are only just emerging, with the handful of work published to date reviewed and discussed in this thesis (Fisch, Franken and Thurik 2021; Nejati and Shahidi 2013; Ortiz-Terán, Turrero et al. 2013; Laureiro-Martínez et al. 2014; Lawrence et al. 2008; Halko et al. 2017; Lahti et al. 2019; S. Shane et al. 2020; Yang and Li 2017; Ooms et al. 2023). Three studies involved EEG, five used fMRI, and two employed neurocognitive testing only. Therefore, this is an exciting time for this field of research. This thesis provides additional empirical work using fMRI and neurocognitive testing, offering new theoretical insights and new methodological approaches to studying entrepreneurs. Our main recommendation is that the field continues progressing in this same vein. As we show here, and Ooms et al. (2023) demonstrates, a neuroscience approach should utilise and borrow the wealth of expertise already existing in neuroscience and apply these methods to entrepreneurs. As we proposed in Chapter 2, looking at entrepreneurship through a neuroscience lens is likely to provide the most novel insights and complement existing theories in entrepreneurship with scientifically valid findings. Therefore, future research could take inspiration from the cross-collaborative themes already identified: (1) impulsivity and risk-taking, (2) decision efficiency: exploration and uncertainty, (3) emotional judgment, (4) interpersonal trust and social cognition, (5) opportunity recognition and (6) creativity.

In this work, we have investigated verbal creativity in Chapter 5 and also piloted work on impulsivity and uncertainty in Chapter 4. This makes it clear that researchers can develop studies from neuroscience theories on such themes and phenomena and apply them to entrepreneurs, an approach we believe will provide neuroentrepreneurship with the most robust scientific rigour. We recommend that researchers looking to use neuroimaging techniques collaborate with institutions with the necessary resources and expertise to ensure the best results possible.

Expanding Findings in Verbal Creativity

In this thesis, we provide novel insights into understanding verbal creativity in the brain of entrepreneurs. I have discussed this in great depth earlier, so I only wish to highlight here the key points and future areas to investigate further. Notably, there seems to be an efficiency in the brain of entrepreneurs, depending on the context, to release constraints on semantic concepts by decreasing activity in the right MFG for unfamiliar word associations. This is linked to a complex interaction in which activity in the MFG increases for more familiar and less creative word associations, married with more deactivation of the DMN. While we have theorised what these findings could mean in the context of the broader literature on verbal creativity and the neural efficiency hypothesis, future work in the field should test the assumptions made here, further exploring the verbal reasoning differences we observed. Finally, as already discussed, seed-based FC analysis approaches for the task, and resting-state data within these regions could provide an additional understanding of the interactions between networks and regions involved in verbal creativity. However, newer dynamic methods already go beyond seed-based approaches and look at how the brain resting state networks (RSNs) fluctuates over time. For example, Leading Eigenvector Dynamics Analysis (LEiDA) would enable the extraction of three state-related measures: the probability of occurrence of a given brain state, its lifetime and the probability of switching from one state to another (Cahart et al. 2022; Cabral et al. 2017). Finally, tangents from this work could begin to analyse and explore how factors such as gender, education, language and neurodiversity interact with the neurocognitive phenomena involved in verbal creativity in entrepreneurs and others.

Trait vs State

In this work, we build a case for which creativity and, thus, disruptive thinking can be positioned as a 'state' in entrepreneurship. This is based on our findings and backed by prior neuroscience research and results in the entrepreneurship literature. Future research may explore other facets of entrepreneurial thinking as 'states'. For example, state uncertainty may also be explored from a computational and cognitive neuroscience perspective in future work (Zika 2023), or researchers could study the introceptive effects of the insula and precuneus together in attributions states (e.g. how one relates experience to oneself or external events) (Xue et al. 2010; Cabanis et al. 2013). This work could investigate how trait findings measured by self-report and state findings measured by experimental tasks and neuroimaging fluctuate within individuals or even develop and strengthen over time with interventions.

6.4.2 *Contributions to Entrepreneurial Practice and Education*

All the work in this PhD leads to one of the main interests in a scientific approach to entrepreneurship: can we find evidence of how entrepreneurial thinking develops?

From its inception, the overarching objective of this research project has been to leverage insights from neuroscience to inform practice, particularly in how entrepreneurship is taught. While the field is still in its early stages, with much left to validate and uncover about entrepreneurial thinking, I have always been committed to making this work practical and applicable. The question of whether entrepreneurial thinking can be cultivated is a central point of focus. I assert that entrepreneurial thinking is a learned competency and expertise; therefore, I believe it can be nurtured, trained, and fostered. In this final section of the discussion and of the PhD, I demonstrate how insights from the empirical work in this thesis have already been integrated into practice and can continue to shape practical applications. I present three cases in which I have personally been involved in research-informed training. This section is less grounded in research methods or educational pedagogy (although informed by my research and others) and more focused on sharing my experiences working at the intersection of research and practice. I hope that these insights can prove valuable and applicable in the real world and that they can inspire and demonstrate ways in which research findings can, in the future, contribute to the ongoing development of entrepreneurial thinking and education.

1. *Case 1: Research-Informed Frameworks: Data-Driven Approaches Shifted the Naming of the Seven Skills Taught at Entrepreneurship Institute.*

   First is a case in which the skills framework from the King's Entrepreneurship Institute evolved to incorporate findings from the research in Chapter 3. Based on 798 people participating in the study, our empirical results catalysed a shift in emphasis from *Resilience* to a more contemporary skill of *'Commit to Growth'*.

   In the UK, a 2017 report revealed 205 incubators and 163 accelerators for entrepreneurship (Bone, Allen and Haley 2017). A further report in 2019 suggested that 80 incubators exist in universities (*New report: Incubators and accelerators in the UK* n.d.). Although many university programs in the UK help teach and develop the skills or mindset to be an entrepreneur, there is no standard educational framework. Often, the set of skills to be taught and developed is decided upon using practice-based insight; there is no data-driven evaluation to see if this skill exists in real-life entrepreneurs. The King's Entrepreneurship Institute (EI) helps all King's College London students, staff, and alumni develop an entrepreneurial mindset. In 2019, the EI put forward the Seven Skills of an Entrepreneurial Mindset (*Learn Entrepreneurial Skills* n.d.); these skills were: Disrupt, Compel, Build a Team, Be Resilient, Think Lean, Validate, and Get it Done. This was developed based on practice-based insights and inspiration from the EntreComp framework, an EU-commissioned framework of entrepreneurial competencies (Bacigalupo et al. 2016). Practitioners in the EI wanted to condense such large frameworks down to essential underlying skills in entrepreneurship to harness and teach their communities, yet had no data available to base this reduction on. Therefore, they relied on their experience and practice-based insights in the field. To *Be Resilient* was defined by the EI as an ability to - Develop a rapid, thick-skinned and grounded "bounce-back-ability".

Chapter 3 in this thesis reduced a long list of the EntreComp competencies into a shorter set of underlying factors. The factor analysis revealed five key underlying competencies: Disruption, Growth, Resourcing, Communicating, and Planning. We compared and contrasted these empirical findings with the EI's 7-Skills framework, showing commonality in the competencies of disruption, communicating (compel/build teams) and resourcing/planning (think lean/get it done). However, while resilience was also shown in our empirical data, this category included an additional high loading from a survey question relating to adaptation, decisions in uncertainty and risk, and assessing strengths and weaknesses. This suggested that this competency is more than just 'bounce-back'; it also incorporates levels of self-awareness in determining one's strengths and weaknesses and in adapting based on setbacks. Therefore, to incorporate these new insights, *Resilience* was changed by the EI to the newly termed *'Commit to Growth'*.

This showcases an example of how evidence-based research can complement practice and validate accepted frameworks. By incorporating data-driven methods, the presumed entrepreneurial competencies were tested in an independent sample for the first time. The power of our factor analysis allowed a data-driven reduction technique to uncover what underlies longer lists of competencies. The benefits of a true researcher-practitioner collaboration ensure good quality and integrity of research and statistical methods applied. The limitation of this work, however, was the self-report nature of the questionnaire we used. The competencies tested are therefore limited by what people perceive about themselves. Moreover, although growth scores increased with experience, we did not find this difference to be statistically significant, suggesting different degrees of variability in growth within those who have and have not found a business. This may suggest it is not a competency unique or necessary to entrepreneurs, such as disruptive thinking and resourcing were found to be. In the future, these assessments should be repeated in larger samples to validate the findings and in the students undergoing entrepreneurial programs to assess their development. In addition, other neuroscience techniques, such as neuroimaging, could also be used to delve deeper into this topic.

2. *Case 2: Research-Informed Feedback: Individual Research Outcome Reports Informed Workshops at Cambridge University for Researchers to Become Entrepreneurs and a Webinar with the Henry Royce Institute.*

Second is a case in which the report people obtained from participating in the online study in 4 became a valuable tool for self-reflection and stimulated regular workshops at Cambridge University.

In the UK, spin-outs from university research are becoming increasingly popular. EnterpriseTECH is an extracurricular program at Cambridge Judge Entrepreneurship Centre (CJEC) that gives PhD students, post-docs, and researchers real-world experience in the startup and commercialisation world, aiming to turn *"researcher to entrepreneur"* (*EnterpriseTECH* n.d.). The program involves a lecture, workshop-intensive series, and collaboration with Cambridge innovators to assess a new product's commercial feasibility. It focuses on the 'Person' at the centre of entrepreneurship. For the last three years, I have been a guest lecturer and mentor in this program and have provided in-person lectures on the entrepreneurial brain, informed by results in Chapter 4. I then translated this in the form of a webinar that I delivered for the Henry Royce Institute for a cohort of material scientists. PhD students, post-docs, and researchers represent a unique and fruitful population to train to be entrepreneurial, as they already have a high degree of openness and intellect. Most of the workshop was about helping them realise this and breaking down entrepreneurship stereotypes.

At the start of these talks, the cohort was informally invited to come up and share their competency, personality and cognitive results from the Entrepreneurial Brain Challenge described in 4 (as every participant receives a personalised report on completing the online study). Consistent with the literature researching scientists, many presented profiles that contrasted to those of entrepreneurs, especially with high conscientiousness (Ramesh 2020). The nature of science trains people to be conscientious in their approach to work, thinking carefully and planning hypotheses and experiments. Yet openness was also high, representing the intellectual curiosity of being a scientist/researcher. A researcher's openness, intellect, creativity, and expert knowledge would also make them brilliant entrepreneurs. Yet carefulness may sometimes prevent scientists from taking that step into the uncertain territory of entrepreneurship and could limit the disruptive thinking and adaptive approach to resourcing needed. During my sessions, I used this explanation to help set the scene for the barriers they might feel in making that initial leap into entrepreneurship. Yet, it also helps them realise the potential everyone has to enter 'states' of creativity and entrepreneurial thinking. The talk I give is guided by explanations of creativity in the brain and the loosening of constraints that may be required on a neurocognitive level; it also gets them to engage in thought experiments that prime creativity by linking distant concepts.

These workshops have mostly been developed iteratively with my research in order to best determine which type of insights may prove most useful. Having participants partake in personality and cognitive assessments, then contrasting this to profiles of entrepreneurs allowed a more personalised exploration of individual strengths and weaknesses. Usually, in extracurricular programs, individuals have no idea or means to test their potential and competence as entrepreneurs. This demonstrates just one simple example of how utilising insights from research helped create an interactive learning experience.

3. *Case 3: Research-informed workshops: theory from this thesis informed creativity workshops for school-age children and undergraduate groups.*

Finally, I discuss a case where the insights and theory gained through studying creativity in the brain were utilised to design workshops to inspire school-aged children and undergraduate students to think disruptively.

In 2022,2023 and 2024, I conducted workshops with groups of 16-18-year-olds who participated in the Institute of Psychiatry, Psychology and Neuroscience (IoPPN)'s Youth Awards (*IoPPN Youth Awards* n.d.). I also delivered these same workshops to third year undergraduate students from the BSc Neuroscience and Psychology at KCL. The workshops have been really popular with the students and I have received excellent feedback about them from both the participants themselves and from academics. The workshops had four main objectives: 1) introduce simple explanations of creativity in the brain, 2) encourage self-reflection on creative abilities, 3) engage in activities that foster a creative state, and 4) use this creative state to tackle a real-world problem that participants are passionate about. The aim was to help individuals recognise their inherent creative capabilities and the importance of harnessing creativity for original problem-solving.

Psychological strategies from the past have aimed to boost state creativity, such as taking breaks or engaging in relatively easy tasks that allow the mind to wander (Baird et al. 2012). Additional strategies include priming creativity with shorter creative tasks (Beaty 2020). Therefore, these workshops incorporated a combination of these approaches with the following structure:

a) **Background:** Participants were first educated about the role of creativity in the brain and the significance of considering it as a 'state'.

b) **Baseline:** Participants performed the classic Alternative Uses Test (AUT), a standard verbal creativity task to establish a creative baseline (Guilford 1967). They then assessed their originality, relevance, fluency, and flexibility in this task, gaining a personal benchmark of their creativity.

c) **Warm-up:** Participants engaged in a game designed to prime creative processes, known as the 'what-if' task. Taken from the book by Hart (2018), this task aimed to stimulate daydreaming and imagination, with participants sharing their ideas within the group. The 'what-if' activity enhanced participants' ability to generate and articulate creative concepts while creating a safe space for creativity to flourish. I adapted this task to naturally guide participants towards topics they felt passionate about or the world's problems they aimed to address, prompting questions such as *"What if you could make up any rule that everyone in the world had to follow, what would it be?"*.

d) **Unconventional Associations:** A simple word association game followed, starting with a picture of a cat (or any other image). Participants were instructed to write down three words associated with the image, add three more, and finally, another set of three words. This exercise encouraged divergent thinking (Acar and Runco 2019), resulting in each participant producing nine words from the original picture.

e) **Solving Real-World Problems:** The final challenge involved devising a solution to a real-world problem, typically inspired by the 'what-if' game. Participants can also be prompted by UN sustainability goals and encouraged to focus on one of these themes if they struggle to develop their own 'pain point' (*UN Sustainability Goals* n.d.). What makes this task particularly interesting is that the solution they have to come up with must originate from one of the nine words they previously generated during unconventional associations. However, before beginning this, they were instructed to go outside for a 5-minute walk (Oppezzo and Schwartz 2014). Participants then returned and worked on their ideas individually or in groups for 15 minutes. At the end of the session, they pitched their proposed solutions to the group, which often took the form of a social enterprise or business idea.

f) **Reflection:** To conclude the workshop, participants reflected on their self-perceived creativity and its importance for their future careers.

This workshop structure allowed participants to explore their creative potential while addressing real-world issues and considering the significance of creativity in their lives. I blended insights from neuroscience with tasks used in creativity research and educational practice. I recommend that the natural use of a neuroscience understanding be to 'inform' practice in such a way. However, this may adapt and evolve as new insights come about. Of interest would be to test the efficacy of these interventions on creative thinking and entrepreneurial intentions (Krueger Jr, Reilly and Carsrud 2000). In such a way, we may, in the future, be able to incorporate neuroscience theory into how entrepreneurship is taught and encouraged (A. Penaluna and K. Penaluna 2021).

6.5 CONCLUSION

An assumption sometimes made when people hear about research in the neuroscience of entrepreneurship is that it will aim to uncover hardwired aspects of the brain that make someone entrepreneurial. Yet, this viewpoint is overly simplistic and misguided because entrepreneurship is not a biological phenomenon but a social construct. It is a label we assign to specific individuals in society who start a business or it is an identity that some people hold about themselves. Entrepreneurship encompasses skills, behaviours, competencies, and a mindset that empowers individuals to think creatively and navigate uncertainty. The brain states underlying such thinking are not exclusive to entrepreneurs; they exist in all humans, originating from our evolutionary history and our enduring capacity to create something never previously imagined, initially for survival and later for increased productivity and efficiency. The quest to identify 'unique' biologically-driven aspects of entrepreneurs that set them apart from everyone else is fundamentally flawed. At their core, entrepreneurs are human beings, and society has thrived on entrepreneurial thinking, challenging established norms and generating new, more efficient ideas and processes. I maintain that this capacity resides within all of us and likely always has. It is an intrinsic facet of human intelligence, promoted or diminished by the environment.

Perhaps what defines an entrepreneurial neurocognitive profile is the ease in loosening one's grip on semantic norms, permitting free-flowing creativity to generate seemingly *absurd* ideas. This could be cultivated through experience and in environments encouraging individuals to think disruptively. It is crucial to acknowledge that any difference between those who embark on an entrepreneurial journey and those who don't is highly likely to be the result of a complex interplay of traits, life and educational experiences, knowledge, skills, environment, and social dynamics, including power. This thesis offers some insights into what this intricate combination might involve. However, I do not intend to present this as the only 'formula' for becoming an entrepreneur. Nor do I suggest that those who do not possess such a profile are incapable of entrepreneurship. Instead, a more constructive approach would be to inquire, "Given that trend A is observed in entrepreneurs who engage in behaviour and actions C, how can person B cultivate a mindset that leads them to engage in C?"

This is not to say that we will never uncover measurable differences in how an experienced entrepreneur's brain functions or responds to stimuli. They are, after all, the people who have demonstrated the most experience in this way of thinking. Evidence in this thesis shows functional differences in the brains of entrepreneurs during verbal creativity. However, I contend a view that these are hardwired inherited differences. These differences are task and context-specific and may be attributed to practice-based effects. My view is that while we can correlate certain traits and neurocognitive profiles with the statistical likelihood of being an entrepreneur, the results are most beneficial in helping individuals comprehend where they stand and recognise the barriers that hinder their engagement in entrepreneurial thinking. I advocate for a process and state-based approach to entrepreneurship that complements the wealth of existing entrepreneurial theories. It avoids the trap of descending into pseudoscience, endeavouring to pinpoint the "brain region underlying entrepreneurial thinking" or the search for a secret brain formula to become an entrepreneur. While such sensationalist claims may grab headlines, they do not align with the reality that practitioners know about entrepreneurship, nor would they gain acceptance in the neuroscientific community.

Entrepreneurs come from diverse backgrounds, cultures, personalities, and abilities and have demonstrated success in numerous ways despite inter-individual differences. Our ability to reshape language into novel concepts that were previously unimaginable into something comprehensible to others is precisely what entrepreneurs do. This analogical reasoning and semantic creativity enabled participants in my functional neuroimaging study to conjure concepts like seats made from grapefruit skin. In real-world scenarios, this thinking allows individuals to envision innovation, such as a switchboard-like device that fits in their hands or wristband that can monitor heart rate and sleep. This notion is encapsulated by the quote that opens this chapter: "If at first the idea is not absurd, then there will be no hope for it" (Albert Einstein). Let his quote motivate us for future neuroentrepreneurship research.

6.6 References

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