The Effects of Neurological Damage on Counterfactual Thinking, Regret, and Decision Making

by

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Abstract

This thesis investigates counterfactual thinking and counterfactually mediated emotions (CMEs) by studying brain-damaged patients and healthy adults. In 5 experiments neurologically damaged patients' counterfactual reasoning, decision making (DM), and experience of CME was explored. 17 patients, with varying lesion sites resulting from a stroke, (7 female) aged 31 to 84 (*M* = 64.9 years) and 17 controls (12 female) aged 28 to 74 (*M* = 59 years) participated. There were three aims: to establish if regret is experienced in brain-damaged individuals; to explore the component processes of CMEs and widen the search for the brain areas that supports these; to conduct research that points to how the experience of regret impacts on future DM and underpins adaptive behavioural change. Through exploring the link between regret and adaptive choice switching, investigating counterfactual reasoning abilities, CME responses, emotional responses to The Regret Gambling Task (RGT), and responses in a task designed to measure risk taking, this project sheds new light on how neurological damage affects counterfactual reasoning, emotions, and DM. In addition, two experiments were conducted with undergraduate students to explore whether CMEs are produced slowly, through deliberative processes, or quickly and effortlessly. Results were interpreted as evidence for fast and effortless CME production.

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Abbreviations

ACC: Anterior cingulate cortex

APFC: Anterior prefrontal cortex

AS: Asperger syndrome

CFT: Counterfactual thinking

CIT: Counterfactual inference test

CME: Counterfactually mediated emotions

DACC: Dorsal anterior cingulate cortex

DLPFC: Dorsal lateral prefrontal cortex

DM: Decision making

fMRI: Functional magnetic resonance imaging

HFA: High-functioning autism

IOFC: Inferior orbitofrontal cortex

IPFC: Inferior prefrontal cortex

IPL: Inferior parietal lobe

LOFC: Lateral orbitofrontal cortex

MS: Multiple sclerosis

OFC: Orbitofrontal cortex

PFC: Prefrontal cortex

PMFC: Posterior medial frontal cortex

RGT: Regret Gambling Task

ToM: Theory of mind

TPJ: Temporoparietal junction

VBM: Voxel-based morphometric

WM: Working memory

MS: Multiple sclerosis

Chapter 1

General Introduction

1.1 What is Counterfactual Thinking?

Counterfactual thoughts are conceptions of what might have been; an alternative world (Epstude & Roese, 2008). For example, if a student fails an exam they might think 'if I had revised more, I would not have failed'. This reflection on previous events is thought to be of evolutionary value, we experience counterfactually mediated emotions (CMEs) such as regret so we can learn from our mistakes (Epstude & Roese, 2008). Thus, next time the student has an exam they may revise more in order to not fail a second time, avoiding the negative emotions that were associated with the previous exam.

Inference is a key aspect of producing a counterfactual as it is necessary to infer or predict how the outcome would have been different if alterative actions had been taken. The produced inference must meet several criteria to differentiate it from imagination or fantasy. Firstly, the counterfactual world must closely mirror the actual world. The imagined alteration in behaviour must be tied to a specific situation and fit with previous knowledge the individual has about the situation, thus limiting the number of changes to the real world (Dehghani *et al.,* 2012). Minimising the number of changes between the real and alternative world allows for the counterfactual to be realistic; an outcome that could have genuinely occurred (Petrocelli *et al.,* 2011). In order for a thought to be considered a counterfactual- and not a fantasy- it must not violate the laws of nature (Dehghani *et al.,* 2012).

Furthermore, counterfactual thoughts are produced predominantly in situations where the individual had a high level of personal control over the outcome (Rips & Edwards, 2013). For example, when contemplating why I failed an exam, I would produce an alternative world where I revised more and thus received a higher grade. I do not, generally, think that I would have not failed the exam if I had developed the ability to read minds and copied the person next to me.

In a recent review article Van Hoek, Watson and Barbey (2015) describe counterfactual reasoning through a three stage model; activation, inference, and adaption/learning. The model describes the process in which counterfactuals are produced. Using the example from above, when a student receives a grade following a recent exam, memories from the exam are activated (such as the specific questions) as well as a mental simulation of the event itself (the student's answers to the questions). As these memories are accessed, activation spreads, triggering further mental simulations of relevant information (such as previous exams) thus allowing the individual to compare and infer how the current scenario could have been different; a better grade could have been achieved through more revision. This is known as the counterfactual. Through comparing the actual outcome to the counterfactual, the interpretation of factual events is influenced (failure due to lack of preparation or alternatively failure due to missing important lectures because of other commitments). This process facilitates adaptive learning that alters behaviour in future similar circumstances (revising more for an exam). The authors build on The Mental Model Theory of counterfactual thought (Byrne; 2002, 2007) in which counterfactual thinking (CFT) is the tool that we use to search for possible alterative outcomes among hypothetical worlds that run parallel to the actual world. In addition to this, The Structured Event Complex Theory suggests that regions in the prefrontal cortex (PFC) support CFT through representing motivations and intentions, enabling behavioural change (Barbey *et al.,* 2009).

1.2 What are Counterfactually Mediated Emotions?

Over the past decade much research has focused on the concept that successful decision making (DM) and behavioural modification is influenced, not only by cognitive processes, but by emotions (Kirman *et al.*, 2010; Mellers, 2000). One focus of this research has been the concept that CMEs, specifically regret, have a key role to play in understanding DM. However, it is unclear how the experience of regret directly, or indirectly, effects behavioural change (Connolly & Zeelenberg, 2002; Roese *et al.*, 2007; Zeelenberg & Pieters, 2007). In order to experience the feeling of regret and therefore undertake behavioural change, one must first engage in CFT (O'Connor, McCormack & Feeney, 2012).

Regret has been defined by Van Dijk and Zeelenberg (2005, pg152) as "A negative emotion that we experience when we realise or imagine that our present situation would have been better, if we only had decided differently." This is an example of a downward counterfactual. Whereas, relief originates from the comparison of the present situation to a more negative hypothetical (Coricelli & Rustichini, 2010). Relief is an example of a downward counterfactual. In this scenario the individual would feel better about the choices they made through avoiding a more negative outcome (Roese, 1994).

Regret and disappointment are both emotions that are experienced as a result of an undesirable outcome and a product of CFT where the actual outcome is compared with a hypothetical outcome (Zeelenberg, van Dijk, & Manstead, 1998). However, there is an important distinction between the two emotions. Zeelenberg *et al.* (1998) suggest that regret is experienced after an individual makes a decision that ends in a negative result. Importantly the individual feels responsibility for the outcome. Whereas disappointment is caused by more general counterfactual thought after a situational change. The individual does not feel personally responsible for a negative outcome. Throughout this project I will focus on the experience of regret and not that of disappointment because regret, over disappointment, is more likely to result in behavioural change (Zeelenberg *et al*., 1998) due to the more intense feeling of sadness (Camille *et al.,* 2004).

Although the majority of research on successful DM focuses on regret, and its counterpart relief, it is important to note that there are multiple emotions that arise from counterfactual thinking. The experience of shame and guilt are also deemed CMEs. Shame arises after thoughts that manipulate an individual's perception of self; 'If only I was fitter, I could have won that game'). Guilt arises after thoughts that manipulate an individual's behaviour; 'If only I hadn't forgotten my friend's birthday, she would be not upset' (Niedenthal, Tangney, and Gavanski, 1994). Michl *et al*. (2014) investigated the neuroanatomy that supports shame and guilt. The authors found a shared network for the emotions in the following areas: anterior cingulate cortex (ACC), parahippocampal gyrus, fusiform gyrus and medial temporal gyrus. Activation in the medial and inferior frontal gyrus was found during shame conditions only and activation in the amygdala and insula was observed in guilt conditions only. The ACC, medial temporal gyrus, inferior frontal gyrus, medial frontal gyrus, amygdala and insula are all implicated in regret also.

Research investigating the neuroanatomy that supports CFT has shown that there are key brain regions that support CMEs and its component processes. I will discuss the relevant research and the regions that support CFT and CMEs later in the introduction.

1.3 Project Justification

The aim of this PhD project was to investigate CFT, regret, and DM in neurologically impaired patients. Recent research conducted with neurologically impaired patients has suggested that particular brain areas are implicated in regret (e.g. Camille *et al.*, 2004, Canessa *et al.*, 2009; Clausi *et al.*, 2015). Camille *et al.* (2004) in particular reported a subgroup of patients who do not seem to experience regret or the behavioural modification (after losing) that non brain-damaged individuals demonstrate.

The neuroscience literature focusses on the experience of CMEs (mainly regret). However, the experience of regret is dependent on CFT; thoughts about what might have been and CFT is a complex higher cognitive process that develops gradually (e.g. Beck, Riggs, & Burns, 2011). In particular, individuals must be able to hold multiple possible worlds in mind and make comparisons between them. To gain a full understanding of the neurological processes involved in CFT and DM, a project must explore the component processes of CMEs and widen the search for the brain areas that support these.

My focus for this project will be on the experience of regret. Classic models of regret and consequent DM traditionally state that individuals anticipate potential regret as a consequence of hypothetical actions and act in a manner which will avoid this regret (Loomes & Sugden, 1987). In line with this assumption, research has shown that individuals anticipate regret as a consequence of their actions and make choices in an attempt to minimise the experience of regret (Zeelenberg, 1999; Mellers *et al.*, 1999). As previously described, Camille *et al.* (2004) showed that patients with orbitofrontal cortex (OFC) lesions initially do not experience regret in a simple gambling task and, in addition, the same patients do not become regret averse over time. However, it is unclear if the experience of regret itself has consequences on behaviour independently of anticipated regret. Their interpretation is that OFC patients fail to report and anticipate regret.

Evidence has shown that the experience of regret effects behavioural decisions in an economic context such as negotiation and bidding (Creyer & Ross, 1999). Although Raeva *et al.* (2011) have claimed that the experience of regret itself is not necessary for behavioural modification and adaptive learning. Overall, there is limited experimental research that focuses on the behavioural consequences of regret and not on the experience of anticipated regret (for review, see Zeelenberg & Pieters, 2007).

1.4 Project Aims

There are three general aims of this research. First, to explore the component processes of CMEs, namely regret, and widen the search for the brain areas that support these. Second, to establish if regret or its alleged component processes are experienced in brain-damaged individuals. Third, to investigate, in brain injured patients, how the experience of regret directly impacts future DM and underpins adaptive behavioural change.

In order to explore the component processes of CMEs (Aim 1) it is essential to break down the processes of DM. One way to do this is to better understand the processes involved in the experience of regret and how CMEs are generated in healthy adults. This will be done by investigating whether experiencing regret is an effortful process, or whether its generation is fast and effortless.

It is important to also establish if some patients are unable to experience regret or its alleged component processes (Aim 2). The developmental literature suggests that CFT arises before the experience of regret. I will investigate if this trend is present within the patient group who participate in my research. I will devise an experiment that examines participants' ability to answer counterfactual questions without an emotional element and adapt developmental tasks that require an emotional response to winning and losing. In line with the developmental pattern, patients may not be able to experience regret because they cannot engage in counterfactual reasoning. On the other hand, some patients may have problems in thinking counterfactually, but not experience problems reporting regret. This would suggest that the developmental pattern is not preserved in the patient population.

Developmental work has linked the experience of regret with the ability to engage in future adaptive choice switching (ACS) (O'Connor, McCormack & Feeney, 2014). ACS is the process where individuals modified their behaviour in order to increase their gains (O'Connor, McCormack & Feeney, 2014). However, this relationship has not been investigated with a patient population (Aim 3). It is possible that some patients cannot report regret but their prior experiences still influence their future DM and allow for adaptive future DM. Therefore one aim of this project is to investigate if, when regret is preserved in brain-damaged patients, this experience correlates with behavioural modification, as in children.

The experience of regret has been linked to risky DM (RDM), in that counterfactual information regarding a missed opportunity elicits regret and as a result increases subsequent risk taking (Zeelenberg *et al.,* 1996). I will investigate RDM, an indirect measure of counterfactual consideration, in order to further investigate the component processes of CMEs.

1.5 Research Strategy

Various neurological areas have been shown to be involved in counterfactual reasoning, CME production, and DM; the OFC, middle temporal gyrus, ACC, hippocampus (Camille *et al.*, 2004; Coricelli *et al.*, 2005), the ventral medial PFC (VMPFC), anterior insula (Canessa *et al.*, Chua *et al*., 2009; 2009; Nicolle *et al.*, 2011) and amygdala (Berntson *et al.*, 2011).

These highlighted regions have been established as important for CFT and CMEs. However, to gain a full understanding of the neurological processes involved in CFT (including CMEs) and DM, this project will explore the component processes of CMEs by developing a broad set of tasks while widening the search for the brain areas that support these abilities. I hope to find further brain regions, than those highlighted above, which have previously not been cited as supporting CFT and CME production. Through undertaking this research I am not trying to make methodological changes to how neuropsychological research is conducted, I am merely attempting to find further brain regions that have previously not been cited as important

In order to create a battery of experiments that will provide a comprehensive overview of each patient's counterfactual reasoning ability, experience of CMEs, and ability to make decisions, it is necessary to review the developmental literature. Developmental research is relevant to this project because developmental studies have systematically investigated children's CFT and CMEs. Results from these investigations will allow us to gain a unique insight into the processes and systems that develop gradually, resulting in the ability to think counterfactually as adult. Developmental methods have been adapted for various tasks in the current project because many of the original tasks aimed to identify specific stages in CFT (such as Beck, Riggs & Burns, 2011). Additionally, tasks designed for children minimise demands on executive functioning (EF) and language which need to be considered when working with neuropsychological patients.

I will now review the neurological areas that possibly support CFT, CMEs and DM. I will then discuss previous work on these topics with patients with neurological damage, degenerative conditions, mental health conditions, and healthy controls to highlight the importance of conducting further research with a group of neurologically injured patients with a wide range of damage.

I will then review the developmental literature with the goal of explaining the developmental processes that lead up to an adult like understanding of CFT, CMEs and DM. In addition, I will review studies where I have adapted methodological approaches to tackle the aims of my project.

1.6 Neuroanatomy that supports Counterfactual Thinking and Counterfactual Mediated Emotions

1.6.1 Overview

It is important to understand basic neuroanatomy and how commonly cited brain regions in counterfactual reasoning and DM models are connected through neuro circuitry. If damage occurs in a neural pathway this could result in an inability to complete a task that relies on a specific brain region which could be unaffected by the brain injury. Thus, it is necessary to understand how different brain regions work together to produce a working system.

Research conducted with patients has shown that there are key brain areas responsible for regret as a CME. The OFC, ACC, and anterior hippocampus have been implicated in patient and fMRI (Functional Magnetic Resonance Imaging) studies (Camille *et al.*, 2004; Coricelli *et al.*, 2005). The VMPFC has also been implicated as another key region (Canessa *et al.*, 2009; Nicolle *et al.*, 2011). The amygdala has also been cited as an important area for emotional processing (see Phelps & LeDoux, 2005 for a review).

The PFC is comprised of three regions: the OFC, ACC, and dorsolateral PFC (DLPFC) (Crews & Boettiger, 2009). The OFC is primarily linked with DM that is based upon emotions and stimulus–response. However, due to cortico–cortical connections between the DLPFC and the ACC, these regions also facilitate successful DM (Barbas, 2000). It has been suggested that the ACC is involved in complex DM in conjunction with the OFC, DLPFC, and insula cortex (Kuhnen & Knutson, 2005).

The OFC has multiple limbic connections including the amygdala, hippocampus, insula, medial temporal cortices, entorhinal cortex and para-hippocampal gyrus (Barbas, 2007; Zald & Rauch, 2006). The ACC can be divided into dorsal and ventral components. The ventral ACC is connected with the amygdala, nucleus accumbens, hypothalamus, and anterior insula (Allman, 2001), whereas the dorsal ACC is connected to the lateral thalamic nucleus, caudate nucleus, OFC, lateral intraparietal cortex, and precuneus (Pearson *et al.,* 2011). The DLPFC is connected to the posterior parietal cortex, inferior temporal cortex, superior temporal polysensory areas, ACC, retrosplenial cortex, the para-hippocampal gyrus, dorsal nucleus, caudate nucleus, and thalamus (Osaka, Logie & D'Esposito, 2007).

Rosenbloom and Schmahman (2012) review the role of connectivity in DM and suggested that the above regions interact with each other and also subcortical structures: the limbic system, striatum, thalamus, and cerebellum all of which influence DM (see Figure 1.0 for visual representation). The authors describe a model of DM that defines a cortical area by its neural connections. Thus, a lesion affecting any of cortical or subcortical areas within the DM network might disrupt the DM process.

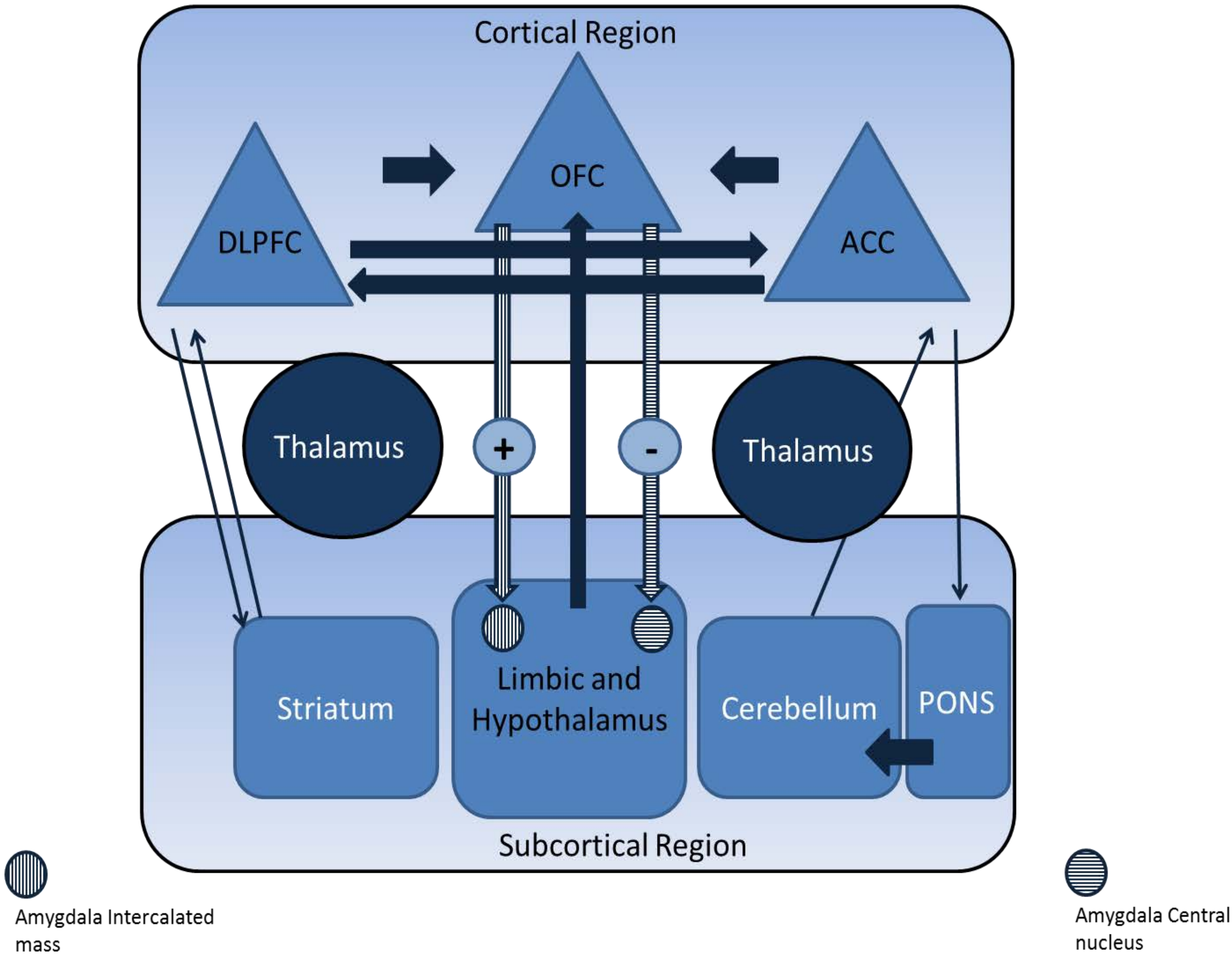


Figure 1.0: Representation of Rosenbloom and Schmahman's (2012) model of the DM Network, demonstrating connections between neocortical and subcortical regions.

1.6.2 Neural Networks in Counterfactual Thinking

Recently, Van Hoek *et al.* (2015) reviewed the neural networks that support CFT, highlighting three systems: the mental simulation network, the cognitive control network and the reward network. The authors quote Barrett and Satpute (2013 p4) when describing counterfactual reasoning; ''networks that underlie domain general functions that cut across different psychological domains''. The notion that three networks work together in combination with one another to allow for counterfactual thought, including CMEs, implies that there is no single counterfactual network or system. In contrast, it is suggested that the counterfactual thoughts and emotions that are produced are dependent on the information that is processed at that time, activating the necessary brain regions associated with each of the three networks.

The first neural network that supports CFT is the mental simulation network. This network is important during the production of counterfactual thoughts because one must hypothetically ‘undo’ the current state of reality and create an alternative reality where a different course of action was taken (Van Hoek *et al.,* 2015). The authors claim that the mental simulation network activates regions in the medial frontal temporal lobes, the posterior cingulate cortex, precuneus, and the lateral parietal and temporal lobes, when engaging in self projection and autobiographical memory retrieval (Buckner & Carroll, 2007). This suggests that the network is utilised when processing an observed outcome and imagining alternative outcomes; counterfactual thoughts. The hippocampus is crucial for mental simulation, as it provides information based on past experiences and memories. This information is used to fit novel situations through activation in the medial PFC.

The second neural network that Van Hoek (2015) discusses is the cognitive control network. This network is split into two; the fronto-parietal network and the cingulo-opercular network. It is suggested that the two networks are responsible for the ability to swap between the current world and the hypothetical world, for the ability to mentally transform the information on reality and the counterfactual to produce a counterfactual inference, and lastly the observed behavioural modification as a result of counterfactual thought. It is likely that inhibition underpins the ability to ignore information about the real world in order to speculate about what didn't happen.

The fronto-parietal control network is made up of the lateral PFC, middle cingulate cortex, inferior parietal lobe, and precuneus. This network facilitates the integration of several pieces of information and regulates thoughts (Chein & Schneider, 2009). Henderson and Norris (2013) demonstrate that the DLPFC was strongly activated in goal orientated circumstances, encoding how desirable an outcome is to the individual. The DLPFC was activated more strongly when participants could have won more than they actually did during a gambling task. Evidence to support the difference between the mental simulation network and the goal orientated cognitive control network comes from Gomez Beldarin *et al.* (2005) who report significantly fewer spontaneous counterfactuals produced by OFC patients during a free recall task. Furthermore, the patient's ability to produce hypothetical scenarios was unimpaired, highlighting the difference in neural networks.

The second section of the cognitive control network is the cingulo-opercular network which includes the dorsal ACC, the posterior medial frontal cortex, anterior insula, frontal operculum (posterior LOFC), and the anterior PFC. The system is considered to be associated with maintaining goal orientated behaviour and monitoring behaviour. Counterfactual thoughts are goal orientated due to their adaptive purpose to regulate and modify behaviour (Epstude & Roese, 2008).

The final neural network to discuss is the emotion and value processing network that is associated with affective learning (Roy *et al.,* 2012). The brain regions highlighted as comprising the emotion and value processing network are the VMPFC (including the medial OFC), amygdala, basal ganglia, inferior OFC, and inferior PFC. The amygdala is cited as being the most frequently linked to emotional and evaluative judgments (Berntson *et al.*, 2011) chiefly when processing negative stimuli.

1.6.3 Counterfactual Thinking and Counterfactual Mediated Emotions in Healthy Participants

Canessa *et al.* (2009) used a gambling task in combination with fMRI in order to determine if the same neural networks are active when not only experiencing regret for oneself, but also when imagining someone else's regret. The VMPFC, ACC, and hippocampus were active in both conditions. It is a possibility that this identical activation is facilitated by a mirror system which enables a theory of mind (ToM) like state. This evidence implies that if the neural network that supports CFT is damaged, patients who are not able to engage in CFT and experience CFE, would also not be able to understand another individual's CFE.

Research by Van Hoeck *et al*. (2012) has directly investigated the link between episodic memory and CFT. The brain network that supports episodic memory has been implicated in more general functioning (e.g. imagining oneself in an alternative perceptive or time) (Spreng *et al.,* 2008). Therefore the authors aimed to investigate if this neural network is activated during CFT. fMRI was used to compare activity when participants imagined an upward counterfactual compared to re-living a past negative event and envisaging positive future events. Neural activity for episodic memories and counterfactual production was overlapping; hippocampal area, temporal lobes, midline, and lateral parietal lobes were activated. Although CFT was shown to recruit additional areas, such as the bilateral inferior parietal lobe and posterior medial frontal cortex, Van Hoeck *et al.*'s (2012) finding demonstrates that the ToM network and the counterfactual network have commonalities which would go some way to explaining the identical activation observed in Canessa *et al.'s* (2009) gambling task.

Contrary to the belief that regret is required for behaviour modification (Epstude & Roese, 2008; O'Connor, McCormack & Feeney, 2014), research by Raeva, Dijk and Zeelenberg (2011) investigated the possibility that experiencing regret is not critical for successful DM. Healthy participants were presented with two DM exercises. The initial task was designed so that participants either would or would not experience regret. This was achieved by manipulating the amount of feedback participants were given after they made a choice. The subsequent task required the matching of two monetary outcomes in concordance with attractiveness. The outcomes were matched in attractiveness by manipulating the prize amounts and the probability of the participant winning the prize. The higher monetary reward had a lower probability of winning. Participants were asked to state the amount of money they would accept if the probability of winning was 100%, thus matching the attractiveness of the two options. It was found that regardless of the experience of regret in the initial task, DM was not significantly different. Therefore, the authors argue that experiencing regret is not necessary for behavioural modification. The authors highlight the role of comparing the present situation to 'what might have been'. It is suggested that due to this comparison of the known and the hypothetical, a comparative mind-set is created which may 'carry-over' to future decisions. Therefore, the experience of regret itself is not the key factor in future DM. This evidence implies that something other than regret is responsible for behavioural change; it is possible that CFT alone can direct goal orientated behaviour, without experiencing CMEs.

1.6.4 Counterfactual Thinking and Counterfactually Mediated Emotions in Acquired Brain Damage

In order to establish a fully comprehensive understanding of CFT and the role regret plays in DM, a broad search for supporting brain areas is necessary. Camille *et al.* (2004) designed the Regret Gambling Task (RGT) for patients with OFC lesions and healthy age-matched controls. The task involved two wheels of fortune, both offering different amounts of points indicated by sections of the wheel (-50, 50, -200, or 200). An arrow was pictured in the centre of both wheels. Participants chose one of the two wheels to gamble on. The arrow on the chosen wheel spun and landed on one of the two sections on the wheel, participants won the number of points associated with that section. The chances of winning the points were manipulated by changing the percentage of each wheel which corresponded with its allocated number of points; for example during some trials there was a large chance (a greater percentage of the wheel) of losing a low number of points and only a small chance (a smaller percentage of the wheel) of winning a high number of points. During half of the trials participants received information on the outcome of their wheel only (partial feedback). On the other half of trials participants received information on the outcome of the unchosen wheel also (complete feedback). Regret can be induced during the complete feedback condition as participants are provided with information about the outcome of the unchosen wheel which provides a counterfactual alternative; participants are now aware of the actual outcome and the other possible outcome that could have occurred, had they made a different choice of wheel. Disappointment is induced in partial feedback trials as the desired result (the higher number of points) is not obtained yet the participant had no control over the outcome. Both patients and controls reported feeling happier after winning and sadder after losing. Controls reported regret in high-risk complete feedback trials. This negative emotional response (regret), in controls, was felt more keenly in complete feedback conditions rather than partial feedback conditions. This is an example of the amplification effect as the emotional response was more extreme during regret trials (complete feedback) compared to disappointment trials (partial feedback). The authors found that the amplification effect was reversed in patients with OFC lesions; the difference in mean emotional ratings when then obtained outcome was 50 or -50 and the unobtained outcome was 200 or -200 was less in the complete feedback condition compared to the partial feedback condition. Thus, in contrast to controls, regret was not reported over disappointment.

Coricelli *et al.* (2005) highlighted differing neural responses to regret through using Camille et *al.'s* (2004) RGT. Activity in the medial OFC, ACC, and hippocampus increased proportionally with the experience of regret. While activity within medial OFC and amygdala represented participants' tendency to become regret averse as the experiment continued. This activation also occurred prior to participants making a choice between the two gambles; suggesting that the same neural network is recruited for the experience of regret and also regret anticipation.

Levens *et al.* (2014) also used the RGT to compare the experience of regret in VMPFC and lateral orbital frontal cortex (LOFC) patients. It was found that VMPFC patients made financially worse choices, in comparison to controls, yet reported regret after the counterfactual was revealed. Whereas, LOFC patients made financially better choices, in comparison to VMPFC patients, yet did not report regret post-counterfactual. The authors suggest that the VMPFC is recruited when choices and anticipated emotions are considered and consequently is involved in guiding future DM. The LOFC is thought to be linked with experiencing regret after a choice is made which is turn is associated with signalling that behavioural modification is required. These findings point to the distinct functions of the different brain regions and their involvement in DM and emotional responses and explain the differing activation in Coricelli *et al.*'s (2005) study.

In more recent years the search for brain regions that support CFT and regret has expanded. The cerebellum is not traditionally cited as a key area when considering CMEs, although the area has been implicated in DM (Guggisberg *et al.*, 2008; Rosenbloom *et al.,* 2012). Clausi *et al.* (2015) showed that patients with cerebella lesions were indeed able to make choices that minimise regret, but were impaired in evaluating the feeling of regret subjectively. The authors used the RGT (see Camille *et al.*, 2004). In addition to this, the counterfactual inference test (CIT) was administered. During the CIT participants are presented with descriptions of 4 events that two people experience. Participants are tasked with inferring how one of the protagonists would feel based on the counterfactual. For example 'Jack misses his train by 5 minutes. Ed misses his train more than an hour. Who spends more time thinking about the missed train?' Participants must choose one of the available responses: Ed, Jack, Same or Can't tell (Hooker *et al*., 2000). The patients did not show any deficits on the general neuropsychological assessment and CIT performance was not different to that of controls. There was no significant difference between patients and controls during partial feedback trials when disappointment and joy were reported. During complete feedback trials there was no significant difference between the two groups when relief was analysed, however there was a significant difference for regret. Patients reported significantly less regret than controls when the outcome of the chosen gamble was lower compared to the outcome of the unchosen gamble. Additionally, there were no within group differences for regret and disappointment in the patient group. Analysis of choice behaviour showed that patients acted to maximise expected value and minimise future regret. There was no difference between patients and controls for choice behaviour. In addition to this, analysis of skin conductance responses showed that patients, like controls, differed significantly between regret and disappointment trials. There were no between group differences. This implies that the patient group experienced the same automatic response to regret and disappointment as the control group. Results from the study implicate the cerebellum in the expression of regret and demonstrate that cerebella damage can affect self-monitoring of regret.

The authors note that the apparent link between the cerebellum and the ability to monitor one's own regret could be due to the cerebellum's connectivity with the PFC, limbic system, and basal ganglia. Habas *et al.* (2009) used resting state fMRI to implicate the cerebellar systems in nonmotor functions. Analysis showed that the cerebellum contributes to intrinsic connectivity networks that are in part responsible for executive control, episodic memory/self-reflection, salience detection, and sensorimotor function. Therefore, damage to the cerebella might interrupt the cortico-cerebellar loops which may play a role in social cognitive processing.

In order to establish if the cerebellum does play a role in social cognitive processing, specifically counterfactual reasoning and the experience and expression of regret, several patients with cerebella lesions will be tested during this project.

It has been speculated that the frontal cortex is linked to the ability to engage in CFT; Gomez-Beldarrain, Harries, Garcia-Monco, Ballus and Grafman (2004) used an economic DM task with patients with right frontal lobe lesions and parietal lobe lesions. Patients listened to information from four advisors regarding the outcome of a forecasting task. They then aimed to predict the successful sales of consumer products over the oncoming month. The results indicated that frontal cortex lesions result in impaired reasoning when forecasting oneself into the future; greatly affecting DM.

1.6.5 Conclusion

The VMPFC, and in particular the OFC have consistently been signposted by neurological research as key brain regions associated with CFT (Camille *et al.,* 2004; Canessa *et al.,* 2009; Coricelli *et al.,* 2007; Nicolle *et al.*, 2011). Research has suggested that the VMPFC is recruited when choices and anticipated emotions are considered and consequently is involved in guiding future DM (Levens *et al.,* 2014).

It is clear that the OFC is involved in producing counterfactual thoughts and regulating emotional responses. It appears that the OFC integrates cognitive and emotional information in order to process how rewarding an outcome would be and in turn creates a 'value signal' (Coricelli *et al.,* 2007). The produced value signal can be memorised and utilised by the lateral PFC to plan a course of action which will obtain the reward outcome. The medial PFC also acts upon the value signal by evaluating the success and effort of the action taken (Ursu & Carter, 2005; Wallis, 2007). Overall, the OFC dictates DM through interaction with other brain areas, such as the amygdala. This interaction allows the OFC to create a representation of outcome reward and its value, resulting in behavioural modification (Coricelli *et al.,* 2007).

Despite these regions being flagged as having an influence on counterfactual production and CMEs, we still understand very little about the neurological processes involved in CFT and DM. For example, we do not know if damage to brain areas outside those listed can affect individuals' experience of CMEs. It is unclear if brain injured patients can experience regret yet not engage in behaviour modification. Additionally there is, to my knowledge, no research which investigates the link between brain injured patients' ability to answer counterfactual questions and their experience of CMEs (the developmental literature would suggest that an ability to pass tasks assessing counterfactual reasoning comes before the experience of CMEs). Therefore this project aims to develop a broad set of tasks while widening the search for the brain areas that support CFT, CMEs and DM.

1.7 Developmental Literature

1.7.1 Overview

The development of CFT and CMEs has been widely investigated in children. It is important to conduct developmental research with children of varying ages as the results allow us to gain a unique insight into the processes that develop gradually, resulting in the ability to think counterfactually as adult. In addition, developmental tasks can be adapted for the purpose of this project.

It is clear from the developmental literature, which will be reviewed in detail, that there is a hierarchy in the development of counterfactual abilities. Counterfactual questions that require future hypothetical thinking are passed at 3 years whereas counterfactual conditional questions are passed at approximately 4-5 years (Beck *et al.*, 2006; Riggs, Peterson & Mitchell, 1998; Robinson & Beck, 2000). The ability to experience CMEs appears to develop after counterfactual reasoning, with the experience of regret preceding the experience of relief (Weisberg & Beck, 2010). Behaviour modification and ACS appears to be the last ability that develops and is possibly dependent on the experience of regret (O'Connor *et al,* 2014).

1.7.2 Counterfactual Thinking in Children

Riggs, Peterson, Robinson and Mitchell (1998) showed that children of 4 years can answer counterfactual questions with responses that indicate an understanding of counterfactual alternatives. Children were given a false belief task in conjunction with a physical state task, both investigations necessitated similar counterfactual processing but the latter did not demand understanding about beliefs. Children were asked what physical state the world might be in if a previous event had not happened. For example, Jenny, the story’s protagonist, creates a painting which she leaves outside while re-entering the house. While Jenny is inside, and cannot see outside, a gust of wind blows the painting into a tree. The counterfactual question asked: ‘‘What if the wind hadn’t blown, where would the picture be?’’ 3-year-old children made realist errors on this task. This means that children described a scenario that was correct in the present and used existing knowledge(“the painting would be in the tree”) instead of how the scenario ‘would be’ in the counterfactual (“the painting would be on the table”). Further evidence that children indeed develop CFT at 4 years comes from Kuczaj and Daly (1979), who reported children using counterfactual language within their speech.

It is possible that performance on counterfactual tasks is affected by inhibitory control. The role of inhibitory control in counterfactual production has been investigated by Beck, Riggs and Gorniack (2009). The authors tested 3 and 4 year old children on various tasks assessing counterfactual ability. Counterfactual performance for both 3 and 4 year old children was predicted by inhibitory control. It is possible that the development in inhibitory control is what facilitates successful CFT; without the inhibition to ignore a known outcome, individuals may have deficits in their counterfactual ability

Thinking counterfactually is particularly challenging for young children. Robinson and Beck (2000) used future hypothetical questions ‘What if next time he drives the other way, where will he be?’ and counterfactual conditional questions ‘What if he had driven the other way, where would he be?’ 3-4 year olds found future hypothetical questions easier to answer than counterfactual conditional questions. Additional evidence that at 3 years of age children find future hypothetical questions easy to answer was provided by Beck *et al.* (2006), Perner *et al*. (2004) and Riggs *et al*. (1998).

Drawing from this evidence that children are able to speculate about events that occur in the future, suggests they are able to ignore the current facts, using inhibitory control, and project themselves into a future state. Therefore, it is unlikely that the children fail the counterfactual conditional questions at this age, purely because they cannot ignore current reality. If this was the case, children would not pass the future hypothetical questions correctly as they would be unable to project themselves into the future and consider alternative possibilities. It is possible that after brain injury, patients may not be able to disengage their attention from the known outcome and so may struggle with future hypothetical and counterfactual questions. However, projecting one's self into the future, according to developmental research, appears to be much easier. Therefore, patients, like children, may have the ability to consider future alternatives but not think counterfactually.

1.7.3 Is Basic Conditional Reasoning the same as Counterfactual Thinking?

Rafetseder, Cristi-Varga and Perner (2010) aimed to pin point the stage in development where children are able to engage in CFT. They argue that when 4 year old children pass counterfactual conditional questions, they may not need to engage in real CFT. They suggest that basic conditional reasoning (BCR) can be used to answer questions by applying regularities and logical rules. In other words, children might answer using general knowledge of the world rather than considering a specific alternative that might have been. Children were shown a story depicted by dolls; a mother of two children (a small girl named Julia or a tall boy named Simon) placed sweets on either the top shelf of a cabinet or the bottom shelf. Once the mother had left the room, the children looked for the sweets and took them to their room if they were found. In one trial, the sweets were hidden on the top shelf where the tall boy, Simon, finds them and takes them into his room. The child was then asked *'what if Julia had come, where would the sweets be?'* If BCR was used to answer this question, the response would be 'in Julia's room' because the question states that Julia would have looked for the sweets before Simon. However, this would be incorrect as Julia cannot reach the top shelf and so would not have retrieved the sweets in order to take them to her room. Thus, CFT is required to answer this question correctly (on the top shelf). The results of the experiment showed that only 35% of 6 year old children answered questions requiring CFT correctly.

In addition to this, Rafetseder and Perner (2010) used a further study that isolated CFT from BCR to show that children at age 6 are able to reason the correct response. Children were told a story that depicted a doctor in two locations: a hospital (typical) or at a park (atypical). In both conditions children were told that the doctor was called to an emergency at a swimming pool. The children are then asked "If there had been no emergency, where would the doctor be?" In the typical condition the correct response is 'at the hospital.' However, because a doctor's logical location would be in a hospital, BCR could be used to correctly answer this question. However, CFT is required to respond correctly in the atypical condition because doctors are not generally located in the park. Children under 6 were not able to correctly answer questions in the atypical conditions, demonstrating a lack of counterfactual reasoning.

More recently Rafetseder, Schwitalla and Perner (2013) continued to investigate how BCR can influence the apparent ability of children to pass counterfactual tasks. Through using the same methods as described above by Rafetseder, Cristi-Vargas and Perner (2010), the authors showed that children did not reach 'adult like' counterfactual reasoning until

12- to 14-year-olds. They concluded that counterfactual reasoning is not full developed before the age of 12.

It is possible that some patients, after a brain injury, have problems reasoning counterfactually. If this is the case then these patients may rely on BCR to answer counterfactual questions. It will be possible to establish, using a task which asks varying counterfactual questions (such as future hypothetical and basic counterfactual) if some patients, like the children discussed by Rafetseder, answer using typical regularities (BCR) or if counterfactual reasoning is preserved.

1.7.4 Counterfactually Mediated Emotions in Children

Amsel and Smalley (2000) investigated regret and relief in children aged 3 and 5. Children played a game where two cards were placed face down and one card was facing upwards. The aim of the game was to choose one of the two face down cards and to try to beat (numerically) the face up card. In all trials the children were required to rate their feelings on their chosen card and then again when the unchosen card was turned over. If children considered what they could have won had their choice of card been different, then we would expect their emotional rating to go down after learning the alternative card was a higher number. This behaviour would indicate the experience of regret. Conversely, children's emotional rating should increase upon finding out the unchosen card was a lower number; a demonstration of relief. It was found that for both 3- and 5-year-old children, their emotional rating did not change once the alternative cards was revealed, regardless if it was higher or lower than the face up card (therefore, no regret or relief were demonstrated). However, all children acknowledged they would have been happier if they had selected the face down card that ultimately ended up winning. Therefore, even though CFT could take place, neither 3- nor 5-year-old children reported experiencing CMEs.

Subsequently, Weisberg and Beck (2010) found evidence that 5-year-olds experience regret. The authors devised a task where children chose one of two coloured boxes. A number of stickers was won according to the box chosen. The contents of the chosen box were revealed first. An emotional rating was then taken from the children using a 5 point smiley face scale. The non-chosen box was then opened, revealing its contents. A second emotion rating was taken (how the child now felt about their chosen box). Both regret and relief trials were created. In the case of regret trials, the alternative box had a higher number of stickers in than the chosen box. In relief trials, the alternative box had a lower number of stickers in than the chosen box. Children aged 5-6, 6-7 and 7-8 were tested. All age groups reported regret with no significant difference separating the age groups. However, only 7-8 year olds reported the feeling of relief. This task will be adapted for the purpose of my research to assess if patients with neurological damage can report the experience of regret and relief.

It is possible that when children were asked to rate their emotional response to their chosen box a second time they felt they were required to change their original answer. This would cause the second emotional rating to change. In order to control for this, O'Connor, McCormak and Feeney (2012) incorporated a baseline trial where the chosen and alternative box contained the same prize. The inclusion of this trial identified children who changed their emotional rating without a systematic reason. The authors found evidence for the experience of regret emerging at 6-7 years. These children were also able to answer questions about their emotional experience of regret using counterfactual explanations. No evidence for this behaviour was recorded for 4- to 5-year-olds. Taking into consideration the methodological improvements made by O'Connor, McCormak and Feeney (2012), my research will incorporate a baseline trial.

In order to establish that the measure of CMEs used by Weisberg and Beck (2012) was reliable the authors made some methodological modifications. A new experiment was devised where children chose between one of two cards; win or lose. During regret trials, participants either won 2 or 3 tokens and had a missed opportunity to win 8 (win trials) or participants lost 2/3 tokens and had a missed opportunity of winning 3 tokens (lose trials). The reverse pattern was used for relief trials. As before, participants were required to rate their emotions. For the purpose of this experiment the authors altered the rating scale used to allow participants to rate their emotional responses categorically the second time. A horizontal 5 point smiley face scale (ranging from very happy to very sad) with a three pronged arrow was developed. One arrow pointed up vertically with the other two arrows pointing out towards the left and right respectively. Above the vertical pointing arrow, a 'window' was cut into the cardboard. The window could be placed over one of the 5 smiley faces on the scale and was used to signify the child's emotional response to the outcome of their chosen box. The child was then asked to point to one of the three arrows depending on how they felt after seeing the alternative prize. If the child pointed to the leftward pointing arrow this signified that they felt sadder, if they chose the rightward pointing arrow, they felt happier, and finally if the child chose the vertical upward pointing arrow, they felt the same as they previously rated themselves. The 5 point smiley face scale and three pronged arrow will be used in my investigation in patients' experience of regret and relief.

Results showed that regret after winning was reported at 4 years, regret after losing as well as relief after winning was reported at 5 years, but relief after losing was not reported until 7 years. These findings support the claim that previous experiments examining the experience of relief have been artificially difficult. Additionally, it would appear that regret and relief are experienced earlier than previously reported by other authors.

However, it could be suggested that even the children who reported feeling sadder in Weisberg and Beck's study are not experiencing regret. The authors assumed that participants think counterfactually; 'I should have picked the other box'. However, children may have simply felt frustrated at their decision, thinking 'I do not have the higher number of tokens'. To address this Weisberg and Beck (2012) manipulated the responsibility children had for which box they opened, which should impact counterfactual thinking but not frustration. Six- to 7-year-olds reported more sadness when their feelings of responsibility were stronger. Thus it appears they were experiencing regret.

1.7.5 The Relationship between Adaptive Choice switching and Regret

The relationship between ACS and the experience of regret has been investigated in adults as well as children. It has been suggested that adults anticipate regret as a consequence of DM, and in order to limit this negative experience, will make active attempts to avoid similar regret inducing consequences (Zeelenberg, 1999; Mellers Schwartz & Ritov, 1999).

Adults have been shown to anticipate regret and as a result consider alternative courses of action in an economic context (Bell, 1982). Creyer and Ross (1999) demonstrated that the experience of regret impacts on future DM during in an investigation into adaptive behaviour when negotiation and bidding. O'Connor, McCormack and Feeney (2014) investigated the relationship in children. Children's DM was examined over a two day experiment. On day 1 children chose to open one of two boxes. They rated their emotions after seeing what they won (the prize in the chosen box) and again once the alternative prize (the unchosen box) was revealed. There were three conditions; baseline (both boxes contained the same number of tokens), regret (the unchosen box contained more tokens) and relief (the unchosen box contained fewer tokens). On day 2 children were shown the boxes from the previous day and reminded which box they initially chose to open. They were given one token which they could use to exchange for the decision to switch their box from day 1. Children were categorised as engaging in ACS when they chose to exchange their token for the opportunity to switch boxes in the regret condition; this would accumulate more tokens overall. Results showed that children who reported regret on day 1 were more likely to engage in ACS on day 2. The authors interpreted this as evidence to suggest that regret facilities learning after an undesirable outcome.

1.7.6 Developmental Conclusion

It would appear from developmental research that there is a hierarchy in the development of counterfactual abilities. Children begin to answer future hypothetical questions correctly at 3 years of age. Counterfactual conditional questions are answered correctly at 4-5 years (Beck *et al.*, 2006; Riggs *et al*., 1998; Robinson & Beck, 2000). Counterfactual emotions develop after counterfactual reasoning. Regret it thought to be experienced before relief (Weisberg & Beck, 2010). ACS appears to emerge after the development of regret (O'Connor *et al.,* 2014).

It is also important to remember that some authors (Rafetseder, Cristi-Varga & Perner, 2010; Rafetseder & Perner, 2010) think young children pass counterfactual conditional tasks using BCR and so development of adult-like CFT may emerge in later childhood. If this is the case then regret may emerge before full CFT, which brings the described hierarchy into question.

1.8 The Thesis

There are three general aims for this project: to explore the component processes of CMEs and widen the search for the brain areas that supports these; To conduct research that points to how the experience of regret directly impacts on future DM and underpins adaptive behavioural change; To establish if regret itself is experienced in brain-damaged individuals.

Through reviewing the previous research conducted with neurological patients I have identified key brain areas which have been associated with CFT, CMEs and DM. I have established that there is a need to widen the search for brain areas that support these abilities and establish if there is a relationship between CFT and CME production and also regret and adaptive behaviour modification. Developmental research has shed light on these relationships in children; demonstrating a clear hierarchy. One experiment tested with adults, the RGT, will be adapted for the purpose of this investigation along with four developmentally designed experiments. In addition to this, I will further investigate healthy adults' experience of CMEs to advance our understanding of how CMEs are produced.

Chapter 2

Is the Processing of Regret in Adulthood Effortless?

A collaboration between: Putt, C., FitzGibbon, L., Feeney, A., McCormack, T., & Beck, S.

The work for this chapter was conducted as a collaboration between the above authors. However I am the primary author of this work.

I formulated the idea for the experiment, programmed the experiment (with Dr FitzGibbon) tested participant, analysed the data (with Dr FitzGibbon), interpreted the findings and wrote the report. Dr FitzGibbon, Dr Feeney, Prof McCormack, and Dr Beck provided feedback on the original development of ideas and writing up.

2.1 Introduction

Successful DM and behavioural modification is influenced, not only by cognitive processes, but by emotions (Kirman *et al*., 2010; Mellers, 2000). CMEs reflect events that did not happen, but could have, and they play a key role in DM. This is especially true of the negative CME regret, which is based on a comparison of what really happened with what might have happened had a different choice been made. However, it is unclear how the experience of regret directly, or indirectly, affects behavioural change (Roese *et al*., 2007; Zeelenberg & Pieters, 2007). To address this we need a better understanding of the process by which CMEs are generated. In this chapter I explore whether experiencing regret is an effortful process, or whether its generation is fast and effortless. In this study both a negative CME, regret, and its positive complement, relief were measured.

Van Dijk and Zeelenberg (2005, pg152) describe regret as "A negative emotion that we experience when we realise or imagine that our present situation would have been better, if we only had decided differently." Whereas, relief originates from the comparison of the present situation to a more negative hypothetical (Coricelli & Rustichini, 2010). During this investigation, in line with previous research (Camille *et al.,* 2004; Coricelli *et al.,* 2005), I will focus on the negative CME, regret.

Kahneman (2013) describes two systems that underpin the workings of DM. His metaphor that thinking happens fast or slow, was developed from Stanovich and West (2000). System one allows individuals to respond to situations quickly through relying on known associations and stimulus similarities. It is characterised as intuitive and effortless, i.e. 'fast'. Whereas system two uses logic and deliberation and thus is slow and effortful. Drawing on this two systems approach, it is possible that CMEs are produced quickly and effortlessly; the experience of a CME is inherently an emotional reaction thus lending itself to system 1. Alternatively, it is possible that CMEs require effortful processing to compare the real and counterfactual world; thus akin to system 2. Note that in this chapter I refer to effort (effortful/effortless) but do not make claims about whether CMEs are automatic. For that claim it would be necessary to show that these CMEs are processed even when they are not explicitly sought and even when they are counterproductive (see Apperly & Butterfill, 2009, for a similar argument about theory of mind).

CFT is often construed in terms of inferences: one needs to work out how the outcome would have been different if alternative choices had been made. The imagined alternative must be closely related to the real world, must be tied to a specific situation and fit with previous knowledge the individual has about the situation, and must not violate the laws of nature (Dehghani *et al*., 2012). Minimising the number of changes between the real and alternative world allows for the counterfactual to be realistic: an outcome that could have genuinely occurred (Petrocelli *et al*., 2011). Making logical inferences about the counterfactual world seems likely to rely on slow, effortful thinking.

Another reason to think that CFT (and hence CMEs) will be effortful is that regret has a protracted development. In a typical study of regret with young children, participants choose to open one of two boxes, winning the number of stickers inside. They then rate their emotional response using a scale comprised of five faces ranging from extremely happy to extremely sad. Only then do they see the contents of the unchosen box. On regret trials the unopened box contains more stickers than the chosen box and during relief trials the unopened box contains fewer stickers than the chosen box. Children rate their emotions a second time after what they could have won has been revealed. It is not until children are at least 5 or 6 that they report experiencing regret (Beck & Weisberg, 2010; O'Connor, McCormack, & Feeney, 2012) and indeed others claim that the emotion is not experienced until early adolescence (Rafetseder, Schwitalla, & Perner, 2012) Furthermore, children under 7 fail to report when others feel regret (Beck & Crilly, 2009; Ferrell, Guttentag, & Gredlein, 2009).

When interpreting counterfactual statements in discourse, encoding counterfactual and factual information does not seem to differ in effort, but integrating counterfactual and factual information relies on cognitive resources. Here encoding refers to the initial formation of a representation of the information, whereas integration refers to using the information in combination with relevant context. Ferguson and Cane (2015) measured event-related brain potentials while participants read factual or counterfactual statements and reasoned about consistent and inconsistent events. In their first experiment, both counterfactual and factual statements led to differences in the N400 between consistent and inconsistent events. This suggests that individuals encode and hold in mind both the counterfactual and factual worlds when making predictions about events in upcoming discourse. However, integrating the counterfactual was more demanding: in a second experiment, the authors divided their sample according to participants working memory (WM) capacity, and found that those who had low WM capacity failed to detect inconsistencies relating to counterfactual worlds (while they were merely delayed for factual worlds).

These processes have not yet been fully investigated in other contexts that elicit counterfactual thought, such as in DM. Very little is known about the processing of factual and counterfactual information that is spontaneously generated from observing decision outcomes. When faced with information about the outcomes of decisions that have been made and decisions that could have made, encoding can be interpreted as the selection and processing of such outcomes. Whereas integration is the comparison between the factual and the counterfactual, in the experiments in this chapter integration is expressed via the emotional responses to the outcomes (regret and relief).

Thus, instead of assessing the cognitive processes of CFT in discourse I will investigate whether emotional responses after DM are affected by manipulating cognitive resources.

One the other hand, others have claimed that CFT occurs automatically, and requires cognitive capacity to suppress it. Goldinger, Kleider, Azuma and Beike (2003) investigated this process of suppression, characterising it as an active process where an individual attempts to remove thoughts from the forefront of their mind. In their study, participants read a story and made decisions based on the story events. For example, in one story the protagonist is watching a baseball game and a light falls on his foot. Participants had to decide how much compensation to award the victim. Critically, in one version of the story the protagonist was sat in his usual seat when the incident occurred, and in the other he had purposely moved to a different seat. In the latter, the counterfactual ‘If only he hadn’t changed seats’ is likely to be available. Participants assigned more blame to the victim when counterfactual thoughts were easily generated. Most importantly, when participants with lower WM span held a further memory load during the DM stage, they were more influenced by the counterfactual world than participants in other conditions: They attributed more blame to the victim and recommended less compensation. However, when participants held a memory load while reading the story (encoding) there was little effect.

The authors interpreted these results as suggesting that counterfactuals are automatically produced during the encoding stage and need effortful suppression at a later stage. In other words, this evidence suggests that CFT is quick and effortless.

Other evidence to support the fast view of CFT comes from recent neuroscience studies of regret. Giorgetta *et al.* (2013) used a paradigm developed by Camille *et al.* (2004). Participants took part in a gambling task while magnetoencephalography (MEG) was used. The task involved two wheels of fortune; each wheel offered two different point rewards, one of which would be won depending on the spin of an arrow. One wheel was categorised as safe and one as risky. The safe wheel had the smaller outcome values whereas the risky wheel had the larger outcome values. 3 different combinations of points were used: (-5, 5 (safe options), -25, 25 (risky option) or -10, 10 (safe option), -30, 30 (risky options) or -15, 15 (safe options) or -35, 35 (risky option). Participants chose which wheel they wanted to gamble on in half of the trials (participant agency trials), during the other half of trials the choice was made by the computer (computer agency trials). Information on the outcome of the chosen gamble/wheel was presented, followed by the outcome of the unchosen gamble/wheel. Disappointment and regret were induced by manipulating the outcome of the two wheels, for example, regret was induced through combining a loss on participant agency trials (the participant chose the wheel that the gamble was placed on) with a win on the unchosen wheel. Disappointment was created using a loss on computer agency trials while the alternative wheel won. MEG results indicated that the regret and disappointment trials were differentiated extremely fast at the neural level (between 190 and 305ms). After 305ms the cortical activity was very similar. The early differentiation in activity was shown to be a result of feedback and agency; and as previously explained, feedback and agency were used to induce feelings of regret and disappointment respectively.

However, Giorgetta *et al*.'s findings do not show how these early neural signals are linked to the emotion itself; a question this experiment aims to address. Giorgetta *et al.'s* research has highlighted the speed at which neural processing of stimuli that induce regret and disappointment occurs. The experiments presented in this paper aim to establish if the experience of these emotions is also fast and effortless.

There is evidence to support both the possibilities that CFT and CMEs are the results of slow, deliberative processes, and that they are fast and effortless. Here I address this by investigating the experience of regret in healthy adults. I used the wheels of fortune paradigm to induce regret in participants, and used two manipulations to see if they are susceptible to manipulations of cognitive load. The logic being that if they are susceptible to these manipulations, then they are more like System 2 processes, rather than System 1. In Experiment 1, the length of time that participants were able to view the outcome of the two wheels was manipulated. In this way the time available for encoding factual and counterfactual outcomes was manipulated. In Experiment 2, the WM load that participants were exposed to was manipulated; load was maintained during both encoding and integration. If generating the counterfactual thoughts that underpin CMEs is effortful, then one would expect both of these manipulations to disturb the experience of CMEs.

2.2 Experiment 1

The design of the experiment was closely based upon Camille *et al.'s* (2004) gambling task where two wheels of fortune were manipulated so that there were different probabilities of winning and losing a high and low number of points. In the first experiment, the amount of time that participants were exposed to the outcome of the two wheels was manipulated. The aim of this experiment was to establish whether there is a difference in reported emotions when the outcomes of chosen and unchosen gambles were viewed for a short length of time (1 second) compared to a longer length of time (4 seconds).

Bault et al. (2015) reported that participants spent roughly 2 seconds looking at the outcomes of both the unchosen and chosen wheel, thus 1 second was chosen as the short exposure to determine if participants required this time to process the counterfactual and factual outcomes. As the 4 second condition gives participants longer to process the outcomes, it is possible that this will elicit stronger CME responses compared to the 1 second condition. This could occur through possible mechanisms such as more comparison between the obtained and unobtained outcomes occurring in the 4 second condition or emotional responses building up over time, thus generating a stronger CME in the 4 second condition.

The unobtained outcome during partial feedback trials is the number of points associated with the section of the chosen wheel where the arrow did not land, for example if the possible outcomes on the chosen wheel are 200 and -50 and the arrow lands on 200 the unobtained outcome is -50. The unobtained outcome during complete feedback trials is the number of points associated with the section of the wheel where the arrow lands on the unchosen wheel. In order to replicate previously analysis with the RGT the points associated with the outcome on the unchosen wheel is not included in analysis.

2.2.1 Method

Participants

A total of 18 participants (16 female) aged between 18 and 24 (*M* = 20.33 years) completed the experiment. All participants were Psychology undergraduate students at the University of Birmingham and were recruited for course credit.

Design

The experiment was administered on a Toshiba 15" laptop and run on PsychoPy, version 1.73.04 (Peirce, 2007; 2009). Each trial presented two wheels of fortune, one on the left side of the screen and one on the right (see Figure 2.0 for example wheels). Each wheel was divided into two sections; red or blue. Each section contained a number which represented a number of points. An arrow was presented in the middle of each wheel pointing upward. Participants chose one of the two wheels. The arrow would spin between 2 and 5 seconds (randomly determined by the programme) and stopped on either the blue or red section, where the corresponding number of points would be won by the participant. The arrows span for the same length of time on both wheels on each trial. The points that were available were: -50-, -200, 50, and 200. In 50% of trials only the arrow inside the chosen wheel would spin, winning the corresponding number of points (partial feedback). During the other 50% of trials, both the arrow inside the chosen wheel and the unchosen wheel would spin (complete feedback). Therefore, the participant would see not only the outcome of their chosen wheel but also the outcome of the unchosen wheel. Participants were split into two groups; fast-slow and slow-fast. During the slow condition, the outcome of the wheel/wheels was shown for 4 seconds. During the fast condition, the outcome of the wheel/wheels was shown for 1 second. Participants in fast-slow group completed the fast condition first followed by the slow condition whereas participants in the slow-fast group completed the slow condition first followed by the fast condition. There were 60 trials in each condition respectively.

Materials

Participants rated their emotions using the arrow keys on the keyboard by moving a marker along a line. The marker started in the centre and could be moved left towards the "Extremely sad" anchor, or right towards the "Extremely happy" anchor. There were 50 interval points on each side of the central starting point.

Procedure

Training: Participants were given 2 practice trials before each of the slow and fast conditions respectively: a partial feedback trial and a complete feedback trial. Each participant received the same practice trials (see Table 2.0). During both practice trials, there was always a -50 or 50 vs a -200 or a 200 score. After each trial was completed participants rated their emotional response to the outcome.

Table 2.0

Combination of points available on left and right wheels, including feedback condition, during training trials.

Left Wheel	Right Wheel	Feedback
-50 / -200	50 / -50	Partial
-50 / 200	-200 / 200	Complete

Experimental procedure: Participants read the following instructions ‘In this game, you are trying to win as many points as possible. You get to choose between two wheels of fortune. After you choose a wheel, you will see an arrow spinning. When the spinning arrow stops, points will be added or subtracted from your running total. You will then be asked to record how you feel about the outcome.’ Participants were also informed that a memory check would be incorporated into the experiment; ‘Sometimes there will be a memory test that asked what happened on that round. You might be asked about your wheel or the other wheel. Before you start you have two practice goes, press space when you’re ready to start.’ On 20% of trials, participants’ memory for the outcome of the chosen wheel or the unchosen wheel was tested. The memory check asked participants either ‘What was the outcome on your wheel’ or ‘What was the outcome on the other wheel’. Participants were then given a choice between two numbers, one of which was the correct answer to the question, for example ‘-50 or -200’; the choices were always the values associated with the two coloured portions of the wheel in question. No feedback was given for the memory check. Both practice trials included the memory check procedure. See figure 2.0 for an example memory trial.

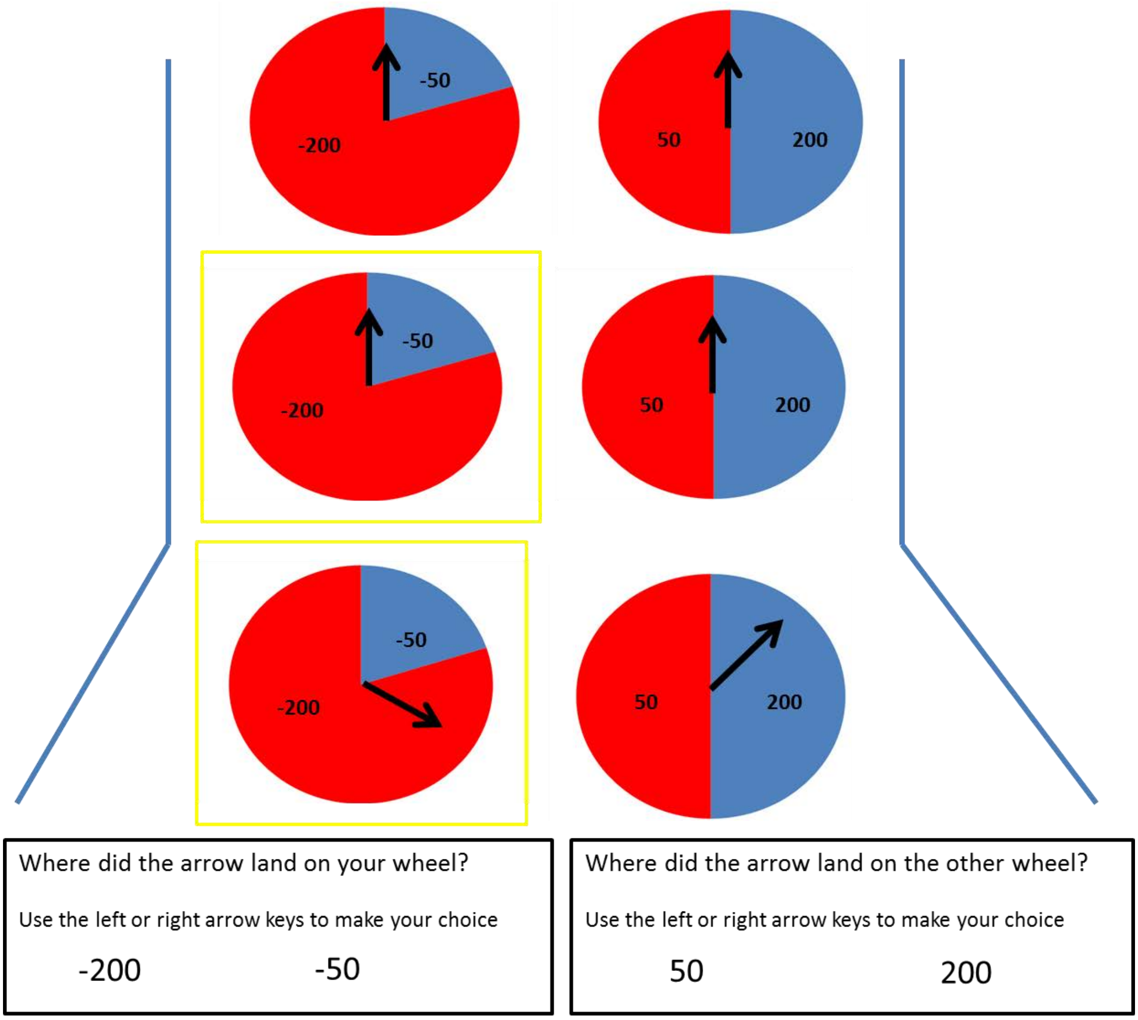


Figure 2.0: Example trial including a memory check.

Note: The memory check is the question written in the bottom two boxes: 'Where did the arrow land on your/other wheel?'

2.3 Results and Discussion

In line with previous usage of the RGT, during complete feedback conditions analysis of emotional ratings were conducted on 50 or −50 for the obtained outcome and 200 or −200 for the unobtained outcome. This combination is chosen for analysis in the RGT as winning 200 results only in possible comparisons where the outcome of 200 is better than any alternative, 50, -50, -200, i.e. only relief can be elicited. The opposite is true for an obtained outcome of 200. However, if the obtained outcome analysed is 50 both regret and relief can be induced by either presenting the unobtained outcome as more desirable, creating regret(200) or less desirable, creating relief (-50/-200). The opposite is true for an obtained outcome of -50.

In Experiment 1, participants chose between two wheels of fortune on each trial. They were then shown either the outcome of the chosen wheel only (partial feedback) or of both wheels (complete feedback). The length of exposure to the outcomes (exposure time) was varied in a blocked within-participants design with the order counterbalanced between participants. In order to examine the effect of outcome exposure time on CMEs, a four-way repeated measures ANOVA was conducted. The four factors, and their respective levels were as follows: exposure time (1 second and 4 seconds); feedback type (partial and complete); obtained outcome (-50 and 50), and unobtained outcome (-200 and 200). Figure 2.1 shows the mean emotion rating following the presentation of the outcome of the trial for each combination of exposure time, trial type, obtained outcome and unobtained outcome.

There were three significant main effects and three significant interactions. Table 2.1 presents the statistics for the analysis.

Table 2.1

Statistics for analysis on exposure time, feedback type, obtained outcome, and unobtained outcome

Effect	**DFn**	**DFd**	**F**	***p***	**η^2**
exposure time	1	17	.077	.79	.005
Feedback	1	17	5.11	.037	.23
Obtained	1	17	42.33	< .001	.71
Unobtained	1	17	43.62	< .001	.72
exposure time*feedback	1	17	.43	.52	.02
exposure time*obtained	1	17	.09	.76	.01
feedback*obtained	1	17	4.55	.048	.21
exposure time*unobtained	1	17	.134	.72	.01
feedback*unobtained	1	17	9.96	.006	.37
obtained outcome*unobtained	1	17	13.62	.002	.44
exposure time*feedback*obtained	1	17	.78	.39	.04
exposure time*feedback*unobtained	1	17	.01	.90	.001
exposure time*obtained*unobtained	1	17	.03	.88	.001
feedback*obtained*unobtained	1	17	3.61	.074	.18
exposure time*feedback*obtained*unobtained	1	17	.84	.37	.05

Note: DFn represents the estimate of variance, DFd represents the degrees of freedom.

There was a main effect of feedback type, $F(1,17) = 5.11$, $p = 0.037$, partial $\eta^2 = 0.02$ Participants reported that they were happier after partial trials than after complete trials. There was a main effect of the obtained outcome, $F(1,17) = 42.33$, $p < 0.001$, partial $\eta^2 = 0.36$. Participants reported that they were happier after winning 50 points than after losing 50 points. There was also a main effect of the unobtained outcome, $F(1,17) = 43.62$, $p < 0.001$, partial $\eta^2 = 0.45$. Participants reported that they were happier after the unobtained outcome was worse than their own outcome than after the unobtained outcome was better than their own outcome.

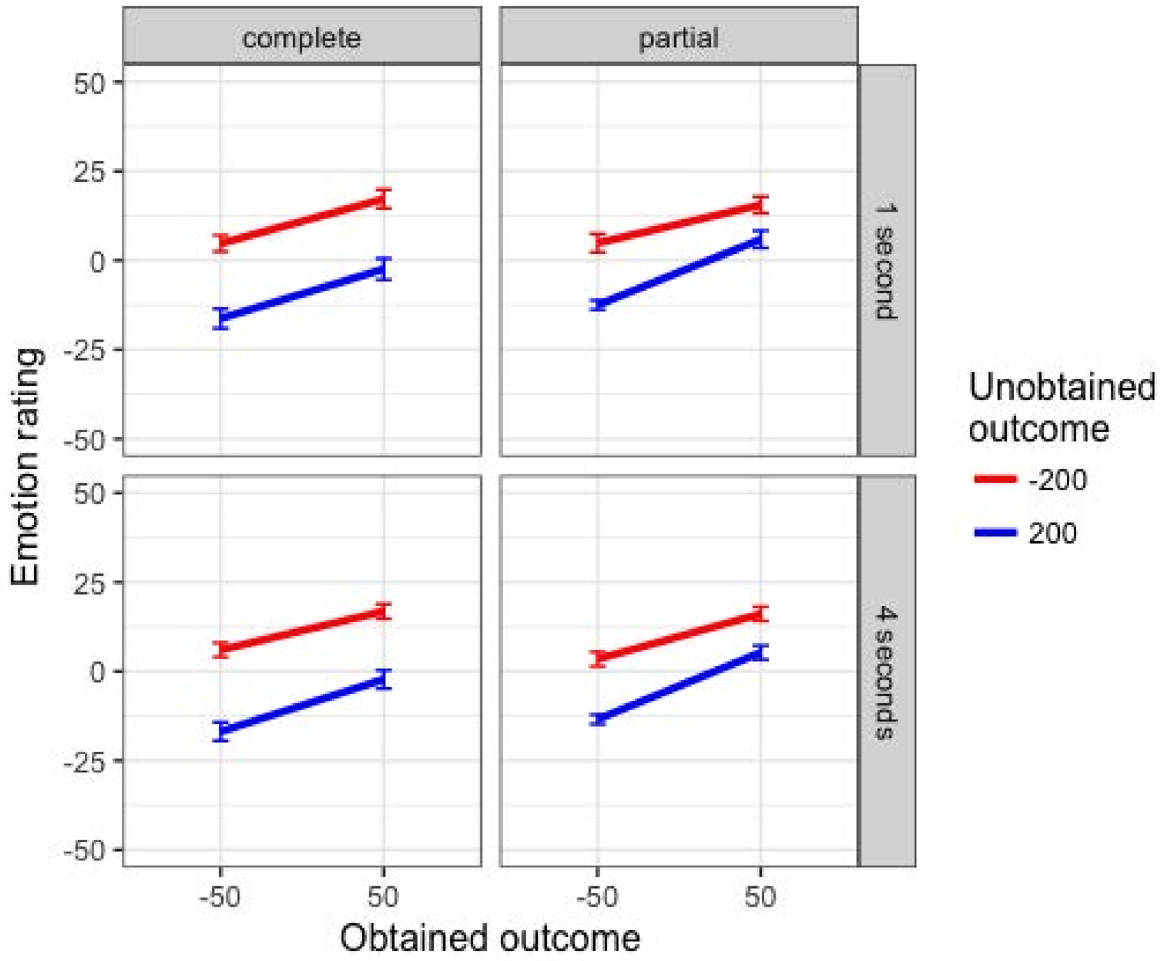


Figure 2.1: Mean emotion rating for each combination of obtained and unobtained outcomes with complete and partial feedback in the two exposure time conditions. The slopes of the lines represent the effect of the obtained outcomes, and the differences between the red and blue lines represent the effect of the unobtained outcomes. Error bars represent standard error of the mean.

There were three two-way interactions. A feedback type x unobtained outcome interaction, $F(1,17) = 9.96$, $p = 0.006$, partial $\eta^2 = 0.033$. We explored all 2x2 interactions using post hoc t tests, with a Bonferroni correction for 4 tests such that $\alpha = .013$. Participants were affected by the unobtained outcome when they received complete feedback, $t(17) = 5.59$, $p < .001$, $d = 1.65$ and when they received partial feedback, $t(17) =$

8.81, $p < .001$, $d = 1.73$. There was not a significant difference between complete and partial trials when the unobtained outcome was negative, $t(17) = 0.91$, $p > .999$, $d = 0.06$ although the difference for positive trials approached significance, $t(17) = 2.68$, $p = .063$, $d = 0.60$. This finding demonstrated the "amplification effect" whereby emotions related to unobtained outcomes are felt more keenly when they were missed by choice (regret and relief) than by chance (disappointment and elation).

An obtained outcome x unobtained outcome interaction, $F(1,17) = 13.62$, $p = 0.002$, partial $\eta^2 = 0.016$, indicated that participants were affected by the obtained outcome when the unobtained outcome was positive $t(17) = 6.43$, $p < .001$, $d = 1.64$, and when it was negative, $t(17) = 5.74$, $p < .001$, $d = 0.89$. Participants were also affected by the unobtained outcome when the obtained outcome was negative, $t(17) = 6.59$, $p < .001$, $d = 1.85$, and when it was positive, $t(17) = 6.22$, $p < .001$, $d = 1.32$. This finding is in accord with eye-tracking data that suggests that people spend more time looking at unobtained outcomes after obtaining negative outcomes than after obtaining positive outcomes (Bault, *et al.,* 2015).

Finally, a feedback type x obtained outcome interaction, $F(1,17) = 4.55$, $p = 0.048$, partial $\eta^2 = 0.003$, indicated that participants were affected by their obtained outcome in the complete feedback condition, $t(17) = 5.20$, $p < .001$, $d = 1.26$, and in the partial feedback condition, $t(17) = 7.61$, $p < .001$, $d = 1.64$. Participants were also affected across feedback type when the unobtained outcome was negative, $t(17) = 1.16$, $p < .001$, $d = 0.17$, and positive, $t(17) = 3.43$, $p = .013$, $d = 0.40$.

Overall, reported emotions did not differ in the two exposure time conditions. This finding is evidence that the length of time participants were exposed to the outcomes does not affect reported CMEs. We interpret this observation as support for the notion that CMEs are produced quickly, with only limited exposure to the obtained and unobtained outcomes required. It should be noted that the manipulation used in Experiment 1 could only affect the encoding phase and not that of integration. It is thus possible that while participants encoded the information quickly, integration of that information was still effortful. To further investigate the nature of counterfactual reasoning, a second experiment was conducted in which the cognitive resources available to participants were manipulated through a cognitive load dual task. Importantly, the load was maintained through both the encoding and integration of the counterfactual information. Through this manipulation it will be possible to establish if CMES are processed effortlessly.

2.3.1 Memory for obtained and unobtained outcomes

Participants' memory for the outcome on the chosen wheel and the unchosen wheel were analysed for a subset of memory test trials on which they received complete feedback, the obtained outcome was -50 or 50 and the unobtained outcome was -200 or 200. Depending on their gamble choices, participants entered between 1 and 3 trials for each combination of wheel tested and exposure time into this analysis. Figure 2.2 shows mean memory accuracy by wheel tested and exposure time condition. Memory performance was analysed using a mixed-effects logistic regression model with memory accuracy as the binary dependent variable, exposure time condition (1s or 4s) and wheel tested (chosen or unchosen) as fixed effects, and participant as a random effect. A mixed-effects logistic regression was chosen as the most suitable method to analyse the memory for the chosen and unchosen wheel due to the limited, and varied, number of trials across participants. It should be noted that if more participants had been served a greater number of memory trials, an ANOVA would have been used instead.

There was a main effect of wheel tested, $z = 3.62$, $p < 0.001$. Memory was better for the obtained outcome than for the unobtained outcome. There was no effect of exposure time, nor was there a significant interaction between wheel tested and exposure time, *p*s > 0.05. This suggests that encoding was poorer for counterfactual than factual information, but the exposure time did not affect the quality of encoding.

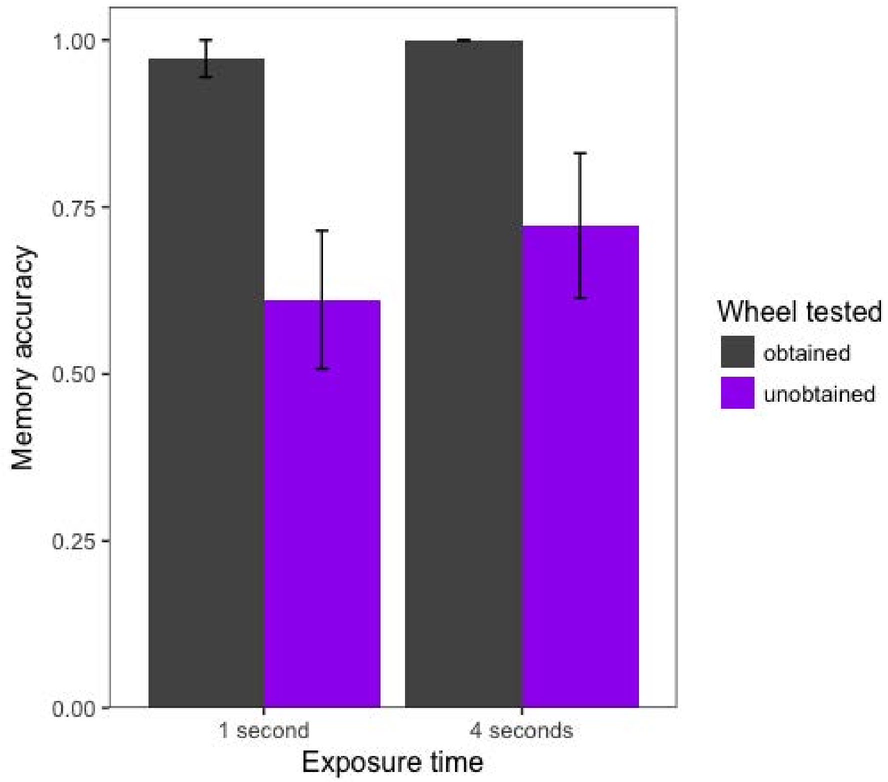


Figure 2.2: Mean memory accuracy when tested on the outcome of the chosen and unchosen wheel, and when exposed to the outcomes for 1 second or 4 seconds. Error bars represent standard error of the mean.

2.4 Experiment 2

Experiment 2 used the same design as Experiment 1. The aim of the second experiment was to establish if cognitive load affected participants' reported emotions. To achieve this aim, WM load was manipulated while participants completed the gambling task. A load was used in which participants had to remember a list of numbers during the trial and were after asked to recall which number was presented to the right of another. Therefore, load was maintained during both encoding and integration. Similar manipulations have been used by Anderson, Reder and Lebiere (1996) and Hinson, Jameson and Whitney (2003). If producing CMEs makes demands on WM, then holding the WM load in mind should lead to reduced task performance. This would suggest that CME production is effortful. Alternatively, the WM manipulation may not affect task performance, which would indicate that CMEs are produced effortlessly.

2.4.1 Method

Participants

A total of 20 female participants aged between 18 and 25 (*M* =19.4 years) completed the experiment. All participants were Psychology undergraduate students at the University of Birmingham and were recruited via the research participation scheme. Participants received 0.55 credits for their participation over a 30 minute time period.

Design

The experiment was set up with the same format as the previous experiment. However, instead of varying the length of time the participants view the outcome of the wheels (fast-slow and slow-fast groups) participants all saw the outcome for 2 seconds.

Additionally, a digit number string which comprised digits between 1 and 9 (digits were never repeated in each number string) was shown to the participants before they chose their wheel. The number strings were created using a random number generator; once a string had been used for a participant, it was not repeated for that participant. Participants viewed the outcome of the wheels for 2 seconds in all trials. There were two conditions during the experiment, high load and low load. During low load conditions, two numbers were shown in the digit string, during high load conditions, five numbers were show in the digit string. There were 60 trials in each condition respectively. The order in which participants received the loads was counterbalanced. Half of trials during each condition were full feedback and half were partials feedback trials.

Materials

The 2 and 5 number digit strings were created by selecting a series of numbers between 1 and 9. Within each digit string, no one number was repeated E.g. 16396 and continuous number patterns of more than three were not used E.g. 456.

Procedure

Participants were given 2 practice trials before the experimental phase began. Participants were assigned to either the high or the low load condition. Participants were informed that a 2 or a 5 digit number (depending on the condition) string would appear between the two wheels of fortune, the digit string was to be remembered. This occurred after the participant had selected their chosen wheel. Participants were required to retain the digit string and answer the following question (in order to unload their WM) after the outcome of the wheels had been revealed; ‘what was the digit to the right of X’. During low load trials, digit ‘X’ was always the first of the two numbers to have appeared, for example if the digit string was 3 9, the participants would be asked to recall the digit to the right of the 3. During high load conditions, digit ‘X’ was any of the first 4 numbers in the digit string, for example if the digit string was 4 8 2 7 9, the participant could be asked ‘what was the digit to the right of [4, 8, 2 or 7]?’. Once the outcome of the two wheels had been revealed, participants were asked to report their emotional rating; the same scale was used as in Experiment 1. Participants then unloaded their working memory. See Figure 2.3 for example of experimental procedure in partial and complete feedback with a memory load.

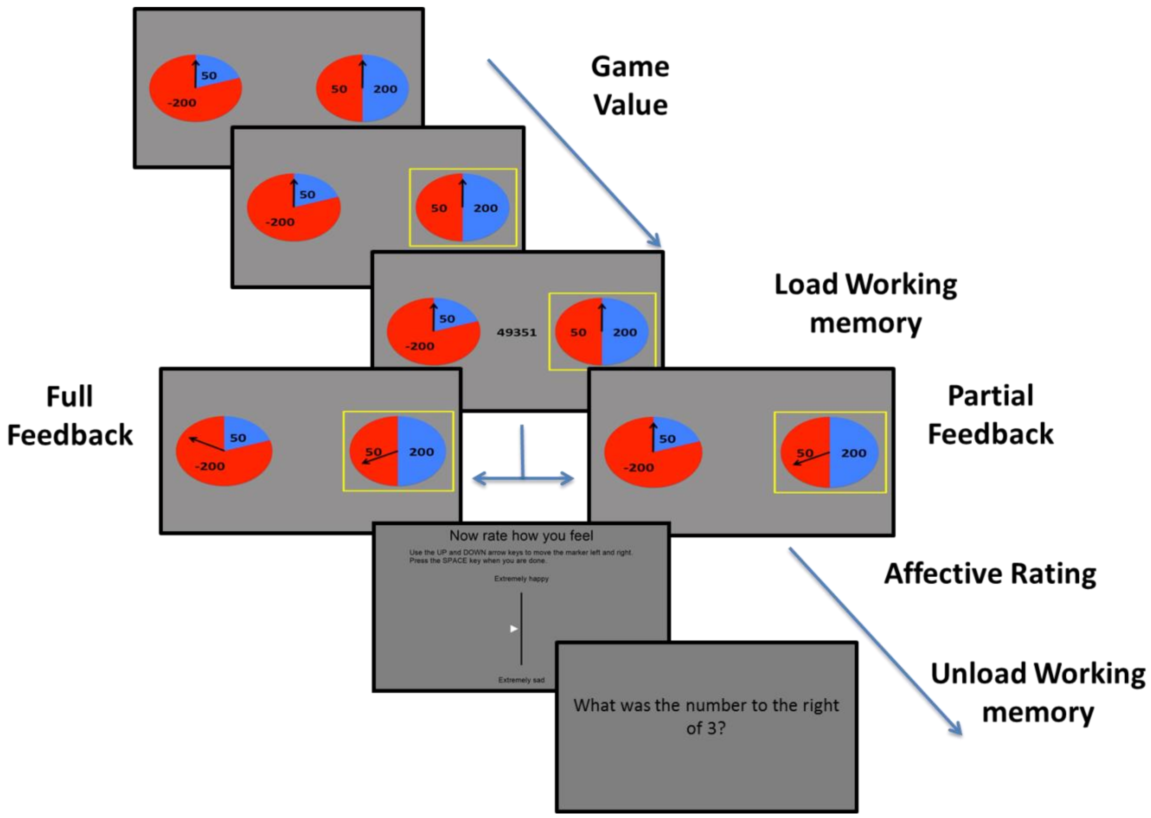


Figure 2.3: Visual example of experimental procedure in chronological order. Figure includes examples of how full and partial feedbacks are presented.

2.5 Results and Discussion

In Experiment 2, participants were given a WM load on each trial. They were required to maintain this load while they observed the outcome(s) of their choice and while they made their emotion rating. First I checked whether participants were able to maintain the WM load in the two conditions, and whether the two conditions differed in effort for the participants. Overall accuracy was very high in both conditions, a paired t-test revealed that participants were marginally less accurate in the high load condition (M = .92, SD = .07) compared to the low load condition (M = .95, SD = .05) WM load; $t(19)= -2.05$, p = .055. Differences in participants' response times when unloading their WM between the WM conditions revealed that high WM load prompted significantly slower responses (M = 1.85, SD = .31) compared to low WM load (M = 1.1, SD = .24); $t(19)= 10.87$, $p<0.001$. These findings suggest that the high WM load condition was indeed more effortful than the low WM load condition.

Figure 2.4 shows the mean emotion rating following the presentation of the outcome of the trial for each combination of WM load, obtained outcome, unobtained outcome and feedback type. In order to examine the effect of WM load on CMEs, a four-way repeated measures ANOVA was conducted with factors WM load (low load and high load); obtained outcome (-50 and 50); unobtained outcome (-200 and 200) and feedback type (partial and complete).

There were three significant main effects. There was a main effect of the obtained outcome, $F(1,19) = 95.64$, $p < 0.001$, partial $\eta^2 = 0.36$. Participants were happier after winning 50 points (M = 10.96, SD = 13.63) than after losing 50 points (M = -4.76, SD = 16.54). There was a main effect of the unobtained outcome, $F(1,19) = 54.82$, $p < 0.001$, partial η^2 =

0.51. Participants reported that they were happier after the unobtained outcome was worse than their own outcome (*M* = 13.67, *SD* = 12.69) than after the unobtained outcome was better than their own outcome (*M* = -7.47, *SD* = 14.05). Finally, there was a main effect of feedback type, $F(1,19) = 4.54$, $p = 0.046$, partial $\eta^2 = 0.008$. Participants reported that they were happier after partial trials (*M* = 4.05, *SD* = 15.65) than after complete trials (*M* = 2.15, *SD* = 18.35).

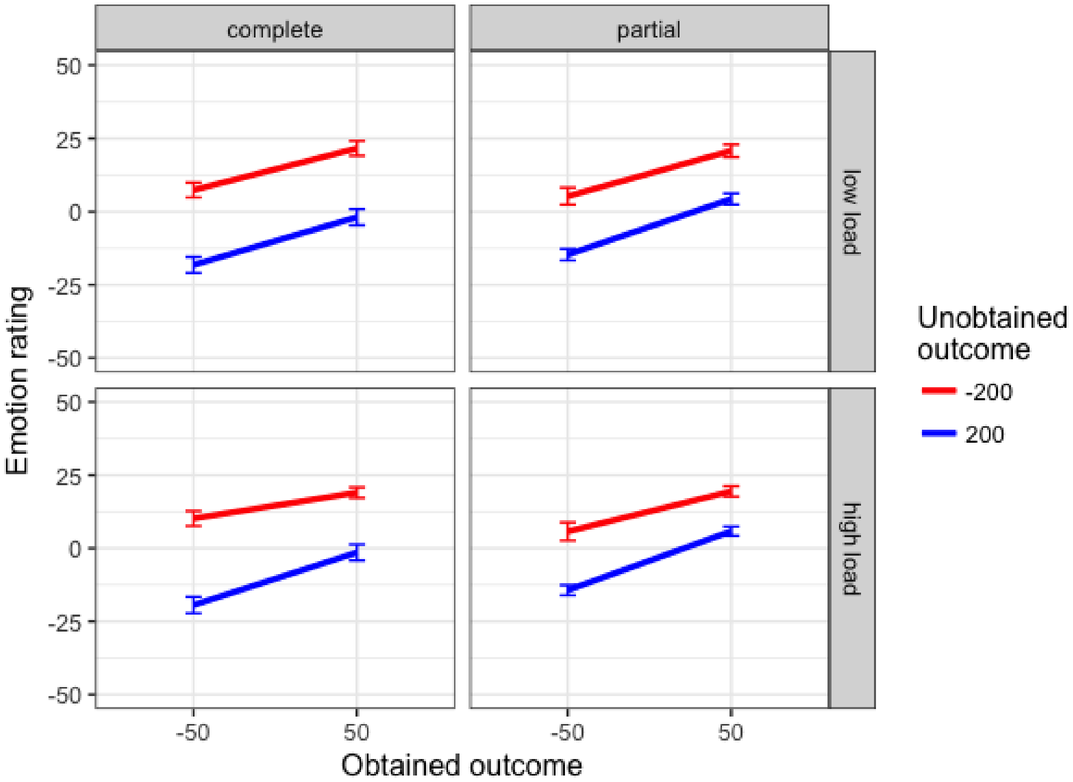


Figure 2.4: Mean emotion rating for each combination of obtained and unobtained outcomes with complete and partial feedback in the two WM load conditions. The slopes of the lines represent the effect of the obtained outcomes, and the differences between the red and blue lines represent the effect of the unobtained outcomes. Error bars represent standard error of the mean.

These main effects were qualified by two two-way interactions and one three-way interaction. There was a feedback type x unobtained outcome interaction, $F(1,19) = 9.12$, $p = 0.007$, partial $\eta^2 = 0.029$. Emotional responses to unobtained outcomes differed in complete trials, $t(19) = 6.58$, $p < .001$, $d = 1.47$, and partial trials, $t(19) = 7.72$, $p < .001$, $d = 1.73$. Across feedback conditions, participants were affected when the outcome was positive, $t(19) = 3.55$, $p = .008$, $d = 0.79$, but not when they were negative, $t(19) = 0.60$, $p > .999$, $d = 0.13$.

An obtained outcome x unobtained outcome interaction, $F(1,19) = 10.79$, $p = 0.004$, partial $\eta^2 = 0.016$ again indicated that participants were affected by the unobtained outcome after obtaining negative outcomes $t(19) = 7.37$, $p < .001$, $d = 1.65$, and after obtaining positive outcomes, $t(19) = 7.15$, $p < .001$, $d = 1.60$. Participants were affected by the obtained outcome when the unobtained outcome was positive, $t(19) = 10.78$, $p < .001$, $d = 2.41$, and negative $t(19) = 7.05$, $p < .001$, $d = 1.58$.

There was also a significant obtained outcome x unobtained outcome x WM load interaction, $F(1,19) = 4.39$, $p = 0.049$, partial $\eta^2 = 0.004$. To examine this three-way interaction, the data were split by WM load condition, and the interaction between the obtained and unobtained outcome was examined for each WM condition. For the low WM load condition, there was no interaction between the obtained outcome and the unobtained outcome, Bonferroni adjusted $p = .38$. In contrast, for the high WM load condition, there was a significant interaction between the obtained and unobtained outcomes, Bonferroni adjusted $p = .002$. This finding suggests that cognitive load interferes with the emotion regulation processes that follow the onset of CMEs rather than the experience of the emotions themselves as the amplification effect was still present after the cognitive load was applied. This fits well with the findings of Goldinger, *et al.* (2003), who showed that participants with lower cognitive capacity were less able to suppress counterfactual thoughts when making judicial decisions.

2.6 General Discussion

We investigated whether the process of experiencing regret is effortful or effortless (perhaps slow or fast). I used a well-established test of regret in which participants made a choice between two risky options and rated their emotion based on the outcome and the unobtained outcome. In Experiment 1, I manipulated the amount of time that participants were exposed to the outcome of the two wheels. The length of time that participants viewed the outcome of the chosen and unchosen wheel did not affect their emotional rating. I then developed a second experiment where WM load was manipulated; the WM load that was given to participants on each trial was either high or low. Results indicated that the WM load did not affect participants' ability to process regret. This suggests that regret is produced and reported effortlessly. In other words encoding and integration happen rapidly in the context of DM. The finding that these processes do not require a significant cognitive effort in relation to DM differs from discourse research (Ferguson & Cane, 2015).

We used methods adapted from the theory of mind (ToM) literature that have argued for the existence of two systems for ToM. The present findings suggest that CMEs rely on fast processing akin to system 1. ToM is closely related to CFT and therefore CMEs, previous research has investigated this link (see Riggs *et al.,* 1998). Qureshi, Apperly and Samson (2010) used a dual-task paradigm to incorporate a Level-1 visual perspective task and a secondary task which isolated executive functioning. On each trial the participants were instructed to either take their own perspective or that of an avatar which appeared on the screen facing one of two ways. Simultaneously an auditory executive task was used (a WM load similar to the digit string used in the current experiment). The secondary executive task did not affect participant's accuracy when assessing the avatar's perspective; however the task did interfere with participants' judging of perspective (self or other). This result points towards two different levels in which we solve ToM tasks. Firstly, a fast system that identifies perspective-taking and secondly a slow cognitively demanding system that is used during more complex thinking about mental states (typically tested in ToM studies). The authors suggest that infants' success in some indirect measure of ToM and perspective taking tasks is due to the utilisation of the first system (Apperly & Butterfill 2009). The findings from the current experiment lends support to Kahneman (2013) first fast system.

Our conclusion that CMEs are produced effortlessly supports Goldinger *et al.'s* (2003) standpoint that counterfactual thoughts are created automatically. In both Goldinger *et al.* and the current investigation, WM was manipulated during a DM process; in order to create a cognitive load. Interestingly, Goldinger *et al.* concluded that the process of ignoring the counterfactual emotion is effortful, but their production is automatic. Thus, their finding that counterfactual thoughts were automatically produced during the encoding stage of judgments is in line with the finding that regret is processed effortlessly.

As previously described, Giorgetta *et al.* (2013) claim that neural signals are differentiated as quickly as 200-300ms when an individual observes loss outcomes in partial and full feedback trials. The results from this investigation build upon Giorgetta *et al.'s* finding that the processing of an outcome happens extremely quickly, as I suggest that the inference that leads to the emotion also happens effortlessly.

However, this claim is out of line with the developmental story, which suggests that experiencing CMEs is cognitively demanding. O'Connor *et al*. (2012) demonstrated that children do not successfully acquire the ability to repot regret until the age of 6. Additionally, Rafetseder, Schwitalla and Perner (2013) suggest that this development does not occur until as late as 13 years. Rafetseder and colleagues conclude that children who fail in their tasks lack an understanding of actions and events that causally underpin counterfactual assumptions. One might assume that late developing processes are challenging and cognitively complex. Furthermore, there is evidence that the development of the ability to experience regret is related to executive processes, specifically attentional flexibility (Burns, Riggs, & Beck, 2012). This also suggested that regret may require cognitive control.

Perhaps a longer-term developmental story is needed here. It could be the case that reporting regret is hard for children but effortless for adults. Burns, Riggs and Beck (2012) showed that that attentional flexibility predicted the experience of CMEs in 5- to 7-year-olds, the age at which children first experience these emotions (*pace* Rafetseder & Perner). It is possible that, with experience, individuals no longer rely on executive skills to process CMEs: the experience of regret becomes effortless. This explanation would account for the developmental and adult evidence by suggesting that for children, who are acquiring the ability, processing regret is effortful, but it is not for adults.

Overall, I aimed to investigate if the process of experiencing regret is effortful or automatic; it was established that the length of time that participants viewed the outcome of the chosen and unchosen wheel did not affect their emotional rating. Due to this finding, a second experiment was devised to which we found that WM load did not affect participants’ ability to process regret. Therefore these results suggest that emotion is produced and reported effortlessly. This finding builds on Goldinger *et al.’s* work that counterfactual thoughts are not only automatically produced during the encoding stage, but suggests that CMEs are also generated effortlessly.

Chapter 3

Patient Methods

3.1 Overview of Project Methodology

I created a test battery to establish if a group of stroke patients' performance on counterfactual tasks, some which included a regret component, differed from that of a group of age matched controls. The test battery was comprised of four experiments: 'Counterfactual Conditional Questions' (Chapter 7), 'Simple Regret' (Chapter 6a), 'Regret and ACS' (Chapter 6b) and Agency[1]. Patients were tested individually either across two 45 minute sessions or in a single one and half hour session. When two sessions were needed, they were completed a maximum of four weeks apart. Control participants were tested in a single one hour session which included a break after 30 minutes.

Participants completed the test battery in the following order during session one: Regret and ACS (Experimental Trial Part 1), Counterfactual Conditional Questions, Regret and ACS (Experimental Trial Part 2). During session two the experiments were completed in the following order: Agency, Regret and ACS (Baseline Trial Part 1), Simple Regret, Regret and ACS (Baseline Trial Part 2).

A second test battery comprised two experiments: 'The RGT' (Chapter 4) and 'Risk Taking' (Chapter 5). For both patients and controls, two separate 45 minute sessions were utilised to complete the second test battery. The two studies were completed no more than 6 weeks apart. It is important to note that the tests are presented not in the order that they were conducted, but in the order that made most logical sense for the thesis.

Ethical approval for experiments conducted with patients, controls and undergraduate students was granted by the University of Birmingham, UK, STEM Ethical Review Committee.

[1] Results for Agency task are not presented

3.1.1 Participants

A total of 17 patients (7 female) aged between 31 and 84 (M = 64.9 years) and 17 controls (12 female) aged between 28 and 74 (M = 59 years) completed all tests in the first test battery. There was no significant difference between the ages of patients and controls; $t(32)=.21$, $p = .22$.Table 3.0 and 3.1 provide information on demographic information.

8 patients participated in the second test battery (see top 8 patients listed in table 3.0). These 8 patients were chosen due to a combination of availability and their responses in the first test battery, effort was made to retain the patients whose responses in the first battery differed from that of controls, although this was not possible in all cases. 15 patients were recruited via the Oxford Cognitive Neuropsychology Centre and 2 patients were recruited via the University of Birmingham.

8 controls participated in experiment examining the use of the RGT (Chapter 4) (see top 8 patients listed in table 3.1). There was no significant difference between the ages of the patients and controls who participated in Chapter 4; $t(14)= -1.41$, $p = .181$. 15 controls participated in the experiment examining risk taking (Chapter 5). There was no significant difference between the ages of the patients and controls who participated in Chapter 5; $t(21)= .55$, $p = .134$.

Throughout my thesis I have opted for the strategy of reporting and discussing only the patients who show a pattern of results different to controls. I have chosen to do this as one aim of this project is to widen the search for brain areas that support CFT, CMEs and DM, thus I am interested in patients who demonstrate different decisional and emotional responses to controls and discussing how their brain damage may have contribute to task performance. I have chosen to do this as I did not want to lose differences in patient behaviour by grouping them for analysis. I had no justification for grouping patients as I did not have a hypothesis regarding how regional damage would affect counterfactual ability, additionally through analysing individual patients against a control mean I am able to make advanced claims about the specific neurology that supports each task for individual patients. I am also able to determine if each patient's cognitive profile affects their performance. A control mean is used to ensure the most accurate behavioural profile of an unimpaired individual is used as a bench mark for comparison. The neuropsychological screening of patients is discussed later in this chapter and throughout the thesis. I will, in the general discussion chapter, compare task performance across all experiments both for individual patients' performance and across the group as a whole.

Table 3.0

Patient demographic information

Patient	Gender	Age at Stroke	Age at Testing	Handedness
PW	F	77	79	R
DJR	M	78	80	R
JB	M	66	68	R
GM	F	67	69	R
JH	M	53	55	R
SAR	F	71	74	R
MP	M	66	82	R
PF	F	65	81	R
TJ	M	66	67	R
PS	F	81	83	R
NB	M	53	55	R
LB	F	44	47	R
RR	M	31	34	R
MG	F	69	71	R
EL	M	62	64	R
MB	M	71	72	R
RP	M	84	85	R

Table 3.1

Control demographic information

Control	Gender	Age at Testing	Handedness
AP	M	72	R
ME	F	74	R
LS	F	62	R
RD	M	61	R
AD	F	60	R
CP	F	59	R
LAT	F	29	R
BS	M	63	R
LT	F	52	R
AB	F	65	R
CM	F	65	R
MW	F	66	R
SW	M	68	R
EP	F	28	R
TH	M	60	R
JB	F	62	R
JM	F	63	R

3.1.2 Neuropsychological screening of Patients

The cognitive profile of each patient was derived 6 months post-stroke using the Birmingham Cognitive Screen (BCoS; Humphreys, Bickerton, Samson, & Riddoch, 2012), an extensive cognitive screen designed to detect cognitive impairments in different domains, including memory, language, attention and executive functioning, praxis and number processing. Within the BCoS there are 22 tests which comprise 32 sub-measures. Individual patients' test scores are compared to age-group specific (50-64 years, 65-74 years or 75+ years) cut offs for each test. Each cut off corresponds to the 5th percentile which was established from 100 controls stratified following the 2001 U.K population census Age X Sex X Education Level distribution (Bickerton *et al.,* 2015).

The BCoS was designed for high inclusion rates, maximizing the number of stroke patients that could be tested. The individual tests were created to minimize the co-occurrence of language or spatial attention deficits, which have been shown to affect results through a co-varying impact on performance which is evident in tests using forced-choice tests and vertical layouts with patients who suffer from aphasia and neglect (Chen *et al,.* 2016).

Through using BCoS it is possible to establish what, if any, cognitive domains each individual patient has difficulty with. Thus, it is possible to establish if a patient's results in an experiment are due to their cognitive impairment (such as WM) or as a result of their brain damage directly. Each patient's BCoS graphic report is presented with their lesion in the below text. Graphical reports were created after BCoS scores were manually entered (http://www.cognitionmatters.org.uk/bcos.php).

3.1.3 Lesion Analysis[2]

For 13 Oxford based patients Magnetic Resonance Images (MRI) were collected using a 3 Tesla TIM Trio scanner at the Oxford Centre for Clinical Magnetic Resonance Research. As in Finsterwalder *et al*. (2017) high-resolution 3D whole-brain T1-weighted scans were acquired using magnetization-prepared rapid gradient echo sequence (MPRAGE) (repetition time 3000 ms, echo time 4.7 ms, flip angle 8 degrees, 1 mm isotropic resolution). Additionally, fluid rapid attenuated inversion recovery (FLAIR) scans were also acquired (repetition time = 5000 ms, echo time = 397, in-plane resolution 1 mm, slice thickness 1.5 mm).

For 2 Birmingham based patients, as in Ultz, Humphreys and Chechlacz (2012), anatomical MRIs were created using a 3-T Philips Achieva MRI scanner with an eight-channel phased array SENSE head coil at the University of Birmingham's Imaging Centre. T_1-weighted sequence (echo time/repetition time = 3.8/8.4 ms, voxel size $1 \times 1 \times 1$ mm^3) were used.

Scan sessions, for 9 patients, were acquired during the chronic stage (> 6 month post-stroke). The remaining scan sessions, for 4 patients, were acquired during the acute stage (< 6 month post-stroke). For 3 patients (SAR, LB and RP) acute (<1 week post-stroke) clinical Computed Tomography (CT) scans, and for 1 patient (MG) clinical MR, were utilized in the lesion delineation procedures.

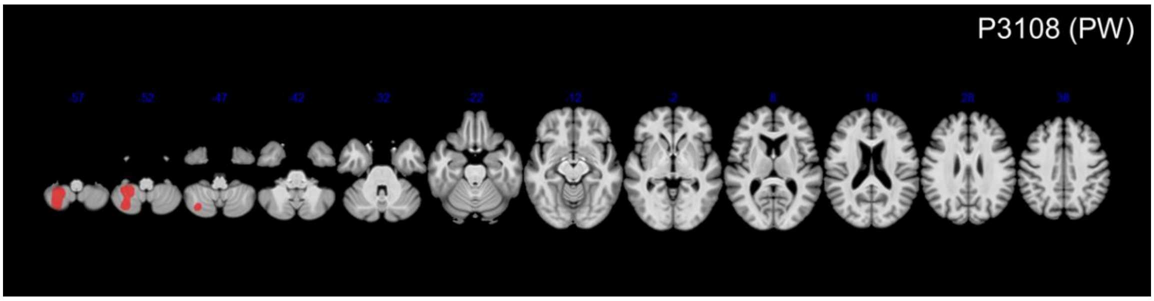
Using MRIcroN software (www.mricro.com/mricron), all lesions were manually delineated, smoothing in the z-direction (5mm full width at half maximum) and binarizing

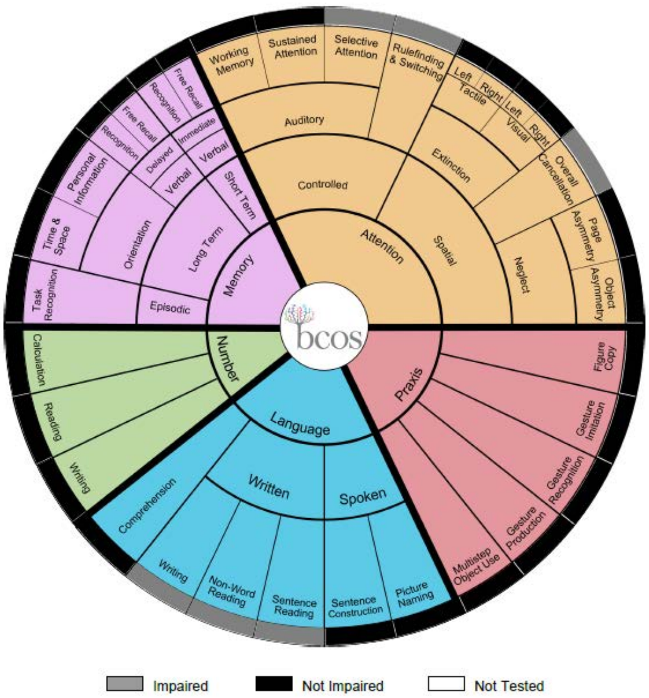
[2] Lesion borders were manually delineated by Jacob Levenstein of The University of Oxford's Physiological Neuroimaging Group.

with a threshold of .5. Patients' anatomical images and lesion masks were then registered to 2x2x2mm stereotaxic space using normalization scripts available within 'Clinical Toolbox' (Rorden *et al.*, 2012; http://www.mccauslandcenter.sc.edu/CRNL/clinical-toolbox) and implemented using SPM8 software (Wellcome Department of Cognitive Neuroscience, University College London, UK; http://www.fil.ion.ucl.ac.uk) (Finsterwalder *et al*., 2017).

PW

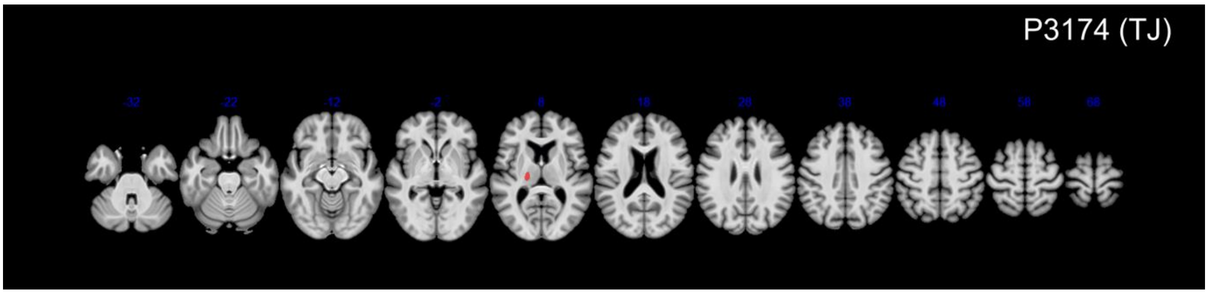
PW suffered a subacute stroke in 2013 resulting in a left sided cerebella lesion. PW had a percutaneous transluminal coronary angioplasty infract as a result of the stroke.

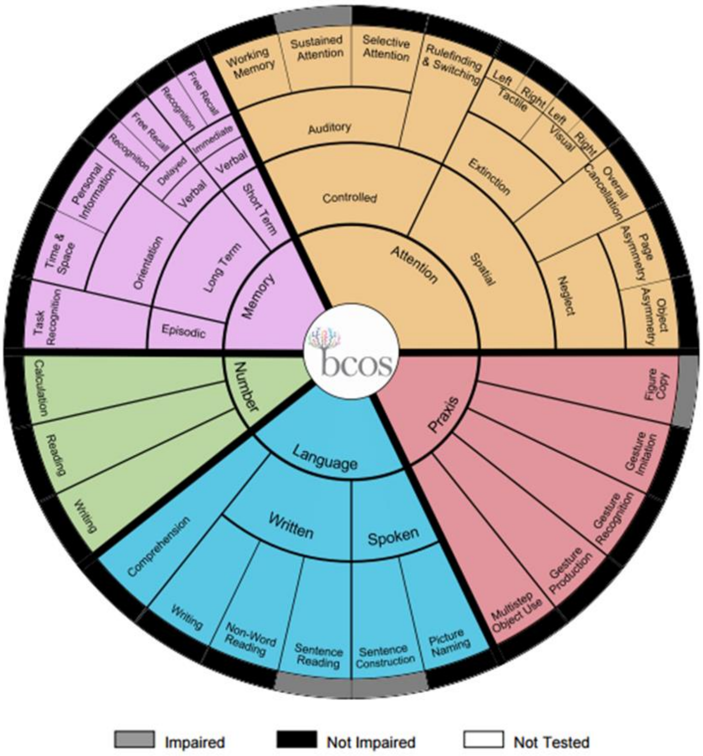




TJ

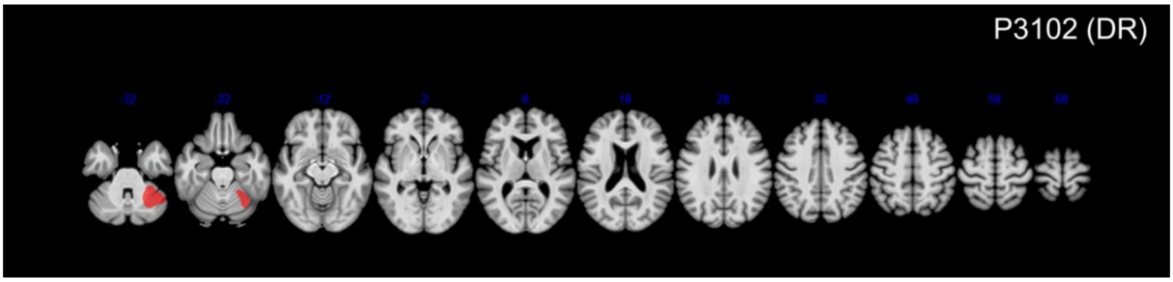
TJ suffered a left thalamic bleed in 2014 which resulted in a lesion in the thalamus.

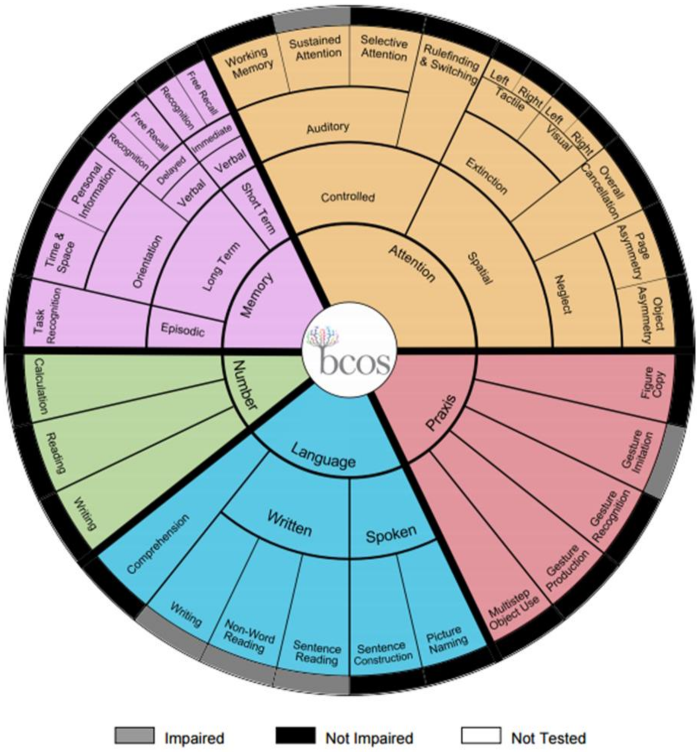




DJR

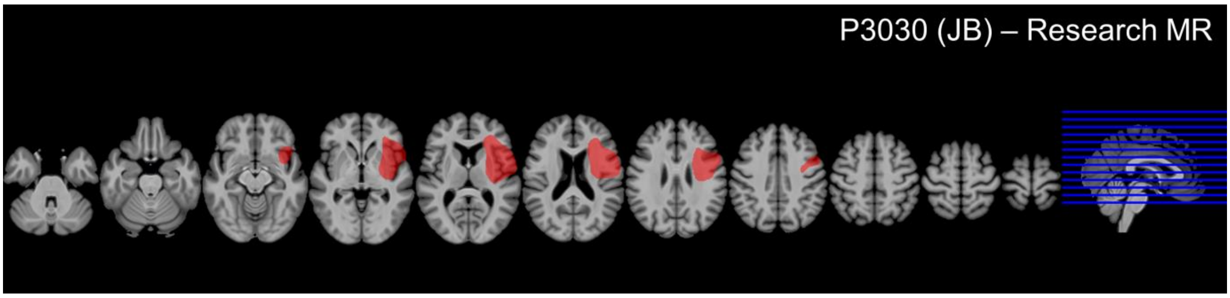
DJR suffered a left sided partial anterior circulation stroke in 2013 which resulted in a right cerebellar lesion.

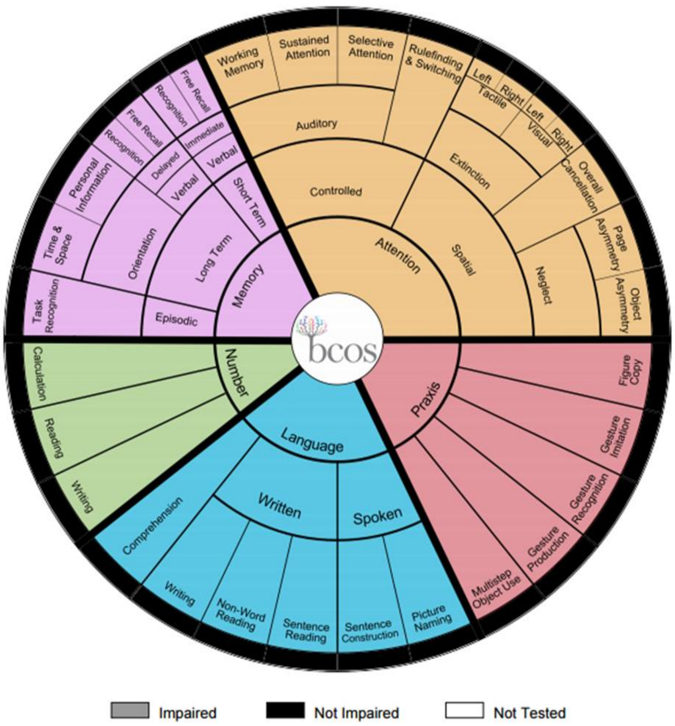




JB

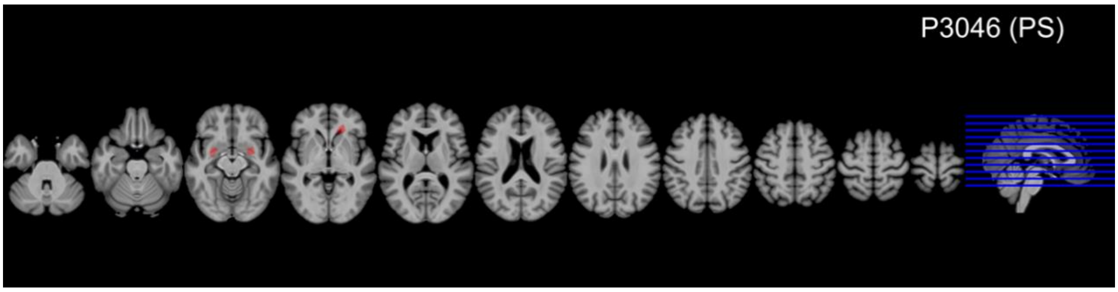
JB had a frontal lobe stroke in 2013. JB's lesion spans the right insula, frontal inferior operculum, heschl gyrus, pallidum, putamen and rolondic operculum. Examination of fraction and extension data demonstrates that JB has damage to the OFC. Although this damage is hard to see on the below scan, it is likely that the lesion extends to caudal end of the OFC.

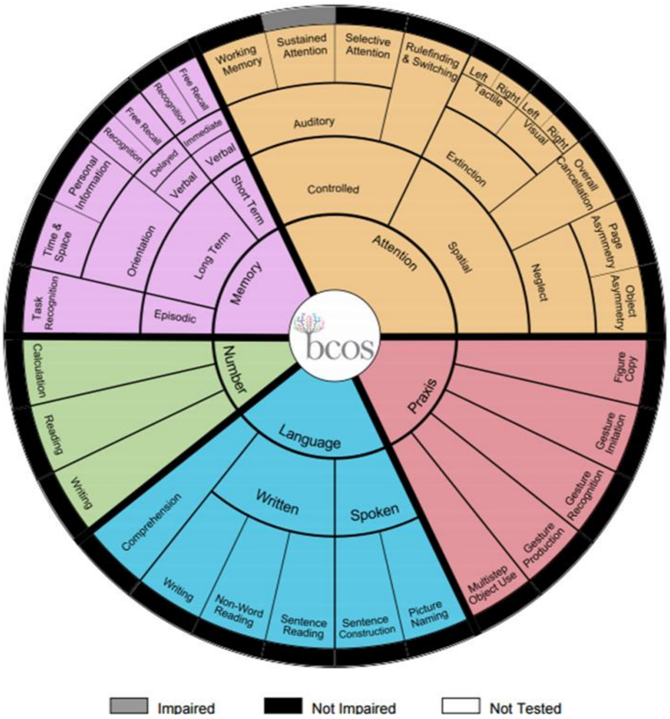




PS

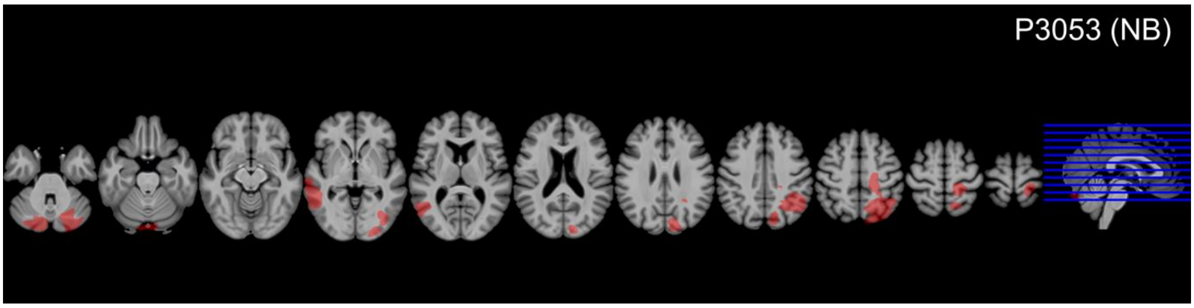
PS suffered a left middle cerebral artery and a posterior cerebral artery embolic stroke in 2012. A bilateral lesion in the amygdala was the result. On inspection of the CT scan, damage to white matter located in the frontal lobe is identifiable. This damage maps onto the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule.

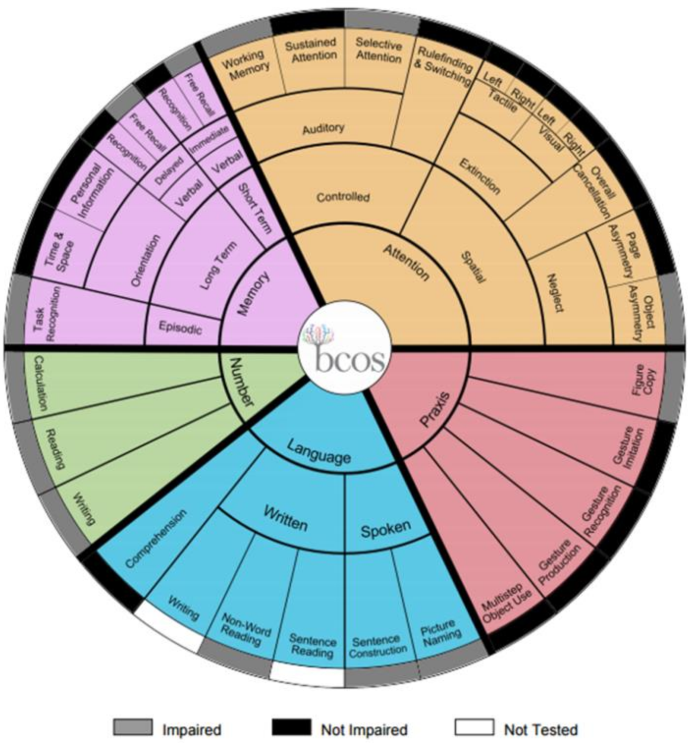




NB

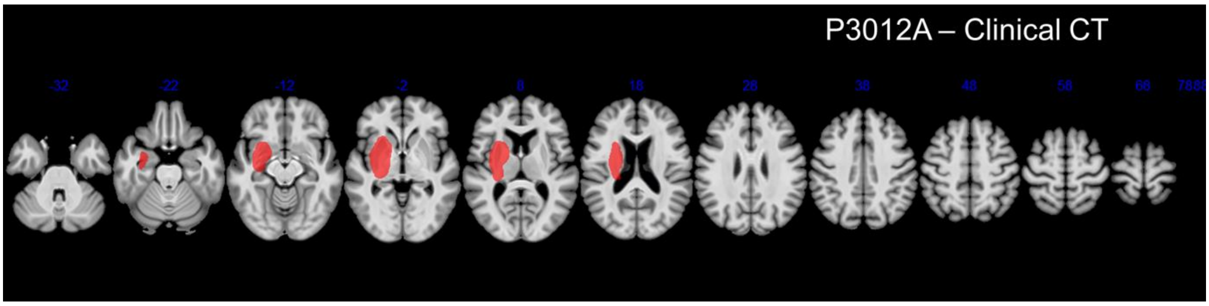
NB suffered a left sided posterior circulation infarct in 2013 resulting in lesions covering the right middle temporal gyrus, right angular gyrus, bilateral cerebellum, right cuneus, right inferior and superior occipital lobe and right superior parietal lobe.

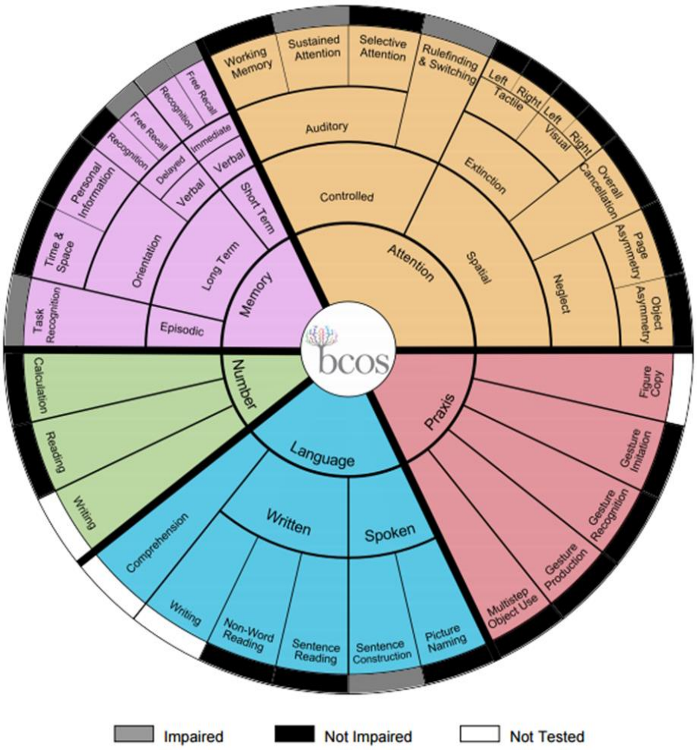




LB

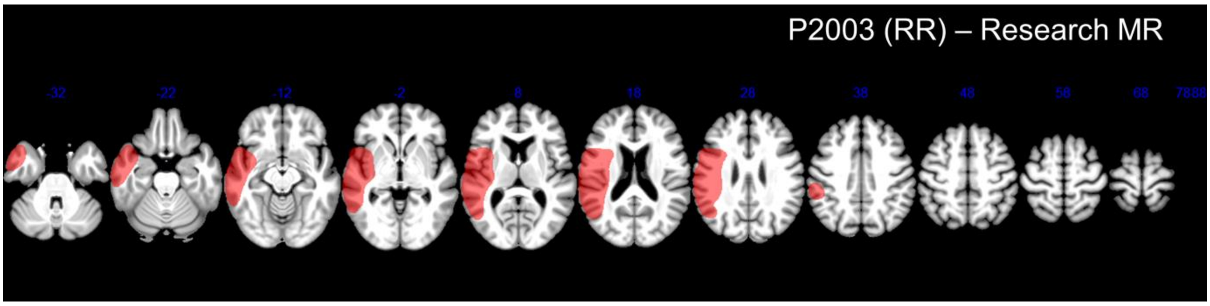
LB suffered a left middle cerebral artery clot in 2012 resulting in lesions in the left insular, amygdala, hippocampus, palidum, putamen and thalamus.

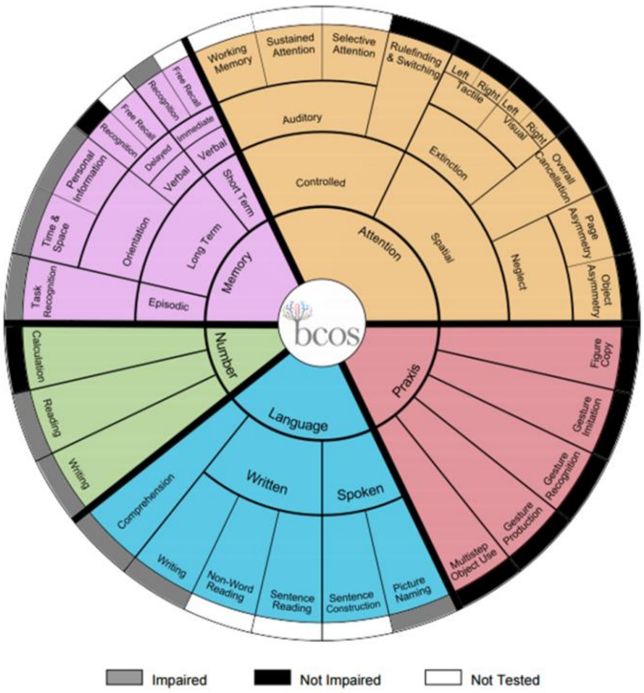




RR

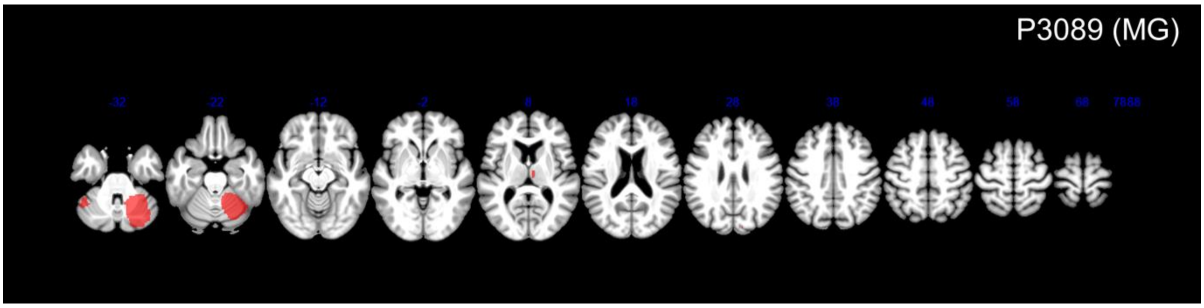
RR suffered a left middle cerebral artery ischemic stroke at the age of 31 resulting in a large lesion to the left temporal lobe, including the inferior, middle and superior temporal gyrus, angular gyrus, temporal pole, and extending into insular cortex, supramarginal gyrus, frontal and central operculum cortex, inferior frontal gyrus, as well as parietal operculum. The possibility of additional damage to the left amygdala cannot be excluded.

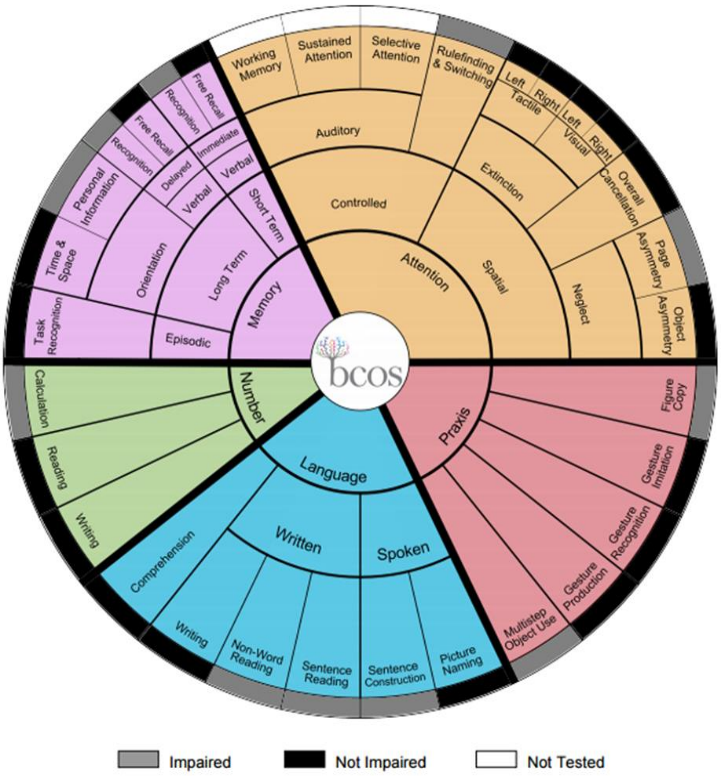




MG

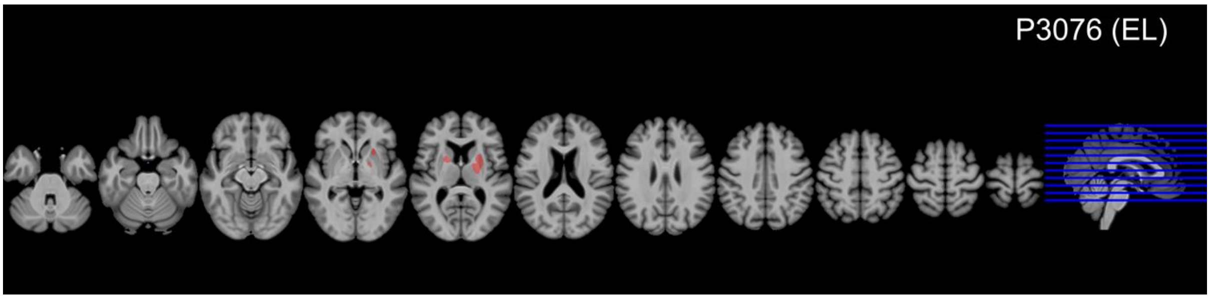
MG had a stroke in 2013 which resulted in a primarily right sided cerebellar lesion with a small amount of damage to the left cerebellum.

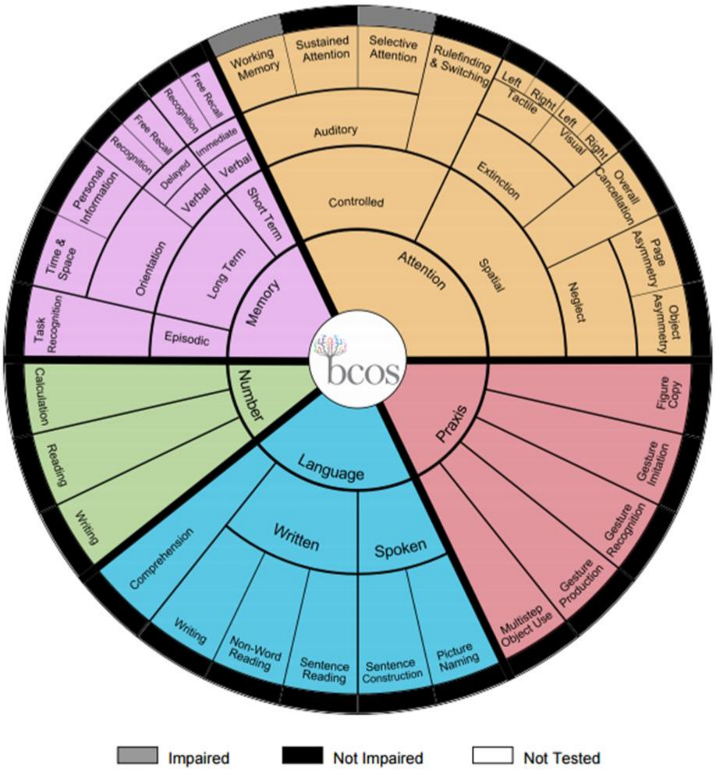




EL

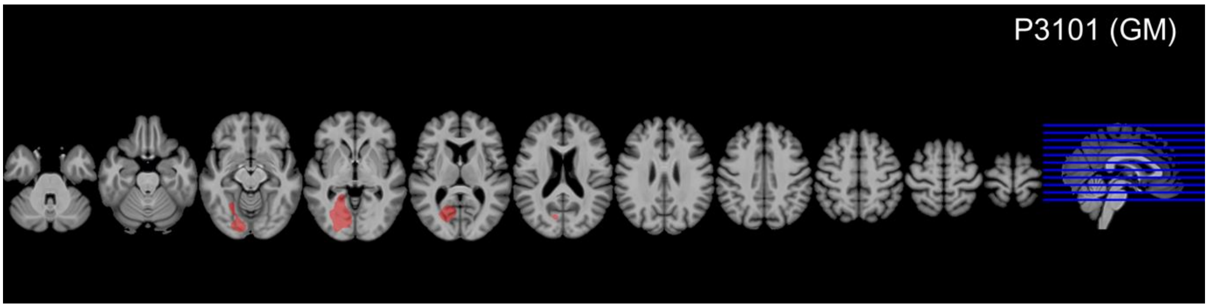
EL suffered a right sided lacunar infract in 2013 resulting a putamen lesion. This damage may extend into the globus pallidus and may have impinged upon the anterior limb of the internal capsule.

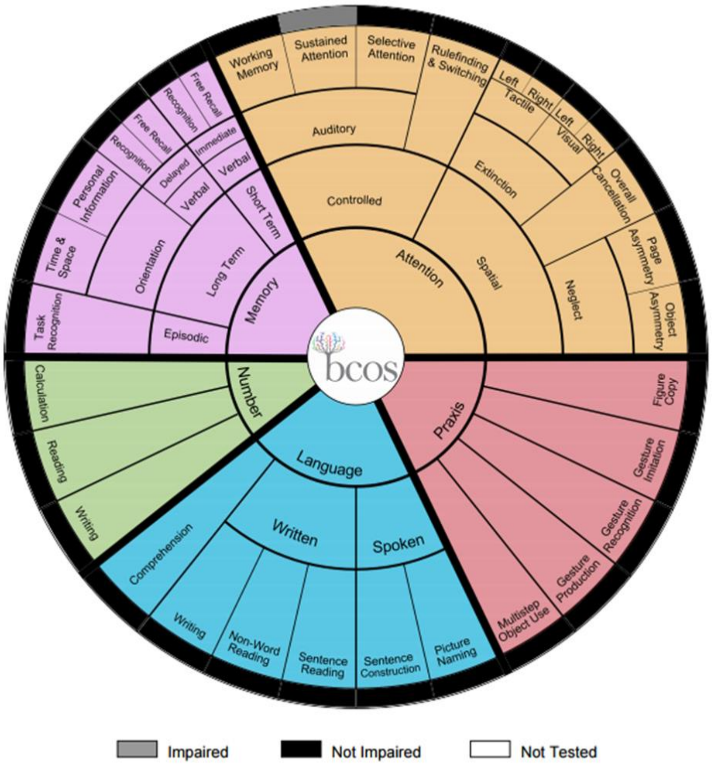




GM

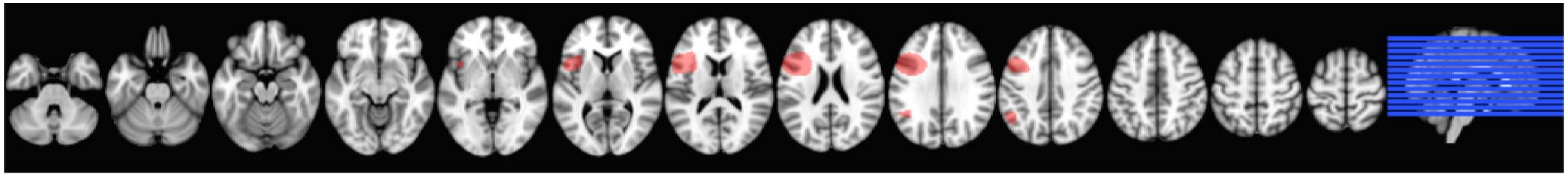
GM suffered a stroke in 2013 resulting in left hemisphere damage in the occipital lobe which extends to the temporal lobe. The majority of GM's damage is in the lingual gyrus and nearby occipital structures including the left intracalcarine cortex and occipital fusiform gyrus.

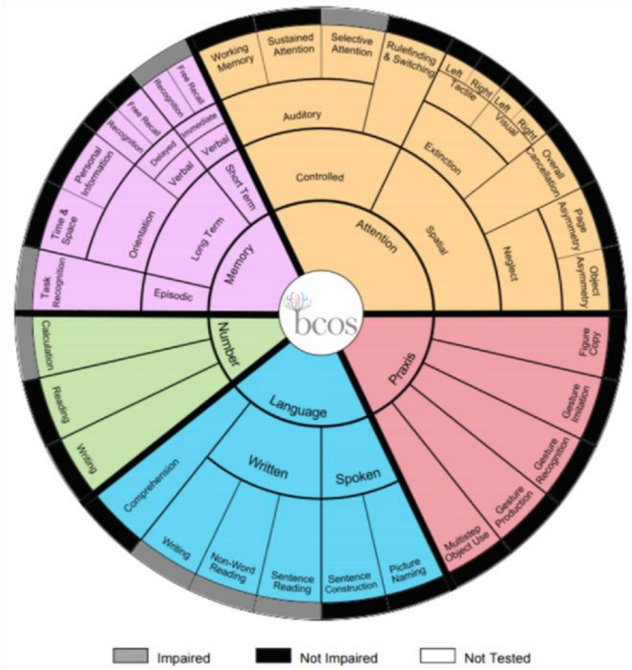




JH

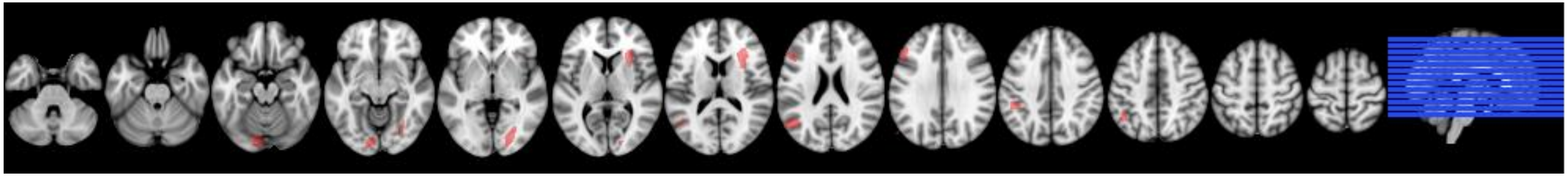
JH suffered a stroke in 2013 causing a primary lesion in left insular and frontal cortex and a second lesion in the left parietal cortex.

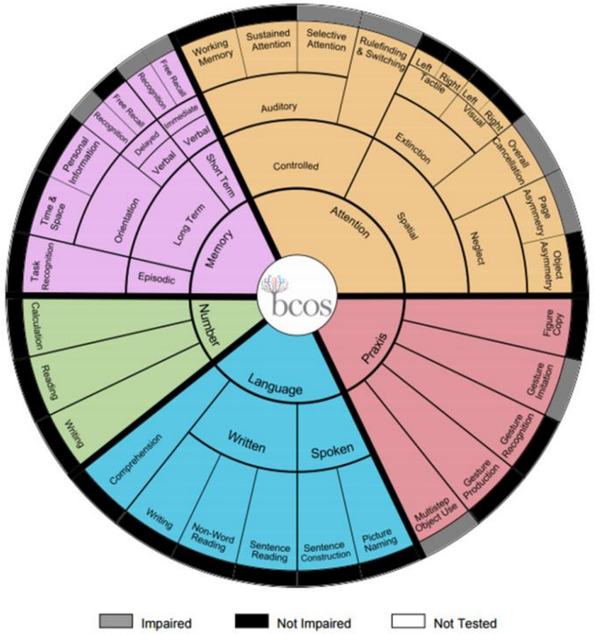




SAR

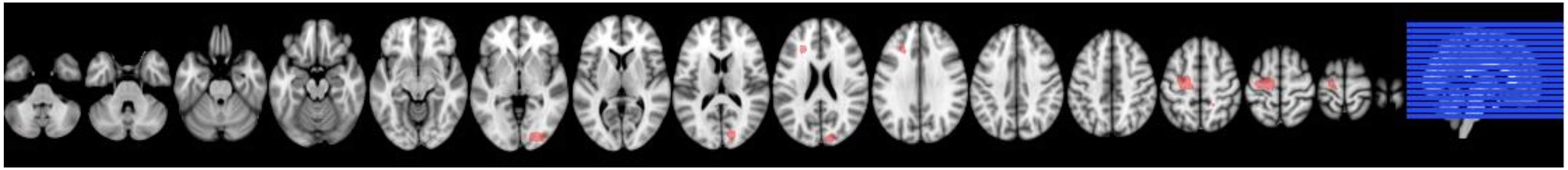
SAR suffered a stroke in 2012 causing bilateral cerebella damage as well as occipital lobe and frontal lobe damage. There is also a small amount of damage to the right insula cortex. This damage maps onto the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule.

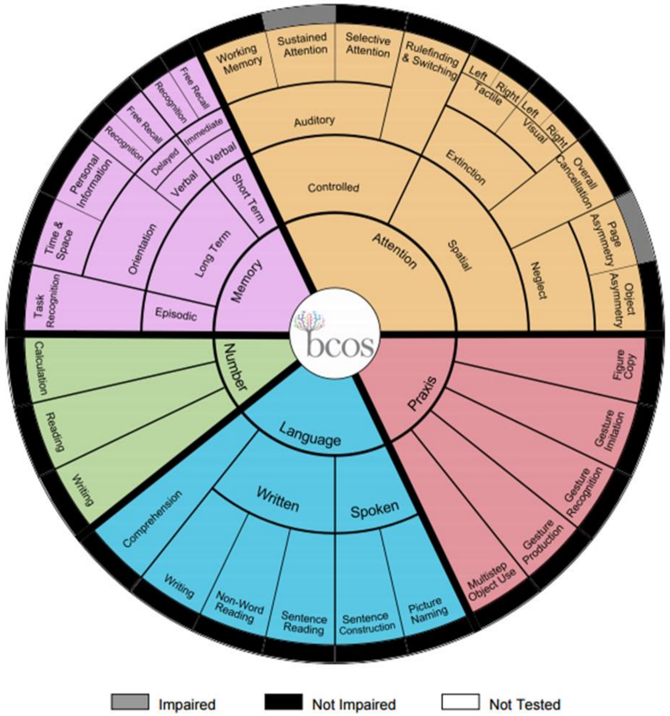




MB

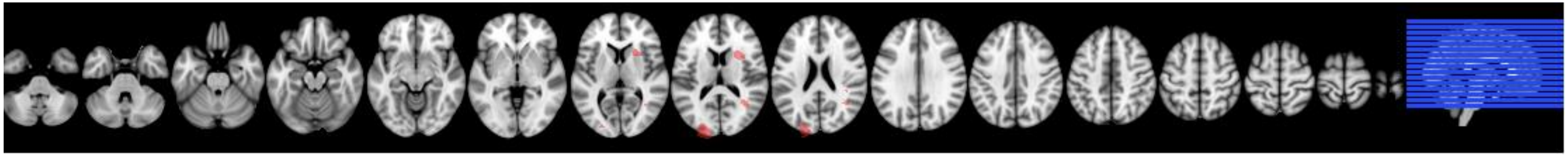
MB suffered a regional myocardial stroke in 2014 causing left parietal and right occipital damage.





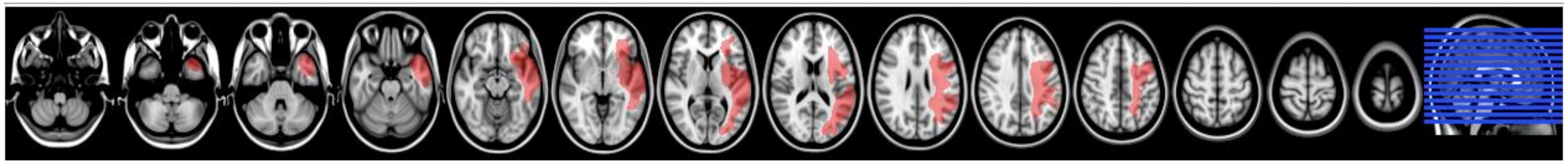
RP

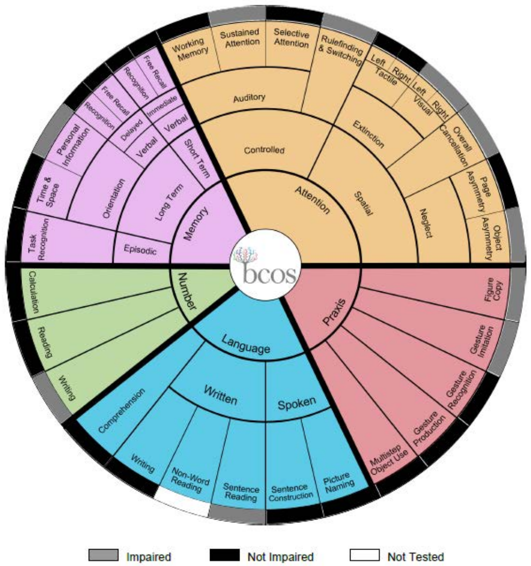
RP suffered a stroke in 2014 causing damage to the right insular as well as frontal and parietal regions. There is an additional lesion in the left basal ganglia. RP has not been tested with the BCoS test battery.



MP

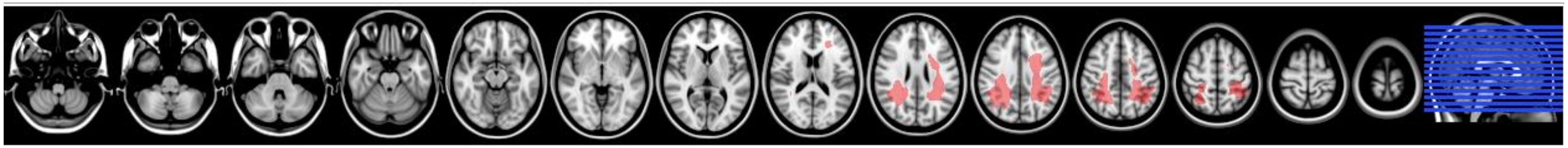
MP suffered a right sided aneurysm in 1998. MP's damage is extensive and affects multiple temporal, frontal and parietal regions. The following key brain areas, for CFT and regret, are impaired: right insular, middle temporal gyrus (anterior and posterior divisions) as well as the temporo-occipital region and the OFC. Additionally, the damage maps onto the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule.

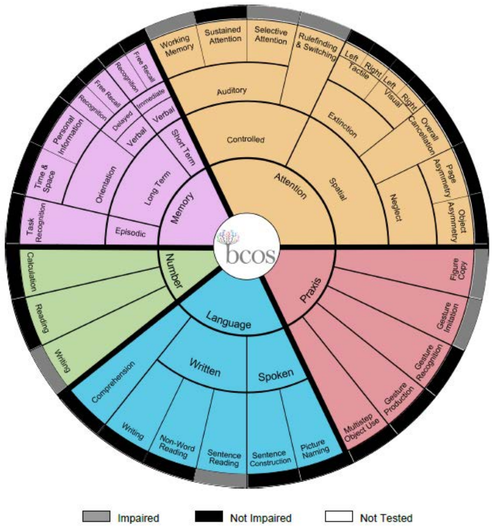




PF

PF suffered a bilateral stroke in 1999 which resulted in bilateral lesions in the superior parietal gyri. The left sided lesion extends into the left angular gyrus and the right sided lesion extends slightly into the right caudate. There is possibly a small lesion in the left thalamus. PF’s stroke resulted in extensive white matter damage which may have affected fibres systems associated with the frontal and parietal cortices. The pathology is not sufficiently focused to make clams regarding the cortical regions that are involved in the tasks used with this project.





Chapter 4

Exploring different emotional responses in the RGT in patients

4.1 Introduction

After the completion of Chapter 2, I decided to use this measure with patients. The first aim of the experiment was to compare results from the RGT from a sub-set of patients who participated throughout the research reported in this thesis, with reported patients in the existing literature. This will allow me to assess if there is any relationship between the results from the RGT and the other experiments used throughout my research. The second aim was to use the RGT to widen the search for areas of brain damage that result in patients reporting emotional responses different to controls. The RGT has been widely used by multiple researchers to assess individual's experiences of regret, quickly becoming the gold standard for analysing CMEs. Thus, I will now review the key literature that has used this task.

One such study that has aided our understanding of the role of the OFC was conducted by Camille *et al.* (2004), who developed the RGT. Partial (eliciting disappointment) and full (eliciting regret) feedback conditions were created to establish if OFC patients' emotional responses to winning and losing were different from healthy controls. It was established that OFC patients, unlike controls, did not report regret over disappointment. It is important to note that OFC patients were not emotionally flat. Patients did report feeling disappointed when losing and feeling happy after winning. For a full description of Camille *et al.'s* (2004) methodology refer back to Chapter 1 'Counterfactually mediated emotions'. This task was adapted for the presented study.

Chua *et al*. (2009) used the RGT with healthy participants to investigate the neural substrates of regret and disappointment. Behavioural analysis showed that during regret conditions (complete feedback) a stronger aversion to losses (numerically identical) was reported in comparison to disappointment conditions (partial feedback). This resulted in a stronger preference for choice switching after experiencing regret. Analysis of fMRI data showed that during both regret and disappointment trials the anterior insula and dorsomedial PFC was active. However, the activation was observed to be stronger for the experience of regret. In addition, enhanced activation in the lateral OFC was recorded for regret. These findings demonstrate that both regret and disappointment share a neural pathway, although the level of activation is altered in accordance with the magnitude of the emotion experienced by the participant.

Further evidence of shared neural pathways for CMEs has been contributed by Canessa *et al.* (2009). The RGT was utilised to show that in healthy participants the same neural network is activated when individuals experience regret and when they observe another individual experiencing regret also. The task was manipulated slightly so that participants not only chose the wheel they wanted to gamble on (own condition), but the participants also observed a third party selecting the gamble wheel and evaluating the outcome for 50% of the trials (other condition). The VMPFC, ACC and hippocampus were all active during own and other conditions. Canessa *et al.'s* (2009) research suggests possible 'mirror-like' neural networks that underpin CMEs.

The RGT has been used, in an Magnetoencephalography (MEG) experiment conducted by Giorgetta *et al.* (2013), to demonstrate that events that typically lead to regret and disappointment are differentiated extremely fast at the neural level (between 190 and 305ms). Similarly to previous research, feedback on gambling trials was manipulated; full and partial feedback. In addition to this agency was also manipulated; human and computer choices were used as well as the outcome of trials; win and lose. It was shown that feedback and agency conditions affected the normal neural responses associated with regret and disappointment. Increased brain activation in the anterior and posterior regions was observed during feedback regret trials, whereas, increased activity in the left anterior region was demonstrated in agency regret trials. Giorgetta *et al.'s* research has highlighted the speed at which neural processing of regret and disappointment occurs.

Damage to the cerebellar has been shown to inhibit patients' ability to report experiencing CMEs. Clausi *et al.* (2015) used the RGT to show that cerebellar patients were impaired, in comparison to healthy controls, in reporting regret. However, the experience of relief, disappointment, and joy did not differ between the two groups. Skin conductance responses (SCR) showed that, despite not reporting regret, patients still had a physiological response to this condition. Interestingly, despite cerebellar patients' inability to report regret, both cerebellar patients and controls demonstrated an ability to anticipate regret and maximized expected values. Unlike OFC patients, cerebellar patients are able to anticipate the most likely outcome of a choice and learn from previous experiences (Camille *et al.,* 2004). These results suggest that the cerebellum is required for conscious self-rating and recognition of adverse emotions.

Research comparing the experience of regret and relief, and how this effects future decisions, in children and adults has also used the RGT. Habib *et al.* (2012) analysed children's, adults' and adolescents' emotional ratings in regret and relief conditions, finding that both the experience of regret and relief are stronger in adults. Additionally, after the experience of regret adults were more likely to modify their choices (gradually becoming regret averse). However, this was not the case for children, suggesting that the experience of regret is not associated with a desire to modify the initial choice. The authors suggest that the difference in emotional capacity and willingness to reconsider decisions is related to the late maturation of the OFC. The RGT has also been used to investigate how CMEs affect DM in adolescent males. Burnett, Bault, Coricelli, and Blakemore (2010) found that the capability to maximise expected outcomes was correlated with age. Interestingly, there was no difference in emotional ratings across age groups although young adolescents showed a greater difference between complete and partial feedback trials than children.

Overall, it is clear that the RGT has produced many interesting findings with various participant groups. Camille *et al.* (2004) demonstrated that damage to the OFC affects the experience of regret, Habib *et al.* (2012) also point to the OFC as important for the experience of regret. Chua *et al*. (2009) showed that regret and disappointment elicit activation in the anterior insula and dorsomedial PFC as well as the in the lateral OFC for regret only. Canessa *et al.* (2009) highlighted activation in the VMPFC, ACC and hippocampus when individuals experience regret and when they observe another individual experiencing regret also. Clausi *et al.* (2015) shed light on cerebellum activity during regret. Overall, there appears to be a network of areas that contribute to performance on the RGT. As an exploratory hypothesis I predict that damage to any of these areas will result in the patient having difficulty performing some, but possibly not all, counterfactual processes. Damage to other brain regions that are connected to those listed may also result in affected counterfactual processing through affecting the counterfactual network indirectly.

It is prudent that this task is used when assessing the group of patients' ability to experience CMEs that are tested throughout my PhD. The patients who took part in this experiment were chosen on the basis of their performance on battery 1 (see Chapter 3) and also their availability. It will be useful to establish if results from the RGT correspond with findings from other experiments examining CFT and CMEs used in my research. Additionally, through using an already established experiment, we can widen the search for brain regions that affect reported emotions and thus add to the knowledge about the relationship between neural regions and the RGT.

4.2 Method

The design of the experiment was closely based upon Camille *et al.'s* (2004) RGT. In the current experiment, a memory check was incorporated on 20**%** of trials. Participants' memory for the outcome of the chosen wheel or the unchosen wheel was tested by a forced answer question which had two numerical responses. Unlike the experiment in Chapter 2, the length of time that participants were able to view the outcome of the two wheels was not manipulated and a WM load was not incorporated. These manipulations were not included because the current experiment was conducted to investigate if any patients did not experience regret (as in Camille *et al.'s*, 2004) or relief, and not to establish if how CMEs are processed.

Participants

A total of 8 patients (5 female) aged between 56 and 81 (M = 71 years) and 8 controls (5 female) aged between 28 and 71 (M = 58.1 years) completed this experiment. 6 patients were recruited via the Oxford Cognitive Neuropsychology Centre and 2 patients were recruited via the University of Birmingham. See Table 4.0 for information on the patients who showed an interesting pattern of results and will be discussed

Patient Profiles

Table 4.0

Description of the patients who are discussed in this chapter

Patient	DOB	Hemisphere	Year of Damage	Description of Lesion
JB	[redacted]	L	2012	Frontal inferior operculum, heschl gyrus, insula, pallidum, putamen, rolondic operculum and OFC
GM	[redacted]	L	2013	Left sided lingual gyrus and nearby occipital structures including the left intracalcarine cortex and occipital fusiform gyrus
MP	[redacted]	R	1998	Extensive temporal, frontal and parietal damage. Damage extends to the right insular, middle temporal gyrus (anterior and posterior divisions) as well as the temporo-occipital region and the OFC. Possible damage to the frontal radiation associated with

				corpus callosum and anterior limb of the internal capsule
JH	[redacted]	L	2013	Primary lesion in left insular and frontal cortex, secondary lesion in parietal cortex
PW	[redacted]	L	2013	Cerebellar
PF	[redacted]	BILAT	1999	Bilateral superior and inferior parietal gyri lesion, left sided lesion extends into the left angular gyrus and the right sided lesion extends slightly into the right caudate. Small left thalamus lesion. Extensive white matter damage to the frontal and parietal cortices
SAR	[redacted]	BILAT	2012	Cerebellar, occipital lobe, frontal lobe, right insula cortex and possible damage to the frontal radiation associated with corpus callosum and anterior limb of the internal capsule
DJR	[redacted]	R	2013	Cerebellar

Note: *L stands for left, R stands for right and BILAT stands for bilateral*

Design

The design of the experiment was identical to that used in Chapter 2.

Materials

Participants rated their emotions using the same scale used in in Chapter 2, however the response scale was flipped vertically. As in Chapter 2, the marker started in the centre of the response line and could be moved upwards towards the "Extremely happy" anchor, or downwards towards the "Extremely sad" anchor. There were 50 interval points on each side of the central starting point.

Procedure

Training: Participants were given 4 practice trials before the start of the experiment. See Table 4.1 for combinations of available points in full and partial feedback conditions. Each participant received the same practice trials in the order shown in Table 4.1. After each trial was completed participants were asked to rate their emotional response to the outcome. During the training phase participants were asked a memory question after each trial. The memory check asked participants either 'What was the outcome on your wheel' or 'what was the outcome on the other wheel'. Participants were then given a choice between two numbers, one of which was the correct answer to the question, for example '-50 or -200'; the choices were always the values associated with the two portions of the wheel in question. No feedback was given for the memory check.

Table 4.1

Combination of points available on left and right wheels, including feedback condition, during training trials.

Left Wheel	Right Wheel	Feedback
-200 / -50	-50 / 50	Partial
-50 / 200	-200 / 200	Complete
-50 / -200	-50 / 50	Partial
-50 / 200	-200 / 200	Complete

Experimental procedure: The experimental procedure was identical to that used in Chapter 2. Thus there were 60 trials.

4.3 Results

4.3.1 The Effect of Feedback

Analysis has been conducted for two purposes. Firstly, to establish if participants and patients experience a different emotional response to regret and disappointment conditions. Evidence for regret is seen when there is a significant interaction between unobtained outcome and feedback condition. Secondly, analysis was conducted to investigate if the patients who took part in this experiment reported different emotional responses to controls.

4.3.1.1 *Controls*

To examine the effect of feedback (complete and partial) on CMEs, a three-way repeated measures ANOVA was conducted, with factors: feedback type (partial and complete); obtained outcome (-50 and 50), and unobtained outcome (-200 and 200). Figure 4.0 shows the mean emotion rating following the presentation of the outcome of the trial for each combination of trial type, obtained outcome, and unobtained outcome.

There were two significant main effects and one significant interaction. There was a main effect of obtained outcome $F(1,7) = 13.87$, $p = .007$, partial $\eta^2 = 0.67$. Participants reported that they were happier after winning 50 (M = 1.28, SE = .26) points than after losing 50 points (M = -.72, SE = .32). There was also a main effect of the unobtained outcome, $F(1,7) = 16.19$, $p = .005$, partial $\eta^2 = 0.70$. Participants reported that they were happier after the unobtained outcome was -200 (i.e. worse than their own outcome) (M = 1.08, SE = .18) than after the unobtained outcome was 200 (i.e. better than their own outcome) (M = -.53, SE = .27).

Separate univariate ANOVAs with 3 factors (trial type, points won and unobtained outcome) were run for each of the controls. Due to the small number of trials (1) that LS encountered in the 'partial feedback, -50 obtained and -200 unobtained' condition, an ANOVA could not be used. After LS was removed, 5 out of 7 controls showed the pattern of two main effects and one interaction, as demonstrated in the group analysis. However, for comparison I will treat the controls as a group.

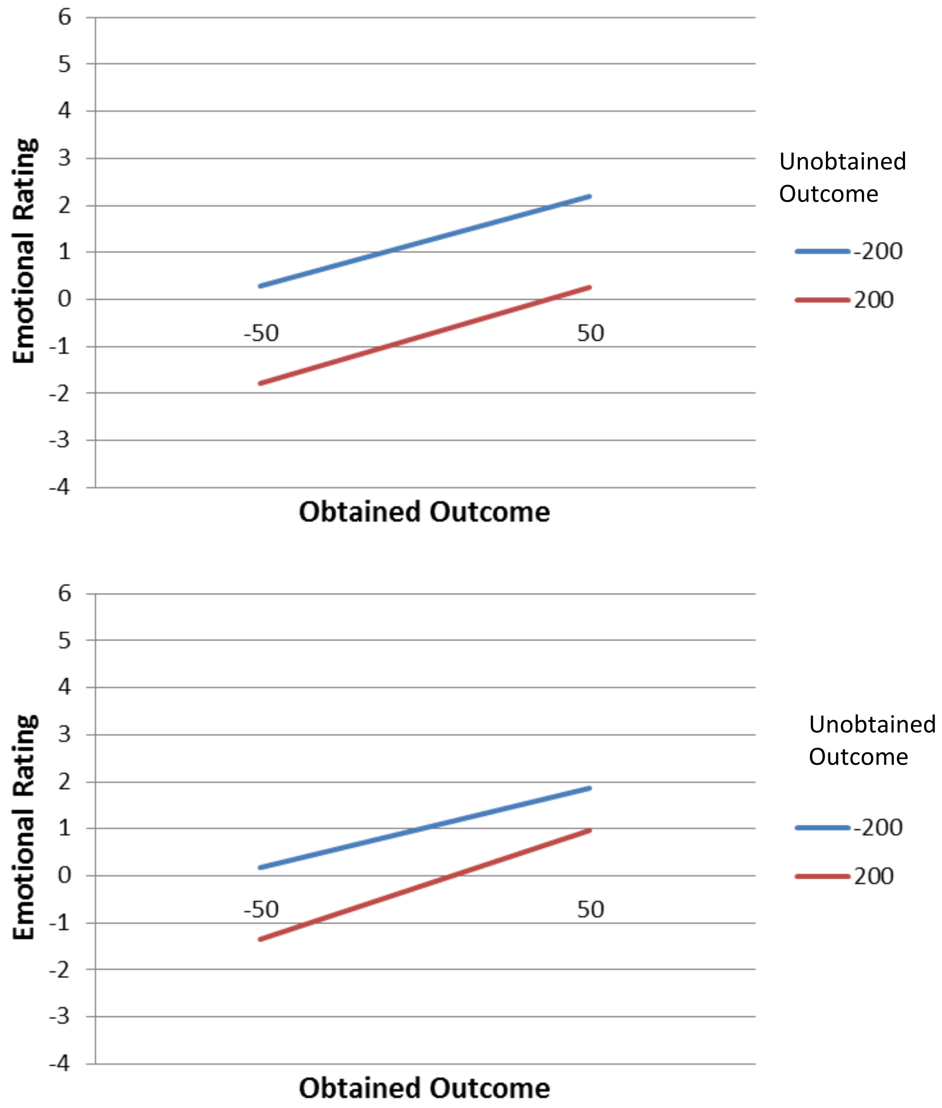


Figure 4.0: Controls' mean emotion rating for each combination of obtained and unobtained outcomes with complete (top) and partial (bottom) feedback. The slopes of the lines represent the effect of the obtained outcomes, and the differences between the red and blue lines represent the effect of the unobtained outcomes.

While there was not a significant effect of feedback (p = .248) there was a significant interaction between feedback and unobtained outcome $F(1,7) = 12.07$, $p = .01$, partial η^2 = 0.63. The interaction indicated that control participants were more affected by the unobtained outcome when they received complete feedback than when they received partial feedback. This finding suggests the "amplification effect" is present, whereby emotions related to unobtained outcomes are felt more intensely when they were missed by choice (regret and relief) than by chance (disappointment and elation).

In order to unpack the interaction between feedback and unobtained outcome I ran four t tests (making a Bonferroni correction for 4 tests, $\alpha = .0125$) to examine the effect of the unobtained outcome. On complete trials participants differentiated between the unobtained outcome of -200 (M = 2.33, SD = .60) and 200 (M = -.10, SD = 1.15); $t(7) = 4.35$, $p = .003$, $d = 2.78$. On partial trials participants also differentiated between -200 (M = 2.04, SD = .629) trials and 200 trials (M = -.49, SD = .52); $t(7) = 5.65$, $p = .001$, $d = 2.78$. Participants did not differentiate between complete and partials trials when the unobtained outcome was -200; $t(7) = -.90$, $p = .40$, $d = .47$, or when the unobtained outcome was 200; $t(7) = -1.38$, $p = .211$, $d = 0.46$. Given the interaction we can infer that the magnitude of the mean difference between 200 and -200 trials is greater in the complete condition compared to the partial condition. This difference explains the ANOVA interaction and further supports the presence of the amplification effect.

4.3.1.2 *Patients*

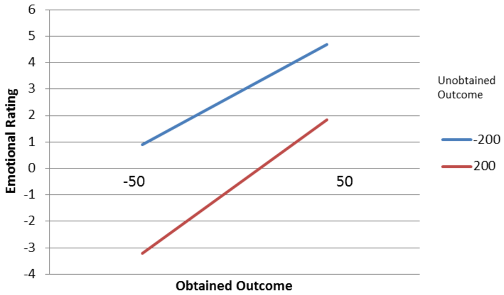
Establishing which patients' emotional ratings are different from controls is important when attempting to investigate a relationship between lesion site and behavioural profile. Moreover, it is important to understand if patients have an isolated problem with reporting emotional experiences in certain conditions (complete/partial or regret/relief). For each patient I conducted a univariate ANOVA with 3 factors (trial type, points won and unobtained outcome) and separate ANOVAs for complete and partial trials to establish if the pattern of patients' emotion responses were different from controls in each of the three conditions. Results from the ANOVAs are presented in Table 4.2. Due to the small number of trials (1) that MP encountered in the 'partial feedback, -50 obtained and -200 unobtained' condition, an ANOVA could not be used, therefore no data for MP is shown in Table 4.2 However, MP's graph does not imply that there are any obvious patterns to his emotional ratings. Each patients' individual mean emotion rating for each combination of obtained and unobtained outcomes with complete (left) and partial (right) feedback is presented in Figure 4.1.

Table 4.2

Results from each patient's univariate ANOVA

	Main Effects			Two way Interactions		
Patient	Obtained	Unobtained	Feedback	Feedback*Obtained	Feedback*Unobtained	Obtained*Unobtained
DJR	.000, 49.21, .61	.000,27.08, .47				.045, 4.38, .12
PW	.000, 16.96, .35	.001, 13.14, .3				.019, 6.15, .17
GM	.001, 14.11, .3	.000, 17.01, .3				
PF	.000, 25.70, .46	.000, 16.77, .66				
SAR	.001, 13.98, .42	.006, 9.69, .34			.037, 5.01, .21	
JB	.000, 142.58, .81		.044, 4.40, .11	.037, 4.72, .12		
JH	.001, 14.29, .36	.000, 18.66, .42				

Note: *The values are presented in the following order: p values, F values and* η^2 *values. Only significant values are presented.*


Emotional Rating
6
5
4
3
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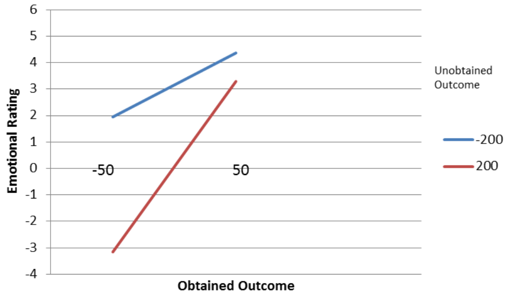
-1
-2
-3
-4
-50
50
Obtained Outcome
Unobtained Outcome
-200
200


Emotional Rating
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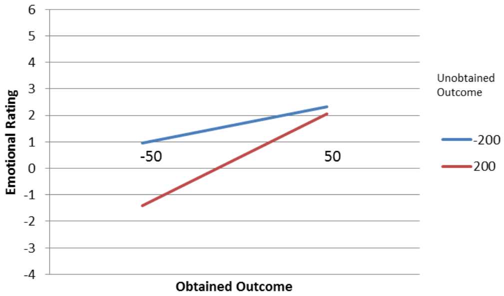
-4
-50
50
Obtained Outcome
Unobtained Outcome
-200
200

DJR


Emotional Rating
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-3
-4
-50
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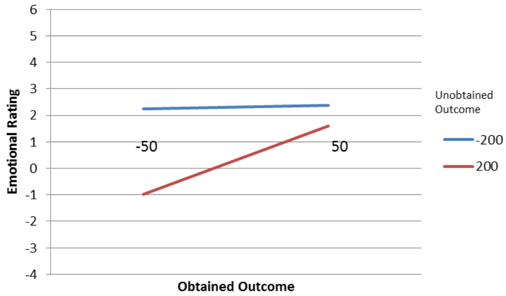
Obtained Outcome
Unobtained Outcome
-200
200


Emotional Rating
6
5
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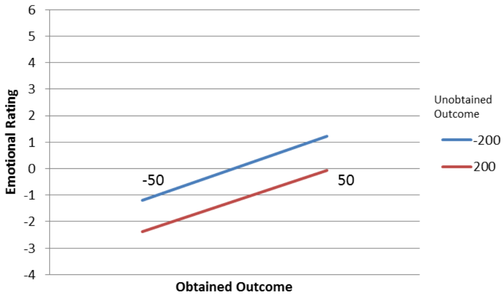
2
1
0
-1
-2
-3
-4
-50
50
Obtained Outcome
Unobtained Outcome
-200
200

PW


Emotional Rating
6
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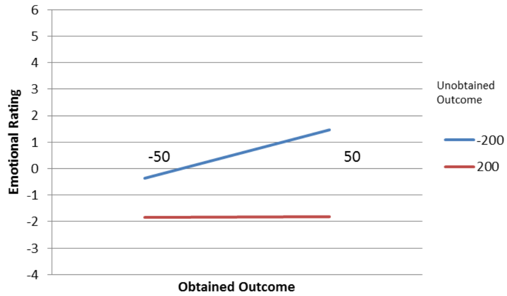
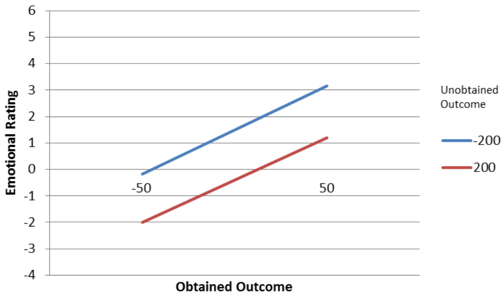
-50
50
Obtained Outcome
Unobtained Outcome
-200
200


Emotional Rating
6
5
4
3
2
1
0
-1
-2
-3
-4
-50
50
Obtained Outcome
Unobtained Outcome
-200
200

GM


Emotional Rating
6
5
4
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2
1
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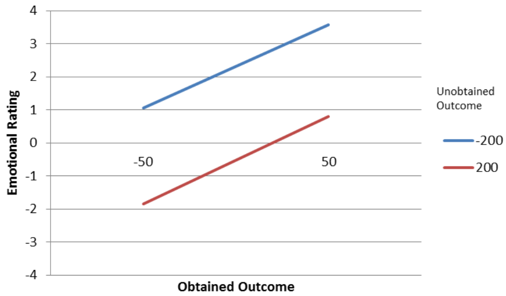
-1
-2
-3
-4
-50
50
Obtained Outcome
Unobtained Outcome
-200
200


Emotional Rating
4
3
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-1
-2
-3
-4
-50
50
Obtained Outcome
Unobtained Outcome
-200
200

PF

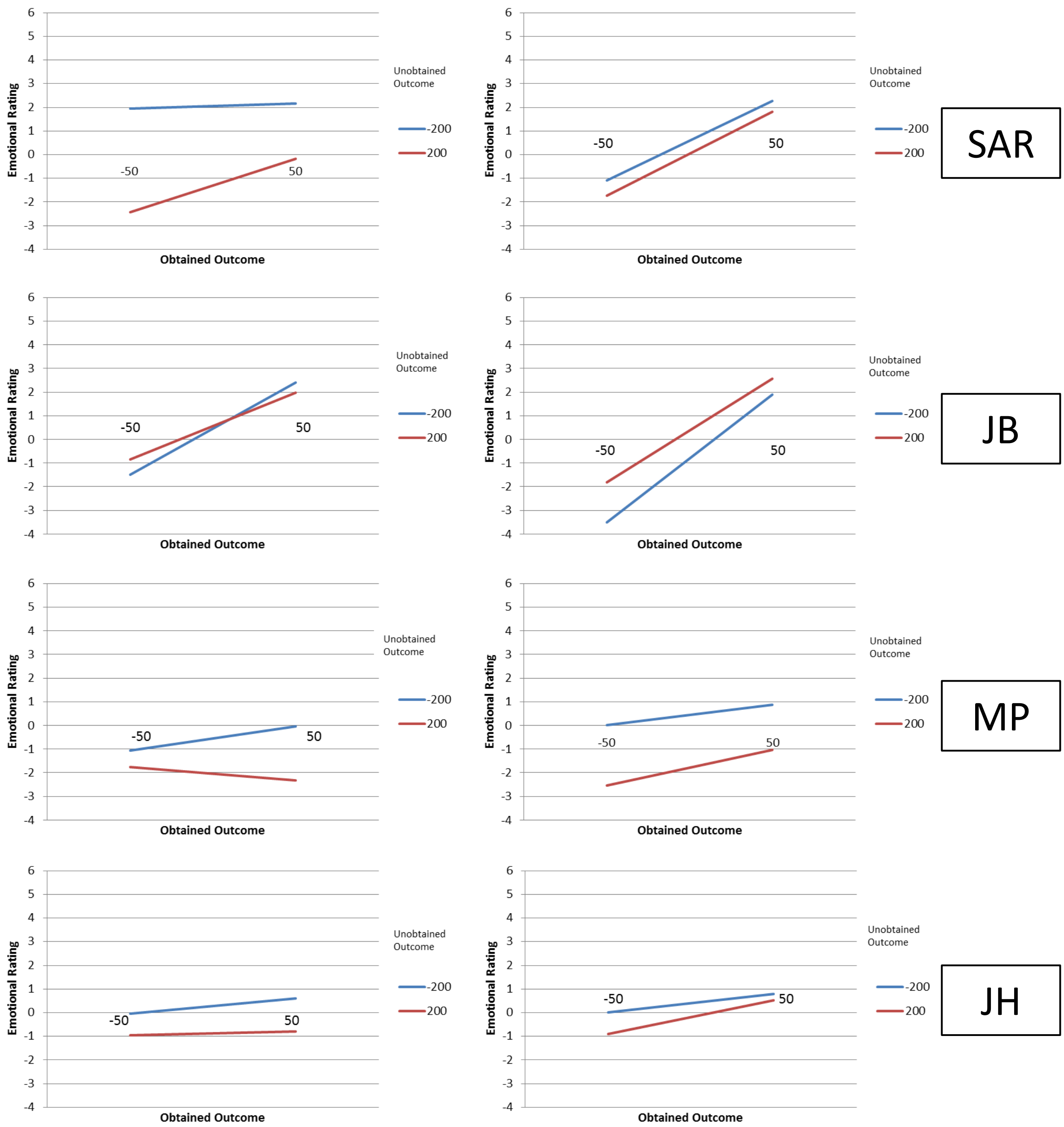


Figure 4.1: Mean emotion rating for each combination of obtained and unobtained outcomes with complete (left) and partial (right) feedback for each patient. The slopes of the lines represent the effect of the obtained outcomes, and the differences between the red and blue lines represent the effect of the unobtained outcomes.

4.3.2 Investigation into the effect of the unobtained outcome

Establishing how patients are affected by the unobtained outcome is important as it sheds light on their experience of regret and disappointment. The amplification effect is present when individuals are more affected by the unobtained outcome during complete (regret) trials, and can be seen in the results of controls in this experiment and also in Chapter 2, compared to partial trials (disappointment). This pattern of responding was reversed with OFC patients in Camille et *al.'s* (2004) investigation; patients were not affected by the unobtained outcome in the complete feedback condition. I investigated the effects of the unobtained outcome by taking the average rating for trials where -200 was unobtained and subtracting this from the average rating for trials where 200 was unobtained. This calculation was conducted for both partial and complete trials. The difference between the average for partial and complete trials produces a figure that is either positive or negative. Positive figures represent the amplification effect whereas negative figures represent a reversal of this (as reported by Camille *et al.* 2004 in OFC patients). The average unobtained ratings for controls (transformed scores) was calculated per participant (see Table 4.3). The standard deviation for these averages was created in order to establish which patients' responses were different from the control population. The effects for patients are shown in Table 4.4; patients' whose responses were 1.5 standard deviations (±1.2) from the control mean (.59) are highlighted.

Table 4.3

Investigation into the effect of the unobtained outcome in control participants

		Trial Type		
Control	Age	Complete	Partial	Difference
AP	72	2.11	1.39	0.71
ME	74	1.58	1.77	-0.19
LS	62	1.36	0.82	0.54
RD	61	-0.07	0.03	-0.1
AD	60	0.67	0.52	0.15
CP	59	2.77	2.59	0.18
LAT	29	2.89	1.59	1.29
BS	63	4.43	2.26	2.17

Table 4.4

Investigation into the effect of the unobtained outcome in patients

		Trial Type		
Patient	Age	Complete	Partial	Difference
DJR	78	1.15	0.91	0.23
PW	77	0.46	0.99	-0.52
GM	67	0.65	1.39	-0.74
PF	65	0.72	1.32	-0.6
SAR	71	1.59	0.72	0.87
JB	66	-0.17	-0.24	0.07
MP	66	0.6	1.04	-0.45
JH	53	1.35	0.66	0.68

NB: Coloured rows highlight patients who fall more than 1.5 SDs away from the control mean. Those patients who fall 1.5 SDs away from the mean are highlighted as 1.5 SDs represent the 95% percentile in the normal distribution curve. Thus, I can be confident that the highlighted patients are responding differently from the controls. This technique is used here and throughout the rest of my thesis.

4.3.3 Memory for obtained and unobtained outcomes

As in Chapter 2 participants' memory for the outcome on the chosen wheel and the unchosen wheel were analysed. In order to examine if there was an effect of participant group on memory accuracy a two-way repeated measure ANOVA was conducted. The two factors and their respective levels were as follows: participant group (controls and patients) and feedback (complete and partial). Figure 4.2 shows the mean memory accuracy by wheel tested and participant group.

There were no significant effects or interactions; control participants' and patients' memory accuracy did not differ ($p = .47$). Feedback did not affect memory accuracy ($p = .07$) and there was no interaction between the two variables ($p = .88$). The lowest memory accuracy percentage for patients was 66% whereas control accuracy, in one instance, was 29%.

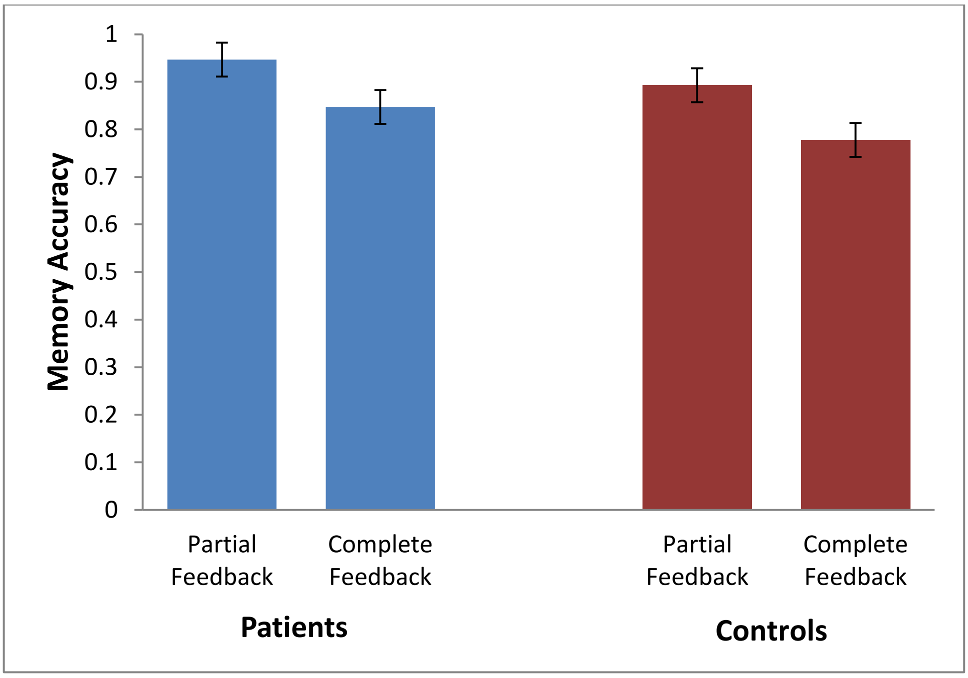


Figure 4.2: Mean memory accuracy when tested on the outcome of the chosen and unchosen wheel for both patients and controls. Standard errors are represented in the figure by the error bars attached to each column.

4.4 Discussion

I investigated the how the experience of regret differs in a group of patients and a group of age matched controls. To do this I used a well-established measure of regret; the RGT. Participants made choices between two gambles and rated their emotions in two conditions where the feedback of the unobtained outcome is manipulated. The experiment was conducted in order to investigate if there is any relation between the patients who demonstrate a difficulty experiencing regret on the well-established RGT and the other experiments used throughout my research. It should be noted that efforts were made to test all patients who demonstrated difficulties with experiencing CMEs during battery 1. Through taking this approach I am also able to widen the search for brain areas that, after damage, influence emotional ratings on this task.

Individual analysis showed that 5 patients did not experience sadness more extremely in regret conditions compared to disappointment conditions i.e. no amplification effect. Only 1 patient showed the same pattern of results to that of the controls (SAR). 1 patient's results (MP) could not be individually analysed due to the number of trials and 1 patient (JB) appears to respond in a pattern which implies he did not understand the task at hand. It is important to note that both JB and MP appear to have OFC damage and thus I might have expected them to demonstrate the same pattern of behaviour observed in the Camille *et al.* (2004) study. However, this is something I could not investigate. Analysis of memory accuracy showed that this pattern of results was not due to poorer memory for patients than for controls.

Analysis of control data on the effect of feedback demonstrated that controls were happier after winning 50 points than after losing 50 points (obtained outcome) and were happier after the unobtained outcome was -200 than 200. Importantly, there was an interaction between feedback and the unobtained outcome. This is the same effect of feedback seen in the undergraduate students tested in Chapter 2. This interaction occurs because controls' emotional ratings for the unobtained outcome are influenced by the feedback they received; controls are rating their emotions as sadder during complete feedback trials compared to partial feedback trials. Thus, the amplification effect is present; more extreme emotions are experienced during regret and relief trials (complete feedback) compared to disappointment and elation (partial feedback). This pattern of results replicates findings from Chua *et al*. (2009) where controls reported a stronger dislike for a loss in complete feedback trials compared to partial feedback trials. The key variable for the amplification effect is choice; participants experience regret and relief when their own choice results in a negative outcome compared to when chance causes a negative outcome (Mellers *et al*.1999; Zeelenberg *et al*., 1998).

Individual univariate ANOVAs were conducted on each patient to investigate if any patients responded in a different way to controls. One patient, MP, did not encounter enough trials in the 'partial feedback, -50 obtained and -200 unobtained' condition for the ANOVA to be conducted, thus MP is excluded from further discussion. It was established that only one patient's results matched that of the controls; analysis of SAR's responses revealed an effect of obtained and unobtained outcome and an interaction between feedback and the unobtained outcome i.e. it appears that SAR experiences regret and relief like control participants. I will now go through each patients' analysis and explain the effects.

Analysis of JB's results showed that he was influenced by the obtained outcome but not the unobtained outcome. This would suggest that JB is not taking into consideration the alternative number of points he could have won; an indication that CFT is not taking place. In addition to this, JB rated his emotions as happier during complete feedback conditions compared to partial feedback conditions. This is the opposite effect of feedback that has been cited in the control literature; regret (a stronger emotion) has been elicited during complete feedback conditions in comparison to disappointment (a weaker emotion) during partial feedback conditions (Coricelli *et al*., 2005). The significant interaction between the obtained outcome and feedback reflects JB's elevated emotional response to the obtained outcome in the complete feedback condition than in the partial feedback condition. It is unclear why JB experiences a more positive emotion after complete trials than partial trials. Thus, it is possible that JB did not understand this task. It is hard to relate JB's responses to any literature conducted with patients or controls; it is unlikely that an individual would feel happier upon discovering their choice led to a loss in comparison to chance leading to a loss. Thus, it is possible that JB did not understand the aim of this experiment (to gain as many points as possible) and responded in a manner that reflects this.

Analysis of results for patients DJR and PW indicate effects of obtained and unobtained outcomes. There was also an interaction between both variables. The interaction revealed that DJR and PW were more affected by the unobtained outcome when the obtained outcome was negative compared to positive. The finding that individuals' emotional ratings are more affected by the unobtained outcome when the obtained outcome is negative has also been described by (Bault *et al.,* 2015). Bault's task was similar to the RGT in that feedback (complete and partial) was controlled during a gambling task between two lotteries. Participants' emotional ratings and eye gaze were recorded. It was found that emotional ratings and eye gaze were affected, during complete feedback trials, by the alternative outcome of the unchosen wheel more after a loss than a win on the chosen wheel. This pattern of results, demonstrated by Bault *et al.* (2015), has only been observed in participants who have initially experienced a differentiation between regret/relief and disappointment/rejoice, thus is it surprising that DJR and PW, whose emotional ratings do not indicate that he experiences regret over disappointment shows this interesting interaction between obtained and unobtained outcomes.

Also JH, GM and PF revealed an effect of the obtained outcome and of the unobtained outcome with no interactions. This suggests that none of these patients are experiencing regret over disappointment.

Additionally, the investigation into the effect of the unobtained outcome demonstrated that GM and PF's responses in partial and complete trials were different to controls; GM and PF were more than 1.5 SDs away from the control mean. The difference between complete and partial conditions was a negative figure, demonstrating that both patients were more affected by the outcome in partial trials over complete. This result is similar to the findings from Camille *et al.* (2004) where OFC patients did not report experiencing regret over disappointment. This pattern has also been observed in Schizophrenia patients (Larquet *et al.*, 2010).

Despite demonstrating similar behavioural responses in this experiment, GM and PF have different pathologies. GM's stroke caused damage to the left lingual gyrus and immediate surrounding areas, whereas PF has bilateral parietal damage which extends to the left angular gyrus and right caudate. Although PF's damage is not sufficiently focused to make advanced claims regarding which damaged region is most likely to have caused her responses in this task, it is clear that PF and GM do not have overlapping damage and in turn the same structures cannot be causing their similar responses.

Previous research using the RGT has implied that regional specificity is accountable for the differentiation between regret and disappointment. The medial OFC has been associated with the experience of regret (Camille *et al*., 2004; Coricelli *et al*., 2005) whereas the middle temporal gyrus and dorsal brainstem have been linked with the experience disappointment (Coricelli *et al*., 2005). Although Chua *et al*. (2009) propose that the same neural network is responsible for regret and disappointment; activating the anterior insula and dorsomedial PFC, while the lateral OFC showed enhanced activation in regret trials alone.

Through widening the search for brain regions that, after damage, appear to influence the ability to distinguish between regret and disappointment, this study has shown that several patients are not affected by the availability of counterfactual information regarding an alternative choice. Thus, these patients do not experience a heightened emotional response in full feedback conditions compared to partial feedback conditions. The patients who have shown this pattern of results have mostly differing lesion sites from each other and importantly do not have damage to the OFC (reported by Camille *et al*., 2004), the medial orbitofrontal region, the anterior cingulate cortex or the hippocampus (reported by Coricelli *et al.,* 2005).

It is important to note that all patients (who we can be confident understand the task) respond with appropriate emotional ratings to obtained and unobtained outcomes. The pattern of emotional responses indicates the preservation of disappointment where the unobtained outcome influences the value rating placed on the obtained outcome. For example patients, like controls, are happier upon obtaining 50 points compared to -50 and importantly are happier when the unobtained outcome is -200 compared to 200. Thus, no patients appear to be emotionally flat, leading me to believe, as demonstrated in Camille *et al.* (2004), that it is the experience of regret that is compromised. I will now discuss the lesion sites of the 5 patients who show differing results from controls and relate their damage to possible reasons behind this discrepancy.

Analysis of JH, DJR and PW's data suggests that none of these patients are experiencing regret over disappointment (no amplification effect). JH has a primary lesion in left insular and frontal cortex and a second lesion in the left parietal cortex. The insula has been cited as an important region for complex DM (Kuhnen & Knutson, 2005) and has also been shown to have limbic connections to the OFC (Barbas, 2007; Zald & Rauch, 2006). The connection between the insular cortex and the OFC may be responsible for JH's emotional responses. It has been demonstrated that the OFC is involved in the experience of regret (Camille *et al*., 2004; Coricelli *et al.,* 2005; Coricelli *et al*., 2007; Levens *et al*., 2014; Sommer *et al*., 2009) and so it is reasonable to suggest that damage that interrupts limbic connections could cause problems in experiencing regret.

It is possible that damage to the frontal cortex, even when the OFC is preserved, could lead to inhibited CFT. McNamara *et al*. (2003) investigated patients with Parkinson's disease and their ability to think counterfactually. It was found that patients had impaired

CFT; this was interpreted as an effect of reduced frontal lobe activation and dysfunction seen in Parkinson's disease. Developmental research has also linked counterfactual ability and the frontal lobe. It is possible that the correlation between children passing counterfactual tasks and tasks of executive functioning are due to frontal lobe maturation (see Beck, Riggs & Burns, 2011).

Larquet (2009) used the RGT with Schizophrenia patients and demonstrated the same pattern of results seen in OFC patients (Camille *et al*., 2004); patients in both studies failed to report regret over disappointment. It is possible that this phenomenon is caused by the frontal lobe dysfunction that is observed Schizophrenia. This suggestion supports findings from Hooker, Roese and Park (2000) who suggest that Schizophrenia patients' impaired counterfactual production is due to frontal lobe dysfunction. Therefore, JH's frontal lesion could affect his ability to think counterfactually and as a result his experience of regret is impaired.

Finally, JH has a second lesion in the left parietal cortex. During Coricelli *et al.'s* (2005) investigation into brain activity in healthy adults during the RGT the parietal cortex was activated in several conditions. Enhanced activity in the parietal cortex was observed during choice selection. The inferior parietal lobe was active when individuals compared the outcome of the chosen wheel and the unchosen wheel and also immediately after the experience of regret. Whereas the superior parietal cortex is active before a choice of maximal expected value. Thus, damage to the parietal cortex could cause a different emotional profile in JH compared to that of controls due to the area's apparent direct involvement in the immediate experience of regret and its involvement in comparing the outcome in the chosen wheel and unchosen wheel (a process that is essential for the experience of regret).

Both PW and DJR have cerebellar lesions. PW's lesion is in the left cerebellum whereas DJR's lesion is in the right cerebellum. Activation in the cerebellum has been shown during DM tasks (Rosenbloom *et al.*, 2012). Its involvement has also been described in the experience of regret in autism (Zalla *et al.,* 2014). However, Clausi *et al.* (2015) were the first to investigate the direct connection between cerebellum damage and the corresponding consequences for the experience of regret. The RGT was used with cerebella-damaged patients and healthy controls. Cerebella patients, like controls, became regret averse; avoiding choices where future regret was likely. However, patients were impaired in their self-rating of regret; there was no difference in emotional rating for regret and disappointment. However, patients were unimpaired in reporting relief. Emotional responses from PW and DJR support the findings from Clausi *et al.* (2015) that cerebellar damage inhibits patients reporting the experience of regret.

Despite the seemingly convincing evidence that cerebella damage affects patients' ability to, at the least, report regret, the only patient to have produced the same pattern of results as the controls during this experiment was SAR who also has cerebella damage. Therefore, is it unclear as to why PW and DJR are inhibited in this task and SAR is not. It is likely that a more fine grained understanding of the cerebellar is needed. Although at this point we can conclude that cerebellar damage can lead to a lack of CMEs, but does not always.

Analysis of GM and PF's data demonstrated that both patients were more affected by the outcome in partial trials over complete trials. This implies that both GM and PF felt stronger emotions during disappointment compared to regret trials.

This indicates that the amplification effect is reversed. To my knowledge this is the only other study (see Camille *et al.,* 2004) which has demonstrated this phenomenon. Therefore, it is interesting that neither GM nor PF have OFC damage. Instead, GM has a left sided lingual gyrus lesion and damage to the nearby occipital structures including the left intracalcarine cortex and occipital fusiform gyrus and PF has bilateral lesions spanning the superior and inferior parietal gyri where the left sided lesion extends into the left angular gyrus and the right sided lesion extends slightly into the right caudate.

The lingual gyrus has been linked to various visual functions such as the encoding of complex images (Machielsen *et al.,* 2000) and processing parts of human faces (McCarthy *et al*., 1999) as well as playing a role in word processing (Mechelli *et al.,* 2000). However, the lingual gyrus, to my knowledge, has not been linked with CMEs.

It is possible that the connection between the lingual gyrus and the amygdala is the reason why GM has a different emotional response compared to controls. Isenberg *et al*. (1999) showed, through using a modified Stroop task, that the both the amygdala and the lingual gyrus became active when participants orally rehearsed emotionally charged words. This pattern of activation was not seen for neutral non-emotionally charged words, Additionally, Kehoe *et al.* (2012) manipulated the emotional arousal associated with various images to investigate the neural correlates of emotional arousal. Stronger activation in the amygdala and lingual gyrus (along with other regions) was recorded when participants viewed high emotion images compared to neutral images. Thus, it is possible that a neural connection between then lingual gyrus and amygdala exists. If this is the case then GM may have affected processing of emotional outcomes which influences her emotional appraisal through a damaged connection with the amygdala.

The lingual gyrus has rarely been associated with CFT and CMEs. DeBrigard *et al.* (2015) demonstrated that the lingual gyrus, along with the VMPFC and lateral temporal gyrus are connected to the hippocampal seed. Although this functional coupling was detected while participants produced counterfactuals regarding ‘other-based’ counterfactuals, it is possible that the lingual gyrus plays a more influential role in counterfactual production, including CMEs, than the literature currently suggests.

Support for this suggestion comes from work by Chandrasekhar *et al.* (2008) who demonstrated that a particular network of brain regions was activated during the feeling of relief (referred to as rejoice by the authors). This network included the right lingual gyrus. Although GM’s lesion is isolated to the left lingual gyrus, there is a suggestion that the area could be involved in the production of CMEs. Further reasons for how GM’s damage, to the lingual gyrus, could affect CMEs are discussed in Chapter 6 and Chapter 8.

PF has bilateral damage to superior and inferior parietal gyri. The left sided lesion extends into the left angular gyrus and the right sided lesion extends slightly into the right caudate. There is also a small lesion in the left thalamus. Due to PF’s left angular and supermarginal gyri and superior temporal gyrus damage she is classified as having damage to the left temporoparietal junction (TPJ) (Samson, *et al.,* 2004). A review on how TPJ damage could affect counterfactual reasoning, and as a result affect the production of CMEs, is discussed in Chapter 7.

The left angular gyrus has been highlighted as a region of interest by Nicolle, Bach, Frith and Dolan (2011). The authors manipulated participants' experience of responsibility over a gamble outcome. The angular gyrus, among other regions, showed increased activation during trials where participants lost a gamble that was chosen for them (less responsibility) and their own choice would have been different. Thus, the angular gyrus is involved in evaluating regret inducing outcomes where an external factor has caused the outcome. The activation in the left angular gyrus increased as a result of perceived outcome negativity. This was interpreted as the regions not having an association with the experience of self-blame. The experience of regret over disappointment is underpinned by the individual's perception of control; regret is felt when there is a choice element and specifically where a violation of expectation has occurred (Girotto, Legrenzi, & Rizz, 1991). Thus, it is unlikely, after considering findings from Nicolle, Bach, Frith and Dolan (2011), that the damage to the left angular gyrus that PF has incurred is responsible for her similar emotional responses in regret and disappointment conditions.

PF's lesion also extends to the thalamus. Rosenbloom and Schmahman (2012) suggest that the thalamus is connected to the PFC and as a result is possibly directly linked to successful DM. The PFC is comprised of three regions: the OFC, ACC, and dorsolateral PFC (DLPFC) (Crews & Boettiger, 2009). The OFC has been linked with emotionally charged DM. However, due to cortico–cortical connections between the DLPFC and the ACC, these regions also support DM (Barbas, 2000). Therefore, the connection between the thalamus and the PFC could be the cause of PF not experiencing the same CMEs as controls.

In addition to PF's damage discussed, PF's stroke resulted in extensive white matter damage which may have affected fibre systems associated with the frontal and parietal cortices. Despite fraction and extension data confirming that the OFC is not among PF's affected anatomy, it is clear that her wide spread damage could have affected the information relay from the frontal and parietal hemispheres to important structures such as the OFC. Thus, it is not possible to draw concrete conclusions as to know PF responds differently to controls in this task. See Chapter 5 and Chapter 7 for further discussion of how white matter microstructural integrity can affect CFT and DM.

It is conceivable that failure in this task could be due to problems with visuo-spatial deficits, and not impairments in CFT. Visuo-spatial perception allows individuals to process visual information regarding the position of objects in space (Pinel, 1993). Visuo-spatial deficits include neglect and extinction. Individuals who experience neglect have impaired awareness of events (including objects) in the contralesional visual field. Individuals who experience extinction also have impaired awareness in the contralesional visual field but when synchronized bilateral sensory stimulation is encountered (Vossel *et al.,* 2013). In order to establish if the patients who responded differently to controls in this task were doing so due to visuo-spatial deficits, their BCoS results were utilised. BCoS scores show that DJR, PW, GM, PF, JB, and JH do not have deficits in neglect or extinction. However, MP has visuo-spatial deficits in object neglect (affecting individual objects) and visual extinction while SAR has page neglect (affecting the spatial frame of reference). It is not possible to rule out MP's visuo-spatial deficits as the cause of his impairment in this task. However, it is interesting to note that the only patient who responses in this task are in line with controls also has a visuo-spatial deficit in page neglect. SAR's success in this task demonstrates that her visuo-spatial deficits has not impeded her performance and sheds light on her abilities despite her neglect.

It is important to note that any patient suffering from simultanagnosia would present as impaired in the current task. Simultanagnosia is a deficit in visual selection characterised by impaired spatial awareness of more than a single object at a time (Chechlacz *et al.*). Simultanagnosia is associated with bilateral parieto-occipital damage (Rizzo & Vecera, 2002). A patient with simultanagnosia would likely fail to process both the chosen and the unchosen wheel in this experiment, making it impossible for them to experience regret and demonstrate the amplification effect in line with controls. The most likely candidate for simultanagnosia is PF, due to her bilateral parietal damage. In order to rule simultanagnosia out as a cause for PF's performance, further tests of her visuo-spatial abilities would be required as the BCoS is not sufficient to diagnose simultanagnosia.

Overall, this study showed that control participants demonstrated the amplification effect, replicating Camille *et al.* (2004). However, 5 patients did not demonstrate this same pattern of responses, implying the amplification effect was not taking place. Analysis of the memory data confirms that this discrepancy between controls and patients is not due to poorer memory in one group. Thus, we can conclude that patients tested in this experiment do not feel emotions more keenly during regret inducing conditions compared to disappointment conditions. Through using the RGT, initially used by Camille *et al*. (2004), I have established that a wider range of patients do not experience CMEs in the same manner as control patients. It is unclear due to the extensive damage caused by certain patients' strokes, which lesion sites cause this discrepancy from controls. However, it is safe to suggest that a range of patients, with differing brain damage, may experience altered emotional responses compared to healthy controls. It is possible that neural connectivity is the reason why widespread damage affects CFT and the production of CMEs.

Chapter 5

Risk Taking in Neurologically Damaged Patients

5.1 Introduction

Regret is an emotion that individuals encounter when considering that the current state of affairs would have been better 'if only' a different course of action had been taken. Experiencing regret is a signal that an individual has negatively evaluated a decision (Zeelenberg & Pieters, 2007). Typically, we make decisions when we do not have factual information about how the outcome would have been altered if a different initial decision was made; in such circumstances regret is induced by creating and comparing the actual outcome to a hypothetical outcome, where we have to imagine what would have happened instead. However, there are situations where factual information is available about how the outcome would have differed if an alternative choice was made, for example placing a bet on a football match; we know which team won, and who we should have placed money on, after the match has ended. In these circumstances, regret is caused by comparing the actual outcome to the counterfactual outcome. Research with healthy adults has shown that the availability of the counterfactual outcome affects behaviour; specifically information regarding a missed opportunity affects risk-taking behaviour (Zeelenberg *et al.,* 1996). Brassen *et al.* (2012) describes behaviour after a missed opportunity as 'regret responsivity'. Regret responsivity occurs after an individual realises that a previous decision has resulted in a missed opportunity to receive a more desirable outcome. This results in subsequent risky taking (i.e. being more likely to task risks).

Risky behaviour is characterised by choices that probabilistically result in loss and adverse consequences. The motivation behind this behaviour is an attempt to maximise the potential gain and is typical when individuals focus on the positive outcome that is available, despite the low probability of attaining it (Clark *et al.*, 2008). Risk taking is a common phenomenon after brain injury and possibly a consequence of some neuropsychological disorders, such as substance use disorders and gambling addiction (Paulus, 2007).

In order to engage in successful DM, one must incorporate information on the expected outcome and actions that may lead to this. This incorporation relies on a series of brain networks that facilitate and underpin successful DM. Disruption to any of the relevant brain regions may result in maladaptive DM and risk-taking behaviour.

One brain region that is widely associated with successful DM is the VMPFC. The VMPFC is comprised of the medial section of the OFC (Brodmann areas 10, 11, 12) and the ventral areas of the medial PFC and ACC (Brodmann areas 24, 25, 32) (Eshel *et al.,* 2007). Individuals who have either sustained an acquired brain injury or have suffered from a stroke in this area have been reported to act in a way which is indicative of poor judgement resulting in riskier DM (Damasio, 1994).

The first laboratory experiment, examining RDM that was conducted with VMPFC patients was the Iowa Gambling Task (Bechara *et al*., 1994). The task required participants to learn the associated wins and losses that occur in four decks of cards. Two of the decks are 'risky'; participants receive some large wins yet they unpredictably experience large losses that result in accumulated debt. The other two card decks are 'safe'; participants can gain small wins, but also small losses, that overall result in profit. Healthy controls chose to select from the safe deck once they had incurred large losses from the risky deck, resulting in an overall profit. However, VMPFC patients did the opposite. Patients did not learn from the outcome of previous choice and continued to select from the risky deck, resulting in an overall loss. This behaviour was interpreted as a fixation on the immediate benefits associated with the risky deck and a lack of consideration for the long term consequences of their risky decisions, the behaviour was named 'myopia for the future'.

The Iowa Gambling Task (Bechara *et al*., 1994) has been used in many further research experiments since the initial study was published. Most research has replicated the initial findings that patients with VMPFC lesions behave in a risk seeking manner. Fukui *et al.* (2005) used the task in attempt to investigate the neural circuitry involved in the task. Healthy individuals took part in the task while fMRI was used. The risk anticipation component of the task induced activation in the medial frontal gyrus. Additionally, during risky decisions, a significant correlation between task performance and magnitude of brain activation was observed. Medial prefrontal activation correlated with participants' net scores. Evidence for the neural circuitry recruited during the task is an indication that neural networks are critical for DM. This evidence suggests that if damage is incurred to the neural network, then DM may be affected indirectly. The neural circuitry that allows for adaptive DM could be as important as the VMPFC itself when considering RDM.

Various brain regions could be involved in DM due to their connectivity to the VMPFC. For example, the insular cortex is highly connected to the VMPFC (Ongur & Price, 2000) as well as being connected to the amygdala and ventral striatum (Reynolds & Zahm, 2005). Activation in the anterior insular cortex has been reported in several stages of DM, such as prior to risk avoidance (activated precedes a riskless choice) (Kuhnen & Knutson, 2005) and risk performance (activation reflects how risk taking an individual is in a given task) (Paulus *et al*., 2003). Lesion studies have also demonstrated the importance of the insular cortex. Clark *et al*. (2008) used four groups of participants in the Cambridge Gamble Task. During this task participants are shown 10 red and blue boxes, the proportion of red to blue boxes were altered in each trial. Within the boxes one token is hidden. The chances of the token being contained inside a particular coloured box is proportional to the number of boxes presented in that colour during that trial. Participants guess which colour box the token is hidden in and are subsequently required to bet a number of points on their decision. Patients with VMPFC damage bet larger amounts, compared to that of controls, on trials where the odds of winning are low, for example when the numbers of blue and red boxes are equal. Patients with insular cortex lesions did not adapt their betting behaviour in accordance with the odds of winning. This profile is consistent with the insular cortex's role of coding the probability of negative outcomes. Overall, the insular group incurred the most bankruptcies throughout the task and accumulated the lowest point score.

In addition to evidence that points to differing brain regions being associated with the decisional processes, Peters and Büchel (2009) note that there are domain-general and domain-specific valuation networks. The authors argue that a domain-general system is required for efficient choice behaviour, which is supported by common neural coding of stimulus value. fMRI was used while participants processed immediate, delayed, and probabilistic decision options. Participants chose between an immediate retrieval of €20 or greater monetary values at a delay, the amount of money gained through accepting the delay and the probability of retrieving the delayed money was manipulated. Behavioural choices did not differ in the delayed and probabilistic decision conditions, and in accordance with this the ventral striatum and the OFC were consistently activated demonstrating a domain-general process when coding for value regardless of the condition: delayed or probabilistic. In addition to this activation, separate neural regions were implicated dependant on the condition. The fronto-polar and lateral parietal cortex and a region in the posterior cingulate cortex was active when participants considered the delayed reward, whereas the superior parietal cortex and middle occipital cortex was active when participants considered the probabilistic reward. These findings are strong evidence for domain-general and domain-specific networks that work alongside one another during RDM.

The aim of the current task is to identify new brain areas that contribute to risk taking. It is possible that particular patients with brain damage in specific areas, that have previously not been reported to affect DM, engage in risker behaviour. Previous tasks used to judge RDM such as the Iowa Gambling Task (Bechara *et al*., 1994) have a large WM component where the participant has to remember which deck of cards is associated with wins and losses respectively. In the current experiment executive demands were reduced by using a simple task which was based up Feeney *et al.'s* (2016) research with children. The task was adapted from Brassen *et al.* (2012) (see also Büchel *et al.,* 2011). In this task participants are presented with a line of eight boxes which are opened one at a time from left to right. Coins are hidden in seven of the boxes, with one box containing a pirate (Feeney) or the devil (Brassen). Participants accumulated the coins as they open successive boxes, however if the box which contains the pirate/devil is opened all the coins are lost. Participants have the choice to 'bank' their coins at any point, before finding the pirate/devil, saving these coins for the rest of the experiment. Once the participant has banked their coins the position of the pirate/devil is revealed (providing information on the missed opportunity).

As in Feeney *et al.'s* (2016) paper, the presented experiment will examine risk-taking behaviour in patients by comparing the number of boxes opened throughout the experiment to the average number opened by controls. Behaviour on trials following a loss will also be explored. Examining these data will allow claims to be made regarding the potential differences between patients and controls of the effects of a missed opportunity.

To my knowledge there are no studies with a patient group that investigate the effect of a known missed opportunity on subsequent DM. It is known that healthy adults engage in riskier behaviour after receiving information on a missed opportunity (Zeelenberg, *et al.,* 1996) thus the current experiment aims investigate risk-taking behaviour and the effects of a missed opportunity on a group of brain-damaged patients. As an exploratory hypothesis, I predict that some patients will not be affected by the missed opportunity and as a result engage in risker DM.

5.2 Method

Participants

A total of 8 patients (5 female) aged between 56 and 81 (*M* = 71 years) and 15 controls (9 female) aged between 28 and 74 (*M* = 60 years) completed this test battery. 13 patients were recruited via the Oxford Cognitive Neuropsychology Centre and 2 patients were recruited via the University of Birmingham. See Table 5.0 for information on the patients who failed, and will be discussed, in this task.

Table 5.0

Description of the patients' information who are discussed in this task

Patient	**DOB**	**Hemisphere**	**Year of Damage**	**Description of Lesion(s)**
JB	[redacted]	L	2012	Frontal inferior operculum, heschl gyrus, insula, pallidum, putamen, rolondic operculum and OFC
GM	[redacted]	L	2013	Left sided lingual gyrus and nearby occipital structures including the left intracalcarine cortex and occipital fusiform gyrus
MP	[redacted]	R	1998	Extensive temporal, frontal and parietal damage. Damage extends to the right insular, middle temporal gyrus (anterior and posterior divisions) as well as the temporo-occipital region and the OFC. Possible damage to the frontal radiation associated with corpus callosum and anterior limb of the internal capsule
JH	[redacted]	L	2013	Left insular and frontal cortex, secondary lesion in parietal cortex.

PW	11/12/1936	L	2013	Cerebellar
PF	[redacted]	BILAT	1999	Bilateral superior and inferior parietal gyri lesion, left sided lesion extends into the left angular gyrus and the right sided lesion extends slightly into the right caudate. Small left thalamus lesion. Extensive white matter damage to the frontal and parietal cortices
SAR	[redacted]	BILAT	2012	Cerebellar, occipital lobe, frontal lobe, right insula cortex and possible damage to the frontal radiation associated with corpus callosum and the anterior limb of the internal capsule
DJR	[redacted]	R	2013	Cerebellar

Procedure

Participants were presented with on screen instructions. The experimenter read the instructions to the participants then gave the participants an opportunity to ask questions about the procedure. The instructions were as follows: '*In this game you are trying to win as many coins as possible. You will see eight boxes. Inside seven boxes there are gold coins. But in one box there is a thief. You can open the boxes one at a time by pressing SPACE. You win* *the coins in the boxes you open. You can end the turn and bank your coins by pressing RETURN. If you open the box with the thief, he steals all your coins on that turn (see Figure 5.0 for example trial). First, let's have a practice. Try to find as many coins as you can.'* There were 6 practice trials before the game started; for the first three practice trials the experimenter completed the trials for the participant in order to demonstrate how to play the game (see table 5.1). The three remaining trials were completed by the participant, if by the third and final trial completed by the participant, no coins had been banked, the experimenter would encourage the participant to bank before the thief was encountered. On trials where participants banked their coins, they were shown the position of the thief in the box array, thus providing the participant with information on the size of the missed opportunity on that trial. The experiment was designed in 4 blocks of 20 trials. This design was used in order to provide patients an opportunity for a break if they became fatigued.

Table 5.1

Example of three demonstration trials and participants' choices during the training phase

Condition	Thief Box	Boxes Opened	Coins Won
	1	1	0
Experimenter Demonstration	5	5	0
	2	1	1
	4	3	1
Participant Choice	3	2	1
	2	2	0

NB: during the participant choice condition, the number of coins won is dictated by the participant's choice of how many boxes to open and when to bank. The table above is an example of one participant's choices during this condition.

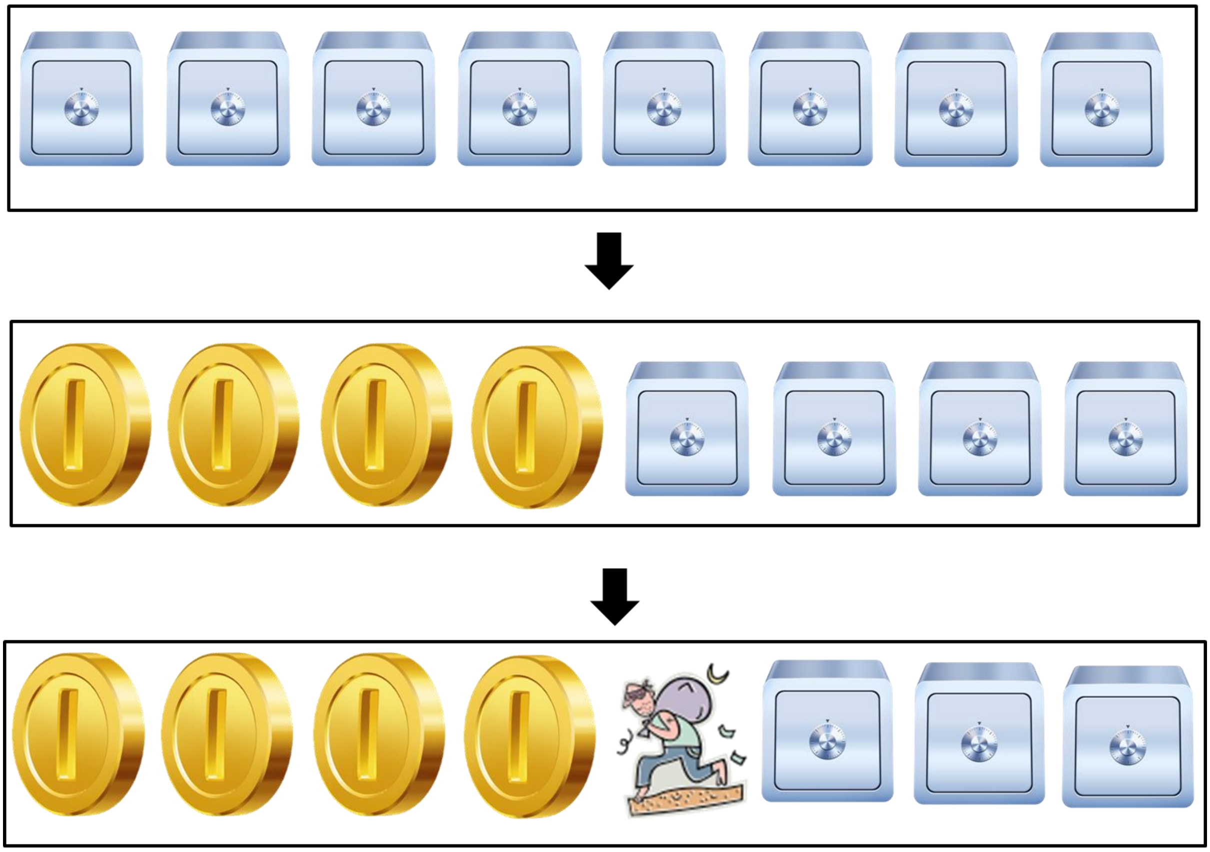


Figure 5.0: Example trial where participant has failed to bank before opening the safe where the thief is hidden. If the participant had banked on opening the fourth safe then they would have collected four coins. However, the participant opened five boxes in this trial and thus failed to accumulate any coins on this trial.

5.3 Results

5.3.1 Conditions

Keep trials were trials where participants chose to bank before encountering the thief. Bust trials were trials where the participant opened the thief box without banking and thus lost their coins for that trial. Four different conditions were calculated based on two consecutive trials from the data: keep_keep, keep_bust, bust_bust or bust_keep.

5.3.2 Data Coding

The analysis conducted by Büchel *et al*. (2011) which established the predictive effect of losses and missed opportunities was replicated. The aim was to predict the number of boxes opened (an indicator of risk taking) in trial t by examining trial t-1, that is, whether it contained a large and small missed opportunity. Missed opportunities were defined as the difference between the number of coins won and the number of coins that could have been won (dependent on the location of the thief). Missed opportunities could only happen on keep trials. A large missed opportunity was defined as there being 3 or more boxes that could have been opened before finding the thief, while a small missed opportunity meant there were only 2 or fewer boxes that could have been opened.

It was hypothesised that a large missed opportunity would lead to riskier behaviour in control participants (Büchel *et al.,* 2011). The aim of the experiment was to investigate if this phenomenon held in the patient population. In order to investigate this, keep_keep trials were analysed to establish if the size of the missed opportunity in trial t-1 affected the number of boxes opened in trial t. The first trial in each block was not used in analysis because there was no t-1 trial due to the break between blocks.

The Number of Boxes Opened

The number of boxes opened by both patients and controls was examined as a measure of general risk taking. Büchel described the point at which an individual is equally likely to continue opening boxes or bank as the 'individual indifference point'. The overall mean group indifference point for controls was 3.05 ±0.08 (mean ± sem), demonstrating that up to 3 boxes controls were likely to continue but after which they were likely to stop. During trials where participants banked before hitting the thief, the average number of boxes opened was 3.56, during bust trials the mean number of opened boxes was 2.58.

The overall mean group indifference point for patients was 3.39 ± 0.18 (mean ± sem), demonstrating that, as for controls, up to 3 boxes patients were probabilistically likely to continue but after which they were likely to stop. During trials were patients banked before hitting the thief, the average number of boxes opened was 3.71, during bust trials the mean number of opened boxes was 3.15. The comparison between the number of boxes opened on average between controls and patients suggests that patients were engaging in risker behaviour, thus this was further investigated

In order to establish if specific patients were choosing to bank more or less frequently than controls, the average number of boxes patients opened and the percentage of boxes opened on keep trials was calculated. The number of boxes patients opened was compared to the control mean (M = 3.07). Patients who were more than 1.5 standard deviations (1.5 *SD*s = .43) away from the control mean are considered to be engaging in more riskier/cautious behaviour (see tables 5.2 and 5.3 for figures).

Table 5.2

Number of boxes opened and percentage of boxes opened by controls

Control	Total Average of Boxes Opened	Percentage of Boxes Opened on Keep Trials
LAT	3.20	48%
AD	2.76	58%
RD	3.09	45%
CAP	3.48	33%
EP	3.49	47%
AB	3.23	43%
ADP	3.12	43%
BS	2.65	57%
CM	2.68	62%
JB	3.03	52%
JM	3.09	56%
LS	3.08	40%
ME	2.98	47%
MW	3.16	56%
SW	2.84	42%

Table 5.3

Number of boxes opened and percentage of boxes opened by patients

Patient	Total Average of Boxes Opened	Percentage of Boxes Opened on Keep Trials
DJR	3.35	43%
GM	2.5	68%
JB	3.45	34%
JH	2.9125	40%
MP	4.1375	35%
PF	2.9	55%
PW	3.375	60%
SAR	3.925	19%

Table 5.3 shows that 2 patients are more than 1.5 standard deviations above the control mean (MP and SAR) whereas 1 participant was more than 1.5 standard deviations below the control mean (GM). No controls were above or below 1.5 standard deviations of the control mean.

5.3.3 Effect of missed opportunity

A paired t test was conducted on control data to establish if the size of the missed opportunity in trial t-1 affected the number of boxes opened in trial t. The data indicated that after a large missed opportunity, controls were significantly more likely to open more boxes (M = 3.99, SD = .80) compared to the number of boxes opened after a small missed opportunity (*M* = 3.57, *SD* = .61); t(14) = 2.79, *p* = .014. Figure 5.1 represents the significant difference.

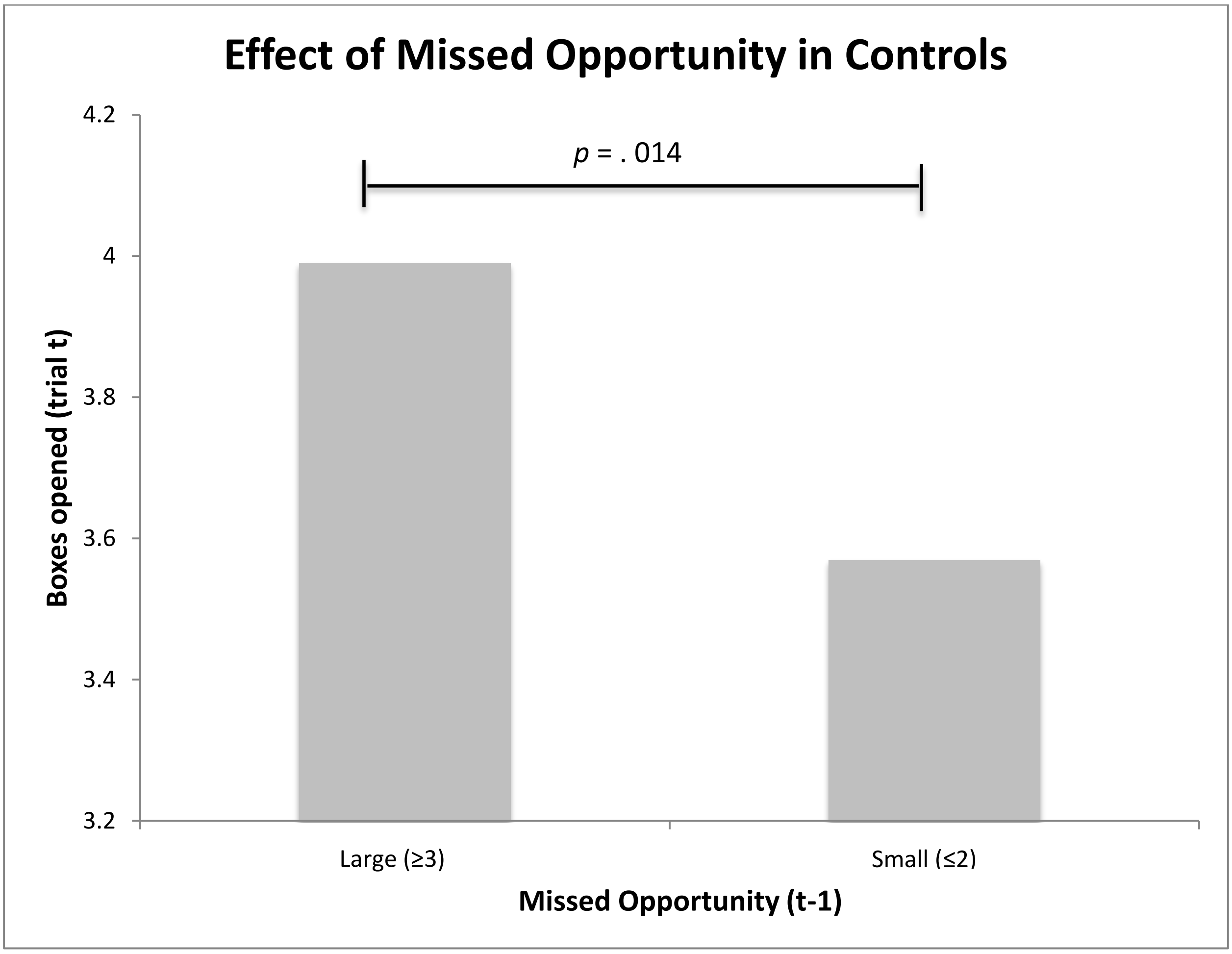


Figure 5.1: Effect of the missed opportunity in controls participants

A t test was not appropriate to run on the patient data due to the limited number of big missed opportunities that were encountered. This was the case because, as previously explained, at least some patients were considerably more risky than controls resulting in more boxes being opened each round, thus creating fewer keep_keep trials to analyse, and in the case of three patients no keep_keep trials that resulted in a large missed opportunity. Table 5.3 demonstrates this; the blank spaces represent the patients who did not encounter any large missed opportunities. Not surprisingly patients MP and SAR are two of the three patients who do not encounter any large missed opportunities; these two patients were previously highlighted as being more risky than the control group. Table 5.5 has been added as a comparison between the number of trial encountered in the large and small missed opportunity conditions.

Table 5.4

The average number of boxes opened in trial t after a large and small missed opportunity for patients.

	Missed opportunity	
Patient	Large	Small
DJR	2.5 (2)	3.29 (14)
GM	2.375 (8)	2.73 (26)
JB	5 (1)	3.83 (12)
JH		4 (12)
MP		4.33 (9)
PF	4 (1)	3 (17)
PW	4 (2)	3.75 (24)
SAR		6 (3)

NB: The number in brackets is representative of how many trials in that condition were encountered and thus how many trials were used to calculate the average.

Table 5.5

The average number of boxes opened in trial t after a large and small missed opportunity for controls

	Missed opportunity	
Control	Large	Small
LAT	3 (6)	3 (12)
AD	3 (9)	3 (16)
RD	3 (6)	4 (11)
CP	5 (2)	5 (12)
EP	5 (6)	4 (11)
AB	5 (6)	4 (11)
AP	4 (7)	4 (9)
BS	3 (11)	3 (22)
CM	3 (14)	2 (19)
JB	4 (3)	3 (19)
JM	5 (3)	4 (17)
LS	5 (2)	4 (13)
ME	3 (5)	3 (11)
MW	5 (10)	4 (15)
SW	4 (6)	3 (18)

Of the 5 patients who encountered large missed opportunities, 3 exhibited behaviour that matched that of controls; JB, PF and PW all opened more boxes after a large missed opportunity compared to after a small missed opportunity. It should be noted that these patients had a maximum of 2 (PW) large missed opportunities, thus it is not possible to make concrete claims regarding these patents' behaviour after large missed opportunity. Additionally, the small number of trials encountered in this condition may be indicative of RDM. Patients DJR and GM demonstrated the opposite pattern of behaviour; opening more boxes after a small missed opportunity. This suggests that patients DJR and GM are not affected by the missed opportunity and thus their behaviour does not demonstrate a willingness to 'make up' for their previous loss. In order to establish if this is indeed the case, a Mann-Whitney test was used on GM's results. The number of boxes opened after a small missed opportunity (*Mdn* =18.5) was not significantly more than the number of boxes opened after a large missed opportunity (*Mdn* =14.25); U = 78, p =.307. DJR has only 2 instances when a large missed opportunity is recorded thus it is not appropriate to run a statistical test to determine if there is a significant difference between the numbers of boxes opened after a large or small missed opportunity.

5.4 Discussion

Research has shown that healthy adults attempt to make up for previous missed opportunities by engaging in risky behaviour (Brassen *et al.,* 2012). Information about what could have been gained, the counterfactual, needs to be accessible to the individual for a missed opportunity to be apparent (Zeelenberg, *et al.*, 1996). The current experiment aimed to investigate the effects of a missed opportunity on a group of brain-damaged patients. Task performance was compared to that of healthy age matched controls. It was hypothesised that a large missed opportunity would lead to riskier behaviour in control participants (Büchel *et al.*, 2011. The aim of the experiment was to investigate if this phenomenon held in the patient population.

5.4.1 Risk-Taking Behaviour

Examining the behavioural data from the task allows us to compare the performance of controls and patients. This is important as it highlights which patients show an unusual pattern of behaviour compared to controls.

To establish if any patients were engaging in risker behaviour than controls I calculated the mean number of boxes opened and compared this to the number of boxes opened by controls. The averages showed that MP and SAR are more risky compared to the control group as a whole, whereas GM is more cautious than the control group.

MP has extensive damage to the temporal, frontal and parietal regions. Due to the size of MP's lesion it is not possible to be confident when drawing claims regarding the damage that may have caused his RDM. Despite this, MP's damage includes the right insular, middle temporal gyrus as well as the temporo-occipital region and the OFC, all of which have been previously cited as key brain areas for CFT, DM and CME production. I will describe the most relevant research which could explain how damage to these areas can result in more risky behaviour than seen in controls.

Research has shown that temporal and frontal regions are involved in tasks containing a risk element. Fukui *et al.* (2005) used the Iowa Gambling Task to demonstrate that the risk anticipation component of the task induced activation in the medial frontal gyrus. Thus it is possible that MP fails to anticipate the repercussions of his choices and therefore does not act to avoid a negative outcome. In addition, Paulus and Frank (2006) highlighted an increased activation in the middle frontal gyrus, middle occipital gyrus and superior temporal gyrus (other areas were also activated) during high probability prospects relative to low probability prospects in a decision weight task. Knuston *et al.* (2008) showed that anticipation of viewing rewarding stimuli increased financial risk taking. Activation correlated with exposure to positive versus negative stimuli while participants anticipated switching between high-risk options to low-risk options. Activation in the right middle frontal gyrus, right inferior frontal gyrus, left middle temporal gyrus, right middle temporal gyrus, left middle occipital gyrus, left precentral gyrus and right lingual gyrus was observed (other areas were also activated).

The parietal and frontal damage which MP has incurred could be affecting the fronto-parietal network described by Van Hoek (2015). The network is thought to play a role in cognitive control when individuals swap between the current world and the hypothetical world. It is important to consider that disruption to neural circuitry could lead to RDM. Bechara *et al.* (1994) claim that damage to the neural circuitry that facilitates adaptive DM could be as important as the VMPFC itself when considering RDM.

In addition to MP, SAR also has frontal lobe damage. Thus, the reasons for frontal damage affecting risk taking described above, can also be applied when attempting to explain SAR's performance on this task. This shared damage to the frontal lobe could imply that this is the cause of MP and SARs performance on this task. However, patients who do not demonstrate risker behaviour than controls also have damage to the frontal lobe (JB and JH), thus it is not possible to make strong claims regarding damage to the frontal lobe causing MP and SAR's risky DM in this task.

MP's damage to the right insula and temporo-occipital region and the OFC could have contributed to his performance on this task. Damage to the OFC has been shown to affect the experience of regret (most famously reported by Camille *et al*., 2004; Coricelli *et al*., 2005) and the role of the insula has been linked to DM and CME production also (Chua *et al*., 2009; Kuhnen & Knutson., 2005). The limbic connections between the two regions could also influence risk taking (Barbas, 2007; Zald & Rauch, 2006). See Chapter 4 for a discussion of how the insula could result in an inability to anticipate risk, due its possible involvement in anticipatory outcomes, or induce a higher rate of risk-aversion mistakes.

SAR also has damage to the right insula cortex. MP and SAR's risky behaviour in this task is in line with findings from Clark *et al*. (2008) who found that patients with insular cortex damage, during the Cambridge Gamble Task, did not adapt their betting behaviour in concordance with the odds of winning. This resulted in insular patients, in comparison to VMPFC patients, incurring the most bankruptcies throughout the task and accumulated the lowest point score. Thus, it is possible that MP and SAR's insula damage has resulted in their risky behaviour in this task.

Both MP and SAR's damage to the white matter located in the frontal lobe maps onto the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule. White matter is crucial for relaying information between grey matter areas; the efficiency of this transfer is reliant on white matter microstructural integrity (Hagmann *et al*., 2008). Therefore if the white matter that relays information between the two hemispheres is damaged then it is likely that signal transfer is affected and thus atypical behaviour may be exhibited.

The relationship between deficits to the corpus callosum and RDM has been directly investigated by Brown *et al*. (2012). Individuals with agenesis of the corpus callosum took part in the Iowa Gambling Task. Agenesis of the corpus callosum occurs in individuals where the corpus callosum does not develop before birth (Jinkins, Whittemore, & Bradley, 1989). Participants with agenesis of the corpus callosum had a lower net gain throughout the experiment while typically showing less consistency in their choice strategy and were more influenced by previous trial, compared to controls. Thus it would appear that the DM process in individuals with agenesis of the corpus callosum is affected. This finding shed light on how the disruption of information between the right and left hemisphere could result in RDM observed in SAR and MP's choices in this task.

The Iowa Gambling Task has also been used with patients with multiple sclerosis (MS). Kleeberg *et al.* (2004) showed that MS patients have impaired DM. MS has been associated with white matter damage located in the corpus callosum (Schnider *et al.* 1993). Kleeberg *et al.* (2004) concluded that areas outside of the amygdalar-orbitofrontal loops are important in DM and damage resulting in functional disconnection that interrupts prefrontal signal transfer (which may result from corpus callosum damage) may result in impaired DM. Therefore, it is possible that the damage to the frontal radiation, described for SAR and MP, is causing their risky behaviour in this task.

The overlapping areas in which patients have shared damage are as follows: MP and SAR have damage to the white matter located in the frontal lobe. PS also has damage to this area but unfortunately, due to availability, did not participate in this task. Future research should look to further investigate if damage to the white matter located in the frontal lobe affects task performance in similar experiments. MP and SAR also have shared damage to the right insula cortex. The insula has been cited as important for counterfactual reasoning in multiple investigations (Berntson *et al.,* 2011; Canessa *et al*., 2009; Chua *et al*., 2009; Clark *et al.,* 2008; Nicolle *et al*., 2011; O'Doherty *et al*., 2003; Palminteri *et al.,* 2012) and thus it is possible that this damage directly affected MP and SAR's performance in this task. However, it should be noted that JB also has right insula damage and does not engage in risker DM than controls. In addition MP and SAR also have frontal lobe damage. However, as explained previously, patients who do not demonstrate risker behaviour than controls also have damage to the frontal lobe (JB and JH). As a result of the overlapping regions of damage in impaired and unimpaired patients it is not possible to make strong claims regarding how damage to the frontal lobe affects DM.

SAR also has bilateral damage to the cerebellum. Although the cerebellum is not traditionally cited as an important brain region when considering DM, Cardoso *et al*. (2014) have used the Iowa Gambling Task to highlight its potential importance. The authors compared performance from patients with cerebellar lesions, frontal lesions, and healthy controls. Despite a wealth of research suggesting that the frontal regions are important for DM (Canessa *et al.*, 2009; Nicolle *et al*., 2011) the cerebella and frontal patient groups' net scores (overall score) were not significantly different to one another. Furthermore, the controls' net scores were significantly better than both clinical groups. This result suggests that the cerebellum might play an active role in successful DM and supports the finding that SAR, with cerebella damage, engages in riskier DM in the presented task.

Although seemingly convincing evidence that suggests SAR's cerebellum damage might play an active role in her risky DM, it is important to note that both PW and DJR also have cerebellum damage. Neither PW nor DJR demonstrate risker behaviour in comparison to controls. Therefore, it is unclear why SAR demonstrates a pattern of responses that is different from controls and PW and DJR do not. It is possible that due to the size of the cerebellum, damage to this area can lead to risker DM but does not always. As previously mentioned in Chapter4, a more advanced understanding of the cerebellum is required in order to make advanced claims about how damage to this area affects behaviour.

Schmahmann and Sherman (1998) coined the term “cerebellar cognitive-affective syndrome” for patients who suffered from impairments in spatial cognition, dysprosody, and anomia. Additionally patients had difficulties in executive functioning, specifically in planning, set-shifting, abstraction, WM, and verbal fluency. These symptoms were mainly observed in patients with abnormalities in the posterior cerebellum. Patients with bilateral damage were more likely to suffer from cerebellar cognitive-affective syndrome. The authors suggest that the impairments observed in the syndrome are caused by disruptions in the neural circuitry that links the cerebellum to prefrontal, temporal, and posterior parietal areas, as well as to the limbic system.

It is possible that damage to the cerebellum affects DM because of its connectivity to other brain regions. Cardoso *et al*. (2014) explain that the cerebellum has efferent and afferent connections to multiple brain regions; dorsolateral and dorsomedial prefrontal cortices, areas of the posterior parietal cortex, the superior temporal region, the thalamus, and the limbic system (Middleton & Strick, 2000; Krienen & Buckner, 2009). In sum, it is likely that the cerebellum has an influence on emotional abilities (Rapoport *et al*., 2000) and damage to this area could account for differences in the experience of CMEs, compared to controls, which may in turn affect RDM.

5.4.2 The effect of a missed opportunity

The hypothesis that a large missed opportunity would lead to riskier behaviour in control participants was tested. The number of boxes opened following a small missed opportunity was compared to the number of boxes opened following a large missed opportunity. The data indicated that after a large missed opportunity, controls were significantly more likely to open more boxes. This result replicated the finding by Büchel *et al.* (2011) that the size of a missed opportunity predicted subsequent risk taking on the next trial.

It was not possible to conduct a comparison between the number of boxes opened after a small and large missed opportunity in the patient group as too few instances where a large missed opportunity was followed by a 'bank' were encountered. Thus, further investigation with patients into RDM should incorporate, where possible, more trials than were used in the described experiment; this would permit analysis of the missed opportunity as was conducted with controls and also individual investigation into if the number of boxes opened in small and large missed opportunity trials is significantly different (as conducted with GM).

Throughout the entire experiment for all 8 patients, only 14 large missed opportunities were recorded. 3 patients, SAR, MP and JH did not encounter two consecutive 'keep' trials where a large missed opportunity was present. This is indicative of high risk taking. Additionally, all but 1 patient have very few large missed opportunities. The only patient who has more than 2 trials in this category is GM (N=8). Large missed opportunities occurred when there were 2 or more safes must be between where the participant 'banked' and the location of the thief. For high-risk takers this situation never occurs because a high number of safes are opened each round. Thus only small missed opportunities are created or the thief is found, creating a 'bust' trial. This was confirmed by determining the percentage of bank trials for each participant (Table 5.2: column 3). Patient SAR banked in 19% of trials and MP banked in 35% of trials. MP and SAR had the two lowest bank percentages out of all patients. Thus, it is not surprising that these two patients did not record any large missed opportunities.

In conclusion, the aim of this investigation was to establish which, if any, patients showed different behaviour to controls in a risk taking experiment. To my knowledge there are no studies with a patient group that investigate the effect of a known missed opportunity on subsequent DM. Analysis was split into risk-taking behaviour and the behavioural effect of a missed opportunity. Analysis into risk taking behaviour highlighted that two patients were demonstrating risker behaviour than controls. The effect of the missed opportunity on controls demonstrated the size of the missed opportunity in trial t-1 affected the number of boxes opened in trial t. 1 patient demonstrated that the missed opportunity did not affect the number of boxes opened in the following trial (GM) although it was not possible to conduct this investigation with other patients who took part in this experiment. These results have shown that two patients with differing neurological damage engage in riskier behaviour compared to controls and one patient is more cautious than controls.

Chapter 6a

A Simple Task Assessing Patients’ Counterfactual Mediated Emotional Responses

6.1 Introduction

The experience of regret is thought to be beneficial and of significant importance to learning. Due to the experience of regret adults are able to learn from our mistakes and make more informed decisions creating desirable outcomes in the future (Roese, 1997). It also seems that anticipated regret plays a role in DM; we act in a way that will avoid negative outcomes (Zeelenberg, 1999). The development of regret has been widely researched in children and healthy adults; however, few studies have been published that examine the experience of regret in brain-damaged patients. I look to establish if regret and relief are preserved in individuals who have suffered a stroke. The patients tested have varying lesion sites. Through testing brain-injured patients who have a wide range of lesion sites I hope to establish if damage to a number of different areas results in patients' inability to experience regret and or relief.

The neurological connections between CMEs and DM have been investigated; research focusing on the relationship between the VMPFC and DM has highlighted the distinct activation patterns in the lateral and medial OFC when regret is experienced (Sommer *et al.*, 2009). Coricelli *et al.'s* (2005) results showed that the activity in the medial OFC increased during initial regret experienced post gamble and also as a result of cumulative regret accumulated through the experiment. The lateral OFC activity increased as a result of the immediate regret experienced caused by the gamble outcome.

Levens *et al.* (2014) investigated how damage to the VMPFC and the lateral OFC (LOFC) affects DM and the CMEs. Patients with VMPFC and the LOFC damage were tested. The authors used an adaptation of Camille *et al.*'s (2004) gambling task. After each gamble was completed the patients rated their emotions on a scale from −50 ("Extremely

Unhappy”) to 50 (“Extremely Happy”). Control subjects showed responses that were sensitive to regret comparisons. It was established that VMPFC patients made financially worse gambling choices than controls while reporting emotions that were sensitive to regret comparisons and similar to the emotions reported by controls. Contrastingly, LOFC patients made financially good gambling choices but their reported emotions were insensitive to regret. The authors conclude that the VMPFC has a role in the relationship between DM and anticipated emotions; whereas the LOFC is involved in experiencing emotions after a decision has been made, influencing subsequent behaviour.

Research conducted into the role of the PFC in the experience of CFT has been conducted by Gomez-Beldarrain (2005). The generation of counterfactual thoughts by 18 patients with strictly PFC lesions and 26 controls was recorded in a task comparing spontaneous counterfactuals and counterfactual responses to cued questions (see Chapter 1 for detailed methodology). Analysis of participants’ responses showed that PFC patients produced significantly fewer spontaneous counterfactuals. Further to this, no relationship between counterfactual production and lesion site within the PFC was observed. There was no difference, between groups, in counterfactual generation in the cued condition. The authors suggest that impaired CFT may be linked to the lack of regret observed in frontal lobe-lesioned patients.

Through using the developmental literature to establish when counterfactual abilities develop, we can gain an understanding of the developmental trajectory that results in functional counterfactual reasoning skills that can be observed in healthy adults. Thus, it is possible to break down different stages that occur through childhood and draw comparisons to the patient data, for example Weisberg and Beck (2010) produce evidence that suggests children are able to experience regret at 5 years but do not experience relief until 7 years. My project aims to use a simple non-verbal task, like the one used by Weisberg and Beck, to establish patients' experience of CMEs.

Weisberg and Beck (2010) found evidence of a developmental dissociation between experiencing regret and relief. The authors devised a task where children chose one of two coloured boxes and a number of stickers was won according to the box chosen. Children rated their emotions before and after opening the second box, which contained more, less, or equal number of stickers. Children were deemed to experience regret if they rated their emotions as less happy after seeing the counterfactual alternative was better than reality. Relief was attributed when children felt happier after seeing the counterfactual alternative was worse than reality. Regret was reported at 5 years of age, but relief was not reported until 7 years of age. Therefore the authors claim that there is a difference in the development of experiencing regret and relief. The finding that 7 year old children do experience regret and relief themselves, suggests that a development in understanding CMEs develops in between the ages of 5 and 7 (Amsel & Smalley, 2000).

The development of regret has also been investigated by O'Connor, McCormack and Feeney (2012) who built on Weisberg and Beck's (2010) boxes game methodology. The authors used regret and baseline conditions to investigate 4 to 9 year olds' ability to report regret. Regret trials were characterised by the unchosen box containing a better prize than the chosen box. Baseline trials were created by both the chosen and unchosen box containing the same prize. Children were deemed to have experienced regret if they reported feeling sadder in the regret condition only. There was no evidence that children aged 4 to 5 experienced regret, whereas there was evidence that regret can emerge at 6 years. The emergence of regret at this age has been linked the children's development of executive function, in particular attentional flexibility (Burns, Riggs, & Beck, 2012). Weisberg and Beck (2012) and O'Connor *et al.* (2012) used an improved methodology to investigate children's regret, which avoided participants being asked to use the same scale repeatedly. Having used a five point smiley face scale ranging from very happy to very sad to rate their emotional response after opening their chosen box, children used a three pronged moveable arrow; one arrow pointed left to indicate feeling sadder, one arrow pointed right to indicate feeling happier and the final arrow pointed upwards vertically to indicate the same emotional response after the alternative box was opened. O'Connor, McCormack and Feeney (2012) found evidence of regret at 6 years and Weisberg and Beck (2012) found evidence of regret in children as young as 4 years (n.b. some authors claim that regret is not seen in children until 9; Rafetseder & Perner, 2012).

Previous work with brain-damaged patients (Camille et al., 2004; Levens *et al.*, 2014; Clausi *et al*., 2015;) and healthy controls (Coricelli *et al*., 2005; Liu *et al.,* 2007; Chandrasekhar et al., 2008; Chua *et al.,* 2009) have used complex gambling tasks in order to induce regret and relief. I present a task that builds upon Weisberg and Beck's (2010) and O'Connor, McCormack and Feeney's (2010; 2014) work to establish if patients with varying lesion sites can report regret and relief in a simple regret task. As in previous research, two boxes will be used in regret, relief, and baseline conditions. The discrepancy between tokens won and lost will be manipulated; small, medium, and large. I predict that some patients will have problems in experiencing CMEs. I am using this simple experiment as a tool to further understand the neural underpinnings of regret and relief and thus at this point I am unsure which patients will be impaired in expressing either regret or relief.

6.2 Method

Participants

A total of 17 patients (7 female) aged between 31 and 84 (M = 64.5 years) and 17 controls (12 female) aged between 28 and 74 (M = 59 years) completed this test battery. 15 patients were recruited via the Oxford Cognitive Neuropsychology Centre and 2 patients were recruited via the University of Birmingham. For the purpose of this paper I will discuss 6 patients who demonstrate difficulty in experiencing CMEs (see Table 6.0).

Table 6.0

Description of the patients' information who are discussed in this task

Patient	DOB	Hemisphere	Year of Damage	Description of Lesion
MG	[redacted]	R	2013	Cerebellar
LB	[redacted]	L	2012	Amygdala, hippocampus, palidum, putamen and thalamus
RR	[redacted]	L	2012	Left temporal lobe, including the inferior, middle, and superior temporal gyrus, angular gyrus, temporal pole, and extending into insular cortex, supramarginal gyrus, frontal and central operculum cortex, inferior frontal gyrus, as well as parietal operculum. Possible left amygdala

GM	[redacted]	L	2013	Left sided lingual gyrus and nearby occipital structures including the left intracalcarine cortex and occipital fusiform gyrus
MP	[redacted]	R	1998	Extensive temporal, frontal and parietal damage. Damage extends to the right insular, middle temporal gyrus (anterior and posterior divisions) as well as the temporo-occipital region and the OFC. Possible damage to the frontal radiation associated with corpus callosum and anterior limb of the internal capsule

Design

Participants completed 42 trials. 18 regret, 18 relief, and 6 baseline trials. In baseline trials, the chosen and alternative boxes contained the same number of tokens; 5, 6, 7, 8, 9 and 10. Regret trials were created by engineering the trial so that the chosen box always contained fewer token than the alternative box. Conversely, in relief conditions, the chosen box always contained more tokens than the alternative box. Within the regret and relief conditions, the discrepancy between the tokens won and lost was altered, therefore creating small, medium and large differences. 'Small' trials had a difference of 1 token, medium trials had a difference of 3 tokens and large trials had a difference of 7 tokens. An overall of 6 trials in each condition were created. For examples of trials see Table 6.1.

Table 6.1

Example trials in both control, regret and relief conditions for small medium and large token discrepancies

Number of tokens won	Number of alternative tokens	Condition
5	5	Control
6	7	Regret Small
4	7	Regret Medium
4	11	Regret Large
6	5	Relief small
10	7	Relief Medium
11	4	Relief Large

Note. These examples were 7 out of the 42 trials used in the Simple Regret task

Materials

Square cards (10x10cm) were used to indicate the number of tokens; which ranged from 1-13. The card value was identifiable by the equivalent number of dots. A set of identical white matchboxes was modified to include a divide, which was only visible when the entire matchbox had been pushed through its rectangular 'sleeve'. Each matchbox contained the same two cards (one either side of the divide) with differing values. The match boxes could be opened at either end, by sliding the sleeve to either the left or right, without revealing the second 'hidden' card. This allowed for the experimenter to control the number of tokens won in each trial (See figure 6.0).

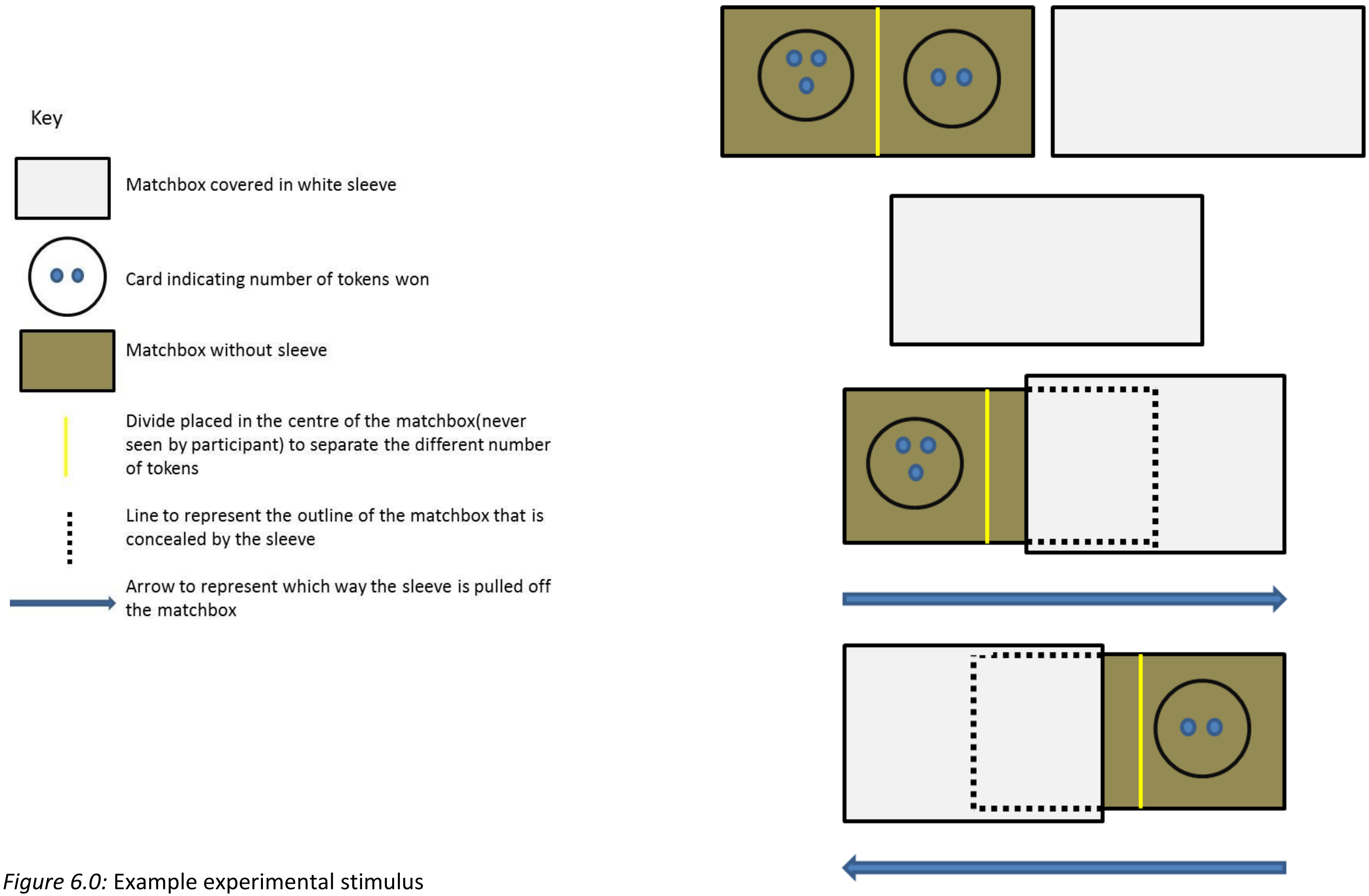


Figure 6.0: Example experimental stimulus

A 5-point scale was used to rate emotions which ranged from very happy to very sad. The scale comprised 5 black and white images of faces (14x17cm) presented on a white A4 sheet of paper (see Figure 6.1). A separate rectangular (50x40cm) piece of paper with a pointer was used. The pointer was created by using three arrows, an upward, downward and a leftward facing arrow (see Figure 6.1).

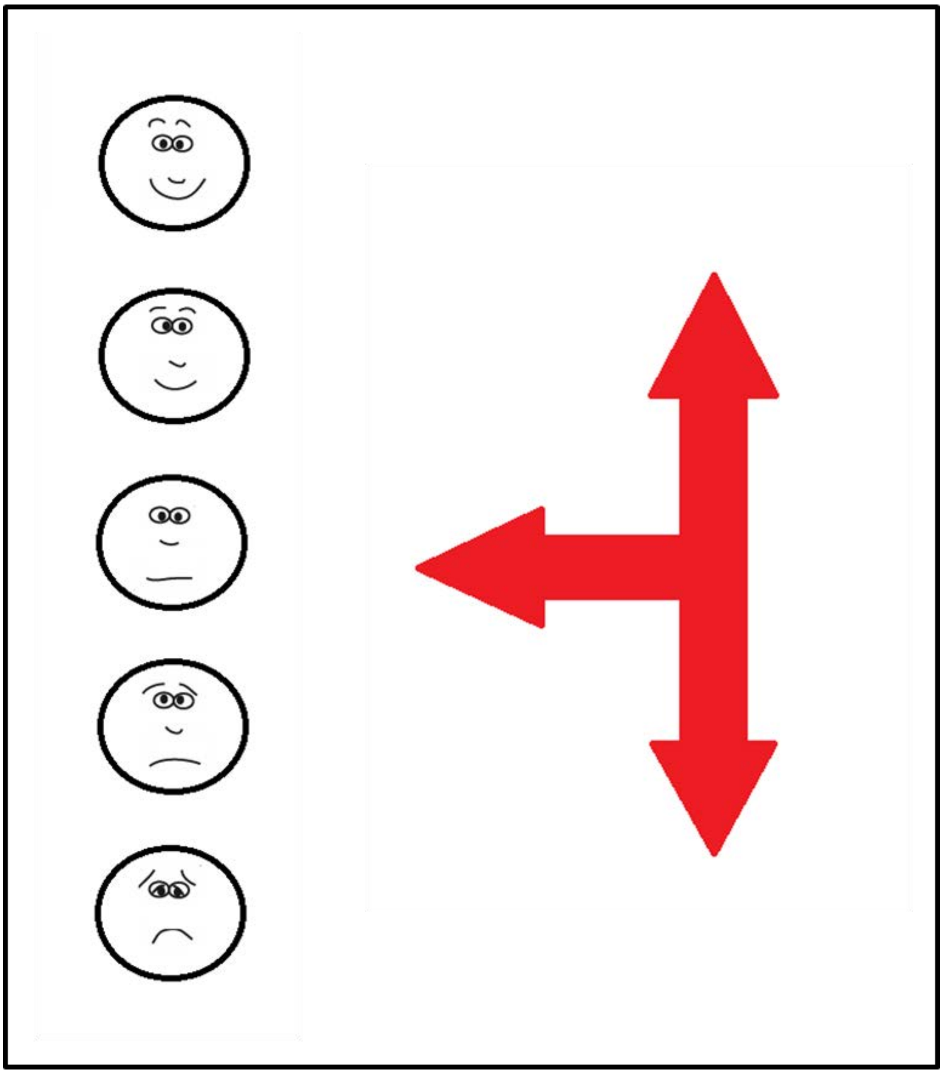


Figure 6.1: Left: A scale of 5 faces ranging from very happy (top) to very sad (bottom). Right: A three pronged arrow used in the second emotional rating.

Procedure

Training: Each participant heard a scripted explanation and was trained to use the 5-point emotional rating scale. This ensured that each participant had experience of the scale and demonstrated their understanding of how to use it before completing the task. Participants heard these instructions. “This is a scale of very happy to very sad faces; the faces are used to show how you are feeling. When this arrow points to one of the faces [pointing to left facing arrow] this means that you are feeling the emotion of that face.” Subsequently, it was explained that participants could use the upward (feeling happier) and downward (feelings sadder) arrows to indicate how their feelings might change. “If something else happens, you can use these arrows to show how your feelings have changed. This arrow [referring to upward pointing arrow] always means that you are feeling happier than you were before. This arrow [referring to downward pointing arrow] always means that you are feeling sadder than you were before.” Participants were told that if they had previously placed the leftward facing arrow at the happiest or saddest face, it was permissible to be ‘off the scale’ happy or sad by selecting either the corresponding upward or downward arrow. “When this arrow [referring to leftward arrow] is pointing to the saddest face, you can use this arrow [referring to downward pointing arrow] to show that you feel even sadder than before. When this arrow [referring to leftward arrow] is pointing to the happiest face, you can use this arrow [referring to upward pointing arrow] to show that you feel even happier than before.” Participants were required to point to the very happy, the very sad and the neutral face in order to ensure they understood which emotion the faces were depicting.

Experimental procedure: Participants were presented with two identical white match boxes (5cm x 4cm x 2cm). The experimenter explained the rules of the task to the participant. "We are going to play a game with these boxes. Inside the boxes are different amount of tokens. If you win enough tokens by the end of the game, then you can take home this prize [a pen]. You are allowed to choose one of the two boxes to open and you win the amount of tokens inside that box." After the participant chose one of the two boxes, the experimenter pushed the match box halfway out of its sleeve, the matchbox was either pushed to the right or the left. Both matchboxes contained the predetermined winning number of tokens on the left and the alternative number of tokens on the right. Therefore, the experimenter controlled the number of tokens shown to the participants in each box. Participants were told how many tokens they had won and asked to rate how they felt about their selected box. The card contained within the chosen match box was given to the participant. The experimenter then opened the unchosen box revealing what the participant could have won. The participant made a second rating, "This is what you could have won, how do you feel about your prize now? Please point to an arrow." The expected response on regret trials was to point to the downward facing arrow, demonstrating a more negative response to the chosen box, whereas on relief trials, the expected response was to point to the upward facing arrow, demonstrating a happier response to the chosen box. It is not clear how either healthy adults or patients will rate their emotions during the baseline condition.

6.3 Results

Participants are categorised as passing a set of trials (e.g. regret medium) if they answered more trials with the expected emotions response (happier in relief conditions and sadder in regret conditions), than would be predicted by chance. This was calculated from the binomial distribution where the probability of scoring 5/6 correct by chance was .018%. To avoid overestimating patients' difficulties a cut off of 4/6 for success was used i.e. anyone responding to 4 or fewer trials with the expected response in a set was categorised as failing the set. The number of expected responses was totalled for each condition (see tables 6.1 and 6.2). There were 6 questions in each of the conditions; therefore the reported figures are out of 6.

Through closer examination of the control participants' data, only 6 participants responded with the expected emotional response (i.e. rating their emotions as sadder on regret trials and happier on relief trials) in the small valance condition. This demonstrated that control participants were not experiencing or at least not reporting, CMEs. It was decided that no further investigation into the small valance condition would take place for patient data. In comparison, controls did show the expected emotional reaction to regret and relief conditions in the medium and large valance conditions; all control participants pass every condition (i.e. rating their emotions as happier on regret trials and sadder on relief trials). Therefore, for medium and large valance conditions, controls and patients are compared.

During the baseline condition all three responses of higher, lower, and the same can be explained though a logical thinking pattern. Participants' response of 'higher' can be explained through participants experiencing relief due to the second box not containing a higher number of tokens. A response of 'lower' is justified by participants feeling regret that there was not more in their box than in the alternative box. Finally a response of 'same' could represent an indifference to the outcome of the second box, due to the number of tokens being equal. However, on closer inspection of controls' responses it appears that all participants respond with the 'same' emotional rating after the alternative box is opened. As a result, I evaluated patient responses in the baseline condition by categorising the 'same' emotional rating after the alternative box is opened as the correct response. Only one patient, MP, answered fewer than four baseline questions as the 'same'. MP demonstrates a pattern of results in that he passes all three size conditions in both regret and relief. However, he fails to pass during baseline conditions. MP is the only patient to fail on the baseline condition alone (see table 6.2). He answered 'same' on 3 occasions, and in the remaining 3 cases MP reported feeling happier after the alternative outcome had been revealed. As explained, this pattern of results could be explained by MP feeling relief that the second box did not contain more points than the initial chosen box, because of this possible explanation I will not discuss MP further.

After an examination of regret and relief trials in medium and large valance conditions, results showed that 5 out of the 17 patients tested failed in at least one condition. Table 6.2 shows the 5 patients who did not answer enough questions correctly (N=4) in order to pass in at least one condition (as well as MP). The remaining 12 patients passed each condition and are not discussed.

Table 6.2

Results of each patient in each of the 6 main conditions and the control. The maximum score in each condition was 6

Patient	Regret M	Regret L	Relief M	Relief L	Control
RR	1	1	0	1	5
LB	1	2	0	0	5
GM	5	5	1	3	6
MG	2	0	5	5	5
MP	5	6	6	6	3
PF	6	6	6	6	5
JH	5	6	5	5	5
MB	5	6	5	6	5
RP	5	6	5	6	6
SAR	5	6	5	6	6
DJR	6	6	6	6	6
PW	6	5	6	5	4
TJ	5	6	5	6	6
PS	5	5	6	6	6
JB	5	5	5	6	6
NB	5	5	5	6	6
EL	5	6	5	5	6

NB: *Conditions where patients failed are highlighted in the first panel*

6.4 Discussion

I set out to explore if regret and relief are preserved in the patient population and if regret still plays a role in learning. The experience of regret and its development has been widely investigated in the developmental research. However, the effect that brain damage has on the experience of regret had not been researched. I aimed to explore this gap in the literature by building upon Weisberg and Beck's (2010) and O'Connor, McCormack and Feeney's (2010; 2014) work to establish if patients with varying lesion sites can report regret and relief in a simple regret task and if the experience of regret correlates with a second task focusing on adaptive choice switching.

Analysis revealed 3 interesting patterns of behaviour among patients. RR and LB failed both medium and large conditions for both regret and relief trials. Second, patient MG failed both medium and large conditions for regret trials. Third, patient GM failed both medium and large conditions for relief trials.

6.4.1 RR and LB

The results suggest that the patients who fail both medium and large conditions for regret and relief trials (RR and LB) are unable to experience CFE. Their responses indicate that they do not express regret when the unchosen box contains more tokens than the obtained box and do not express relief when the unchosen box has fewer tokens than the chosen box.

Patient LB has damage that spans the amygdala, hippocampus, palidum, putamen and thalamus. It is known that the hippocampus is involved in discriminating between the obtained and the unobtained outcome of a choice and that this region may, as a consequence, be involved in the experience of regret (Coricelli *et al.* 2005). The amygdala is commonly linked with emotional arousal and evaluative judgments (Berntson *et al.* 2007; LeDoux, 2000; Dolan, 2002; Ochsner and Gross, 2005). Notably, Nicolle *et al.* (2011) used a paradigm which focused on the experience of regret following high and low levels responsibility after a choice; amygdala activation corresponded with conditions of high responsibility and poor outcome (also see Sander *et al.*, 2003; Li *et al.*, 2011).

Evidence also suggests that the amygdala and the hippocampus could be linked through their influence on one another during encoding. Phelps (2004) reviewed the interactions of the amygdala and hippocampal complex during emotional processing and memory. Phelps claims that the two medial temporal lobe structures interact when emotional stimuli are encountered. The amygdala is thought to modulate the encoding and storage of hippocampal-dependent memories. The hippocampus is claimed to influence the amygdala's response by creating signals that code for the emotional significance of an outcome. This evidence implies that damage to either the amygdala or the hippocampus could cause the responses demonstrated by LB.

Van Hoeck, Watson and Barbey (2015) claim that CFT is reliant on a combination of information processing networks that facilitate adaptive behaviour and goal-directed DM. Within the emotion and value processing network, the authors cite the VMPFC (including the medial OFC), amygdala, basal ganglia, LOFC and lateral PFC as the associated regions. Thus it is clear from previous research that damage to either the amygdala or the hippocampus could cause the lack of emotional response seen in LB. RR's performance on this task could also be due to amygdala damage.

However, two patients who performed in line with controls in this task (PS and JB) also have damage to the amygdala. As a result one must be cautious when making claims regarding damage to this area affecting performance on this task. Although, it is important to note that patients can have similar but not identical damage and it is not possible to determine how extensive each respective patients' damage is and how this relates to counterfactual abilities and CMEs. Thus, I cannot rule out brain areas that are damaged in patients who are not impaired during tasks and apply this to patients who have similar damage and who are impaired.

RR suffered large left temporal lesions extending into his frontal and parietal cortex. Lesions to the left temporal lobe typically result in the patient struggling with: auditory sensation and perception, attention, visual perception, general language comprehension and production, long-term memory, personality changes and altered sexual behaviour (Kolb & Whishaw, 1990; Poeppl *et al.*, 2016). As a result of the stroke, RR presents with Broca's aphasia and when initially seen two weeks post-stroke, RR experienced complete expressive aphasia and some problems comprehending complex instructions (Puvanendran, Dowker & Demeyere, 2015). It is unlikely that RR's damage to the left temporal lobe caused his inability, in this task, to experience CMEs. However the frontal cortex has been linked to CFT in Parkinson's patients (Brown & Marsden, 1990; McNamara *et al.*, 2003) and in patients with Schizophrenia (Larquet, 2009; Hooker, Roese & Park, 2000) as well as lesion studies (Gomez- Gomez-Beldarrain *et al.*, 2005). The link between the frontal cortex and CMEs has also been extensively researched in healthy adults (Canessa *et al.*, 2009; Nicolle *et al.*, 2011) and patient studies (Coricelli *et al.*'s., 2005; Levens *et al.*, 2014; Studer *et al.*, 2015). The parietal cortex has also been associated with counterfactual production; the inferior parietal cortex (Buckner & Carroll, 2007; Schacter, Addis, & Buckner, 2007; Van Hoeck *et al.*, 2013), medial parietal and lateral parietal regions (Addis *et al.*, 2009).

It is known that areas such as the right anterior insula, left insula/superior temporal gyrus/inferior temporal gyrus, superior frontal gyrus, and the lateral OFC are active during the experience of regret compared to disappointment (O'Doherty *et al.*, 2003; Chua *et al.*, 2009). The anterior insula and the posterior lateral OFC have been associated with relief (Berntson *et al.*, 2011; Palminteri *et al.*, 2012). Van Hoeck *et al.* (2015) cite these areas, among others, in the emotional and value processing network; the network is responsible for reward signals that underpin emotional and value processing. This would therefore suggest that damage incurred to these areas, which RR has sustained, could disrupt the process of feeling both regret and relief.

The inferior frontal gyrus was active during Coricelli *et al.*'s (2005) gambling task that monitored neural activity during regret avoidance. Activity in the right dorsolateral PFC was correlated with the immediate experience of regret. Specifically, the border between middle and inferior frontal gyri was activated. This implies that the inferior frontal gyrus is involved in the immediate production of a CME. During the current task participants are required to rate their immediate emotional response to the outcome of positive and negative stimuli. Thus damage to this area may cause disruption in experiencing CMEs that are observed in the control group.

In addition, Van Hoeck *et al.* (2015) discuss the importance of the Cingulo-Opercular Control Network in the process of experiencing CMEs. The network consists of the dorsal anterior cingulate cortex, the posterior medial frontal cortex, anterior insula, frontal operculum and the anterior PFC. The authors state that the control network directly influences behavioural regulation through the experience of regret. Through the experience of regret, the Cingulo-Opercular Control Network updates the outcome that has been encountered and signals when the counterfactual would have produced a more desirable outcome. This signalling results in behaviour modification (Nicolle *et al.*, 2011; Rudebeck *et* *al.*, 2013). RR's damage to the frontal operculum could have resulted in a lack of regret when presented with a more advantageous counterfactual.

Although suggesting that fontal damage is the cause of RR's emotional responses is logical, it is interesting that RP (right hemisphere), JH (left hemisphere) and PS (bilateral) also have frontal damage yet report emotional responses in line with controls. Thus, it is possible that RR's responses in this task are not caused by frontal damage. Unfortunately RR's damage is extensive. As a result it is extremely difficult to pin point the most likely region, where damaged, that has resulted in his performance. It is possible that frontal damage contributes to RR's performance, however, I cannot be confident in claiming this.

6.4.2 MG

Patient MG does not report experiencing regret while her experience of relief remains intact. Previous research with patients, who have OFC lesions, has shown that the experience of regret can be inhibited after a stroke (Camille, *et al.,* 2004). Camille *et al.'*s (2004) OFC patients did report disappointment; patients rated themselves as happier after winning and sadder after losing, although these emotions were not moderated by full (regret) and partial (disappointment) feedback conditions. Thus, it would be interesting to utilise the task used in this chapter with OFC lesion patients to establish if patients would rate their emotions as lower upon realising they could have won a greater number of tokens.

The finding that MG, who has a cerebella lesion, does not experience regret when presented with information regarding the counterfactual possibility suggests that it is not only OFC patients that experience behaviour demonstrated in Camille *et al.'s* (2004) study. This is in line with Coricelli *et al*.'s (2005) observation that the ACC and hippocampus are also implicated. The finding from this investigation establishes that patients without OFC lesions have problems in experiencing regret and thus have highlighted that the OFC is not solely responsible for the mediation of CFE. However, it could be the case that the OFC is one of a few brain regions that play a pivotal role in experiencing regret and once one of these areas is damaged, the individual will experience significant problems in experiencing CFEs.

Recently, neuropsychological and neuroimaging studies have begun to examine the role of the cerebella in DM (Rosenbloom *et al.*, 2012). The cerebellum has been implicated in the pathology of autism, a condition where the experience of regret is dulled (Zalla *et al.*, 2014). The specific involvement of the cerebellum in experiencing regret was not explored until Clausi *et al.* (2015) investigated how cerebellum damage affects reporting regret and the incorporation of regret into adaptive DM for future DM. The authors used the RGT (Camille *et al., 2004;* Mellers *et al.,* 1999) to demonstrate that patients were unhindered in their ability to avoid choices that predicted regret in future trials, however, the same patients were significantly impaired when required to self-rate the experience of regret. The self-rating scores for other emotions, such as relief, were unimpaired. The results from the current study support the findings from Clausi *et al.* (2015) that cerebella damage causes patients to respond as though they do not experience regret while the experience of relief can be unaffected.

Clausi *et al.* (2015) suggest that their findings, that the cerebellum is involved with the self-rating of regret, support Coricelli *et al.*'s (2007) model. The model describes the circuitry of regret comprised of the medial OFC, anterior cingulated cortex, and hippocampus. The cerebellum is thought to monitor alterations in an individual's emotional state by comparing the internal state and the state that is created by an uncontrolled external event (the outcome of a gamble).

Although MG presents with cerebella damage and does not report experiencing regret there are several other patients who participated in this experiment who also have cerebella damage yet do experience both regret and relief. DJR has right cerebella damage, PW has left cerebella damage and SAR and NB have bilateral cerebella damage. This pattern of results would imply that cerebella damage can but does not always lead to disrupted emotional experiences and responses. As highlighted in Chapter 4 and 5, it is not possible too determine how damage to the cerebella affects CMEs, decision making and adaptive choice switching, yet it is clear that further research is needed to determine the relationship between these processes and the cerebella.

6.4.3 GM

In the opposite pattern to MG, GM demonstrates a pattern of results that suggest only the experience of relief is affected, leaving the experience of regret preserved. Previous developmental research has shown that there is lag in the development of regret and relief. Weisberg and Beck (2010) showed that children at the age of 5 reported feeling regret but not relief. Children at the age of 7 not only reported feeling regret but also the experience of relief. This evidence suggests that experiencing and reporting relief is more complex than regret and thus could explain why some patients have difficulty experiencing relief while the ability to experience regret is preserved.

The reason behind the apparent lag between experiencing regret and relief was investigated further by Weisberg and Beck (2012). The authors proposed three explanations for children’s late experience of relief. Firstly, that there is a real lag in experiencing CMEs and regret genuinely develops earlier than relief. Secondly, previous studies used methodologies that make thinking about and experiencing relief harder than experiencing regret. Thirdly, the finding that relief is harder to experience than regret is a false positive. The experiments were created by presenting trials with initially positive or negative outcomes. However, the alternative option was either more positive (regret) or more negative (relief). The children played two versions of the game, one where they lost or won the tokens for themselves and another where the child’s responsibility for the choice was manipulated. Experiment 1 produced results that reduced the lag in reporting regret and relief by incorporating trials where the outcome of the child’s choice was negative, i.e. they lost tokens. Therefore, the authors concluded that previous findings that relief is harder to experience than regret were caused by previous studies using methodologies that make experiencing relief harder than experiencing regret. If this suggestion is correct and relief is not developmentally experienced later than regret then it is no more surprising that GM does not experience relief compared to MG who does not experience regret.

GM’s lesion lies within the left lingual region and surrounding structures. Van Hoeck *et al.* (2014) found activation in the lingual gyrus (along with the cuneus and left occipital gyrus) when an overlap between false belief, counterfactual and basic conditional reasoning was investigated. The authors suggest that the activation in the three additional regions could be a result of increased mental imagery. Additionally, Van Overwalle, D’aes and Mariën (2015) conducted a meta-analytic connectivity modelling study to investigate the functional connectivity of the cerebellum with the cerebrum in social cognitive processes. The lingual gyrus was highlighted as having connections to the cerebrum. However, the lingual region has not been exclusively investigated in studies that focus on the experience of CMEs. To the best of my knowledge, this is the first evidence that directly implicated the left lingual region in experiencing CMEs, specifically relief.

An interesting finding of this experiment is the double dissociation between GM and MG in that MG experiences relief but does not experience regret while GM experiences regret but does not experience relief. This finding could be interpreted as contradicting the developmental literature, where one would expect regret to precede relief such that you would not expect to find a child who would experience relief but not regret (Weisberg & Beck, 2012).

There is an interesting distinction in the literature between the concepts of brain region specialisation (such as Camille *et al.'*s (2004) suggestion that the OFC is responsible for the experience of regret) and that of brain interconnectivity. In the case of Theory of Mind (ToM), some research has demonstrated that brain areas such as the right TPJ, left TPJ, and posterior cingulate have specific and selective roles (Saxe & Wexler, 2005) when considering a protagonist's thoughts or beliefs; these areas were not recruited when participants read about subjective feelings or other socially relevant information. These highlighted regions are also thought to be recruited in early developing ToM and have continued importance into adulthood. This evidence demonstrates that it is possible that some brain regions are adapted for specific cognitive roles. While it is possible that the experience of regret is solely reliant on the OFC and this region alone is responsible for the CFE that guides behavioural modification it is important to consider that interconnectivity plays a role. Saxe and Powell (2005) pp697 acknowledge the possibility that "higher cognitive functions rely on distributed networks of brain regions, each of which participates in more than one function”.

Overall, three patterns of results were observed in a simple task that assessed patient counterfactual responses to winning and losing. Two patients did not experience any CMEs. One patient did not experience regret and one patient did not experience relief while all control patients responded as expected. RR did not report regret or relief. It is not clear which element of his extensive damage causes this lack of emotional response in this task. It is entirely possible that RR’s amygdala damage is the sole reason for his lack of regret and relief (Berntson *et al.*, 2011). Although it is important to consider how neural connectivity has been damaged as a result of his wide spreading lesion. When considering the other three patients discussed their lesion sites paired with their behavioural profile lend support to a network theory that supports counterfactual reasoning and emotions.

Chapter 6b

Exploring the link between the Experience of Regret and Adaptive Choice Switching

6.5 Introduction

After the completion of the Simple Regret experiment, I decided that I would conduct a second experiment that has previously been used to demonstrate the relationship between the experience of regret and the ability to engage in ACS. The aim of this experiment was to investigate how the experience of regret directly impacts on future DM and underpins adaptive behavioural change.

Regret theory (Bell, 1982; Loomes & Sugden, 1982) states that we, as rational adults, are able to anticipate our emotional responses (such as regret and relief) to the outcome of our decisions. Furthermore, we are able to use the predicted emotional response to guide our future choices (Mellers, Schwartz & Ritov, 1999) which will avoid the negative experience of regret which is experienced after a poor choice (Loomes & Sugden, 1987). Research has shown that individuals anticipate regret as a consequence of their actions and will make choices in an attempt to minimise the experience of regret and thus avoid similar mistakes in the future (Zeelenberg, 1999; Mellers Schwartz & Ritov, 1999).

The concept that regret facilitates ACS is supported by research suggesting that healthy adults behave in a regret-averse manner; spontaneously anticipating regret and selecting a course of action that avoids this negative emotion (Zeelenberg, Beattie, van der Pligt, & de Vries, 1996). Furthermore, economic models of DM have been investigated. Research on how the experience of regret effects behavioural decisions in an economic context such as negotiation and bidding has been conducted. Creyer and Ross (1999) asked participants to imagine they were a salesperson and faced several economic decisions e.g. bidding. Participants were assigned to one of four conditions: lose/minimal, lose/substantial, win/ minimal, and win/substantial. Outcome feedback was manipulated.

Results suggested that participants who were provided with negative outcome feedback were more risk averse than participants who received positive outcome feedback. Outcome feedback affected participants' DM in a subsequent trial; after negative outcome feedback, participants' bids were lower compared to when positive outcome feedback was provided. This finding providing evidence that the experience of regret affects subsequent DM.

A similar study to the current experiment has been conducted in the developmental literature by O'Connor, McCormack and Feeney (2014). The authors examined the behavioural consequences of experiencing regret in children over two days. On day 1 children were given the boxes task (see O'Connor *et al.,* 2012 for methodology, and also Chapter 6a). On day 2 children were presented with the same boxes from day 1. They were given the opportunity to make the same choice as they did on day 1 or to swap the original box they opened for the alternative box. If the child wanted to change the box they opened from the day before, it would cost them one token (tokens could later be exchanged for stickers). Due to this deterrent, a rational decision maker should only switch boxes during regret trials and not baseline trials. This was termed ACS. Children who reported regret on day 1 were significantly more likely to show ACS on day 2 compared to children who did not report regret on day 1. In other words, these children switched boxes during regret trials, but did not switch boxes during baseline trials, demonstrating that children's ability to experience regret helps children modify their behaviour in similar future situations. This behaviour was exhibited at about 7 years.

Developmental research, such as O'Connor, McCormack and Feeney (2014), focusses on the experience of regret, while the adult literature focusses on regret anticipation. However, Zeelenberg and Pieters (2007) argue that the function of experiencing regret is to facilitate choice switching when faced with the same decision a second time. As noted by O'Connor, McCormack and Feeney (2014), the process by which this behavioural modification occurs is not fully specified. However, Zeelenberg and Pieters (2007) do state that experiencing regret, in addition to facilitating choice switching, encourages individuals to remember mistakes and missed opportunities. In addition, regret is said to motivate individuals to make up for their mistake and possible losses. Though re-living our mistakes we become more equipped to deal with the same situation the second time it is encountered and allows for the continuation of reward inducing decisions.

Overall, there are three explanations of how regret affects DM (see Figure 6.2 for visual representation). First, that the experience of regret leads to anticipated regret and through this anticipation, we choose to avoid actions that could lead to regret. Previous work conducted by Coricelli *et al.* (2005) supports this explanation. Activity in the medial orbitofrontal region, the ACC and the hippocampus was observed during the experience of regret. Throughout the experiment, participants became increasingly regret averse which was reflected in the activity within medial OFC and amygdala. The same pattern of brain activity was also observed just before participants made a choice. Therefore, the same neural network was active during the experience of regret and also the anticipation of regret. In line with the notion that the experience of regret leads to anticipated regret and through this anticipation, we choose to avoid actions that could lead to regret.

The second possibility is that regret facilitates the memory that particular choices were poor and lead to negative outcomes and as a result we modify our behaviour. O'Connor, McCormack and Feeney (2014) investigated the link between experiencing regret and children's ability to make an adaptive choice switch (paying an initial cost to switch between a low value and a high value box). The results showed that irrespective of experiencing regret, children engaged in ACS after answering a memory question regarding the boxes' contents. Thus, those children who do not spontaneously choose to switch boxes (and have not reported experiencing regret) seem not to have access to evaluative information about the outcome of their choice (winning a better prize as an outcome of the initial cost) without being prompted. In addition to this, when children were asked why they chose to switch their box, those children who reported regret gave explanations based on adaptive switching whereas the children who did not experience regret initially only gave similar adaptive type explanations after they were asked the memory question. These results suggest that the experience of regret elicits a memory, and it is through activating the memory that individuals are able to engage in ACS. Thus the link between experiencing regret and ACS is retrieval of the negative memory.

It is also possible that the experience of regret is directly linked to adaptive switching and anticipated regret is not required in this process. Developmental evidence has produced interesting findings dissociating the experience of regret and anticipated regret. O'Connor, McCormack, Beck and Feeney (2015) invited 6 and 7 year old children to take part in a two day experiment that investigated the experience of regret and anticipated regret on ACS (while manipulating the child's experience of responsibility). On day 1 the children played the boxes task (see O'Connor *et al.,* 2012 for methodology) to investigated their experience of regret. Children were classified as experiencing regret if they rated their emotions as sadder upon finding out that the alternative prize they could have won was more desirable than the actual prize they did win. On day 2 children's ACS was examined using the same methodology as O'Connor *et al.* (2014). Children were categorised as showing ACS if they chose to pay an initial cost to switch their box in regret trials but not in the baseline trials (where the number of tokens was the same in each box). Children were then given a third task which examined their anticipated regret. Anticipated regret was tested using three boxes. Children were told that each box contained one prize of low, medium or high value. In reality, all boxes contained a medium prize. Children were asked to remove one of the three boxes out of the game. Children then chose to open one of the two remaining boxes, winning a medium prize. Children rated their emotional response to their prize (and thus their chosen box) on a 5 point smiley face scale. Children were then asked to rate how they would feel about their chosen box if the unchosen box contained the high value prize. Children were classified as anticipating regret if they predicted their emotions to be sadder if the alternative box contained the high value prize. Results showed that the children who experienced regret in the boxes task were more likely to engage in ACS. Additionally, the same children who engaged in ACS did not accurately predict their emotional response in the anticipated regret trial. This suggests that it is the experience of regret that predicts ACS and not anticipated regret.

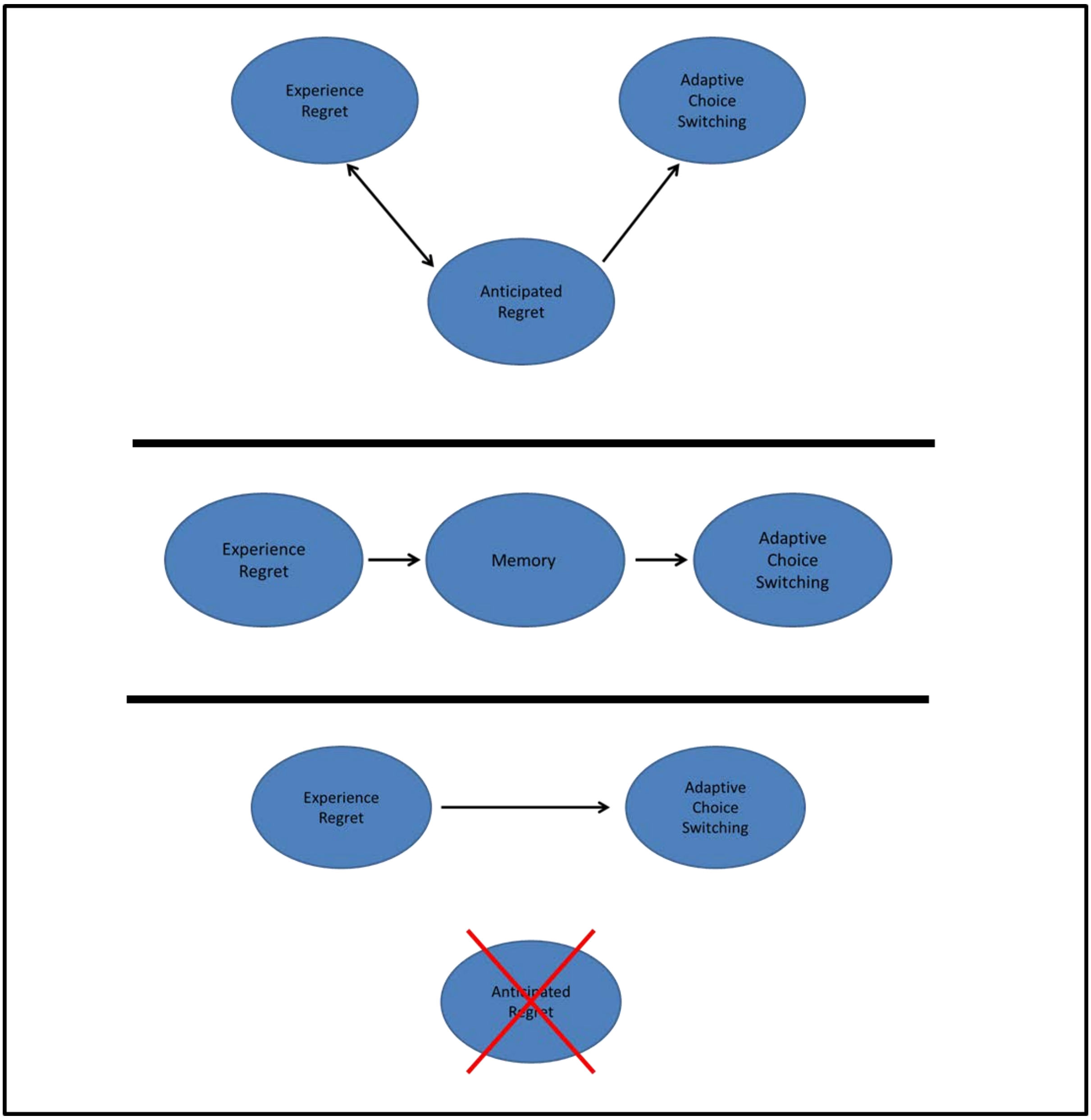


Figure 6.2: Three visual models representing differing opinions on how the experience of regret and anticipated regret affect ACS. Top: model representing Coricelli et al.'s (2005) explanation. Middle: model representing O'Connor, McCormack & Feeney's (2014) suggestion. Bottom: model representing O'Connor, McCormack, Beck & Feeney's (2015) findings.

This experiment was run to establish if the same patients who did not experience regret in the previous study (RR, LB and MG) would follow the developmental pattern described by O'Connor, McCormack and Feeney (2014) and not engage in ACS. Patient GM's experience of regret was preserved in the previous study but her experience of relief was impaired. If the developmental pattern (children who experience regret also engage in ACS) is observed in brain-damaged individuals, then patient GM should engage in ACS. If the developmental pattern is not observed in the patients tested then this finding would suggest that memory of the initial task is sufficient to engage in ACS and the experience of regret is not required.

One group of individuals who have been shown to report no differing emotional responses for regret and disappointment trials in a gambling task are individuals with High-Functioning Autism or Asperger syndrome (HFA/AS). However, these same individuals, regardless of their lack of experienced regret, still chose in accordance with maximizing expected values and anticipating regret (no difference from controls). The experiment conducted by Zalla *et al*. (2014) used partial and full feedback on a gambling task with two wheels/lotteries that offered differing number of points. The finding that emotional ratings for the group with HFA/AS only differed in regret evaluations and not in disappointment, joy or relief conditions suggests that the experience of regret alone is compromised and is described as a diminished self-report emotional awareness. However, the HFA/AS group showed a similar pattern to controls in their choice behaviour, through avoiding a high risk regret possibility (risky wheel) following a regret event, suggesting that HFA/AS individuals can anticipate regret. These findings suggests that the experience of regret is not required for anticipating regret and choice behaviour in line with avoiding possible regret. Thus, it is possible that the patients who did not experience regret in the previous study (RR, LB and MG) may still engage in ACS. See Nicolle, Ropar and Beck (2014) for commentary.

During this experiment, as in O'Connor, McCormack and Feeney's (2014) paper, participants will be asked to make a decision between switching their box and staying with the same box in an ACS task. Adaptive choice switchers are categorised as participants who, after receiving an undesirable outcome, switch their choice when given the opportunity to do so at a later time. A cost of switching was incorporated (half the initial winnings) to ensure that participants were not switching purely because they have been asked if they want to. A memory check was also incorporated to ensure that participants recall their initial winnings and thus make the decision to switch boxes based upon the desire to gain the greatest reward and not because of alternative reasoning. The memory check simply requires participants to recall images previously shown to them, one from a box they chose to open and one from the alternative box they did not chose to open. However, the memory check used by O'Connor, McCormack and Feeney's (2014) required participants, on day 2, to recall the contents of both the alternative and their chosen box. The authors found that if children were asked to recall the contents of the boxes they were more likely to engage in ACS. Therefore I chose to use an alternative memory check as I aimed to investigate if regret plays a role in ACS and thus did not wish to remind patients (as in O'Connor, McCormack and Feeney) of the boxes' contents.

The ability to demonstrate ACS is of particular interest as it sheds light on which participants have learnt from their previous actions and modified their behaviour in order to increase their gains (O'Connor, McCormack & Feeney, 2014). To my knowledge this is the first experiment that examines neurologically damaged patients' ability to engage in ACS.

I will refer to the experiment in Chapter 6a, Simple Regret, as Experiment 1 and refer to the task used in the current Chapter as Experiment 2.

6.6 Method

Design

The ACS task comprised two trials, an experimental trial in which the boxes contained different amounts and the participant always won 20p and missed winning £1 and a baseline trial in which both boxes contained 20p. The task was split into 4 parts that were completed; Experimental Trial Part 1 and Experimental Trial Part 2 were completed in the first session, whereas Baseline Trial Part 1 and Baseline Trial Part 2 were completed in the section session. Thus, participants answer four questions, one for each condition.

Session 1: Experimental Trial Part 1 contained the first section of the memory check followed by the first section of the regret DM task. Experimental Trial Part 2 was completed after the counterfactual conditional questions task and included the second section of the regret DM task, followed by the second section of the memory check.

Session 2: Baseline Trial Part 1 was the first session of the baseline trial and Baseline Trial Part 2 was the second session of the baseline trial.

Materials

Four distinctively different patterned boxes (20x16x27cm) were used as stimuli. Two boxes were used for the baseline trial and the other two boxes were used for the regret trial (DM 1 and 2). Each of the baseline boxes contained a square section of card (20x20cm) with 20p written on each card. Each of the experimental boxes contained a square section of card (20x20cm) with 20p written on one side and £1 written on the other side. Two different coloured draw-string pouches were used in the memory check. One pouch contained an image of a dog the other contained an image of a hammer.

Procedure

Session 1: Participants completed Experimental Trial Part 1. Participants initially completed the first section of the memory check. Two boxes were placed in front of the participant. The participant heard “We are going to play a game with these two boxes. You can open one of the boxes now. Please choose a box.” Once the participant had selected a box, the experimenter removed the lid and revealed either a picture of a dog or a hammer, the participant was given the corresponding picture. The experimenter then opened the second box, saying “We are now going to see what is inside the other box, this box contains a picture of a…” and revealing either the hammer or the dog.

The regret DM task (part 1) was then administered. A pair of new boxes replaced the previous ones. The participant was informed that these boxes contained money instead of pictures, “like before you are allowed to choose one of the two boxes and you can keep the prize that is inside the box- this time the boxes have money inside them.” The experimenter would always show the participant the side of the card, which had 20p written on it. The alternative box was subsequently opened. The experimenter always showed the side of the card which had £1 written on it.

During the same session Experimental Trial Part 2 was completed; the second section of the regret DM task was administered. The same pair of boxes used in the first section of the regret DM task was placed in front of the participant. The participants were informed that the boxes contained the same prizes as previously “These are the two boxes from before, I have set them up so they contain the same prizes as they did before you opened them last time.” The participant was then handed their 20p winnings - in two 10p coins - from the first section of the task. The experimenter further explained how the game worked: “You can keep the 20p that you won from before and open the same box for free, or you can pay 10p and swap your box to the one you didn’t choose earlier”. The participant’s decision was recorded. The economically rational response would be to pay the initial 10p in order to open the alternative box and win £1.

The second section of the memory check was then set up. The two sections of the memory check were completed first and last in order to maximise the reliability of passing. Thus, it could be inferred that those patients, who were successful on the memory check, would also be able to recall the boxes’ content in the test phase of the experiment. The same pair of boxes used in the first session was placed in front of the participant. The participant was asked to point to the box that they chose last time (with the image of the dog/hammer in front of them and then asked “Do you remember what was inside the other box?” Participants’ responses were recorded. In order to pass the memory check, the participant must recall which box they chose in the first section and also recall the image in the alternative box.

Session 2: Participants completed the Baseline Trial Part 1 at the start of their second session. The experimenter placed two different coloured bags in front of the participant, informing them that they could choose one of the two bags: “You are allowed to choose one of the two bags and you can keep the prize that is inside of it- there is money inside the bags. Please choose a bag.” The participant was shown that their chosen bag contained 20p; which was given to them in two 10p coins. The participant then saw that the alternative bag also contained 20p.

After the simple regret experiment was completed, the Baseline Trial Part 2 was run. As in all ACS tasks, the original bags were placed back in front of the participant and they were informed that the bags contained the same contents as earlier in the experiment. The participants were then given the opportunity to open the same bag as previously for free, or pay 10p of their initial winnings to open the alternative bag and win the prize. The economically rational response in the baseline trial would be not to pay to switch bags.

6.7 Results

I created a profile for each individual over the whole ACS task taking into account the regret DM task, the memory check, and the baseline trial. To pass the memory check, the patient must first identify which box their image of a hammer/dog came from. They must then recall the image of the alternative picture. The patients who failed the memory check (PW and MP) recalled their previous chosen box correctly, but did not recall the alternative image. All other patients passed both sections of the memory check.

In order to pass the choice switching condition, the patient must swap the box they originally chose, containing 20p, for a cost. The patient must give away half of their winnings, 10p, in order to open the alternative box and win the corresponding prize. The incorporation of an initial financial loss from swapping boxes discourages participants from choosing the alternative box simply because they have been presented with the opportunity to do so. This ensures that patients who do show a change of behaviour are demonstrating ACS and not just a preference for switching itself. Patients NB and GM failed this condition as they did not agree to incur the initial cost of 10p in order to open the alternative box and win the £1 that was contained inside.

The base line condition is used as a 'control' condition, to check that the patients are not swapping their box in the choice switching phase just because they have been given the option to do so. For patients to pass this condition, they must not take an initial loss of 10p in order to open the alterative box. This is the case because the previously chosen and the alternative box contain the same monetary value. Only patient MP chose to switch on the baseline condition. All control participants passed each of the three conditions. For a full description of patients' performance on this task refer to table 6.3.

Table 6.3

Results for patients in each of the three conditions

	Condition		
Patient	Memory check	Choice switch	Baseline
NB	Pass	Fail	Pass
MG	Pass	Pass	Pass
DR	Pass	Pass	Pass
PW	Fail	Pass	Pass
TJ	Pass	Pass	Pass
RR	Pass	Pass	Pass
PS	Pass	Pass	Pass
JB	Pass	Pass	Pass
GM	Pass	Fail	Pass
LB	Pass	Pass	Pass
EL	Pass	Pass	Pass
MP	Fail	Pass	Fail
PF	Pass	Pass	Pass
JH	Pass	Pass	Pass
MB	Pass	Pass	Pass
RP	Pass	Pass	Pass

NB: The rows highlighted in yellow show the patients who failed at one of the three conditions. For the choice switching condition, swapping boxes is labelled as 'pass'. In the baseline condition, not swapping boxes is labelled as 'pass'.

6.8 Discussion

I set out to establish if there is a relationship between experiencing regret and ACS. Developmental research (O'Connor *et al.*, 2014) has shown that that children's ability to experience regret facilitates children's learning and behavioural modification; the aim of experiment 2 was to investigate if this relationship is present in a group of patients, some of whom have problems in experiencing regret, relief, or both.

Results show that 4 out of the 17 patients show a different pattern of results from the other 13 patients and all 17 control participants. Patient PW failed the memory check. Patient MP failed the memory check and the baseline trial. Patients GM and NB failed the choice switching trial only. Patients who fail the memory check are discounted from being classed as adaptive choice switchers, because we cannot be certain that they choose the alternative box, during the test phase, to increase their gains and thus make an adaptive choice switch (it could be due to non-systematic answering or the preference for switching). Also, patients failing the baseline condition are removed as possible adaptive choice switchers (O'Connor, McCormack & Feeney, 2014).

BCoS results for GM, PW and MP do not highlight a cognitive impairment that may have impacted on their performance during this task. These patients are not impaired in any of the following: number calculation, language comprehension or long term verbal memory: free recall and recognition. This suggests that these patients, whose performance was different from controls, are affected by their brain lesion directly. NB's BCoS results are discussed in this section.

Patient GM and patient NB failed only during the choice switching trial. This suggests that these two patients cannot perform an adaptive choice switch and thus are not learning from their mistakes in a previous trial. As previously reviewed, patient NB reports both regret and relief in Experiment 1. GM failed both medium and large size conditions for relief trials in Experiment 1 yet passes regret trials. This pattern of results is different to what is observed in the developmental literature where children only engage in ACS if they have previously experienced regret.

GM has damage to the left sided lingual gyrus and the surrounding areas. The link between the lingual gyrus and the VMPFC, lateral temporal gyrus and the hippocampus has been highlighted by DeBrigard *et al.* (2015) could explain GM's failure to engage in behavioural modification in this task. Van Hoek *et al.* (2015) describe a reward network which incorporates the VMPFC, suggesting that the VMPFC and the lingual gyrus could be connected. If GM's lesion has disrupted this connection and thus interrupted the reward network, then GM may not compute that encountering an initial lose (half the participant's winnings) would result in an overall greater gain. However, to my knowledge this is the first study that directly links the left lingual gyrus to adaptive learning.

NB has lesions covering the right angular gyrus, left cerebellum, right inferior occipital lobe and right inferior parietal lobe. The literature does not shed light on reasoning for NB failing this task. It is possible that damage to any of these areas has resulted in this pattern of behaviour. It becomes increasingly difficult, when multiple regions have been compromised, to establish the reason behind a patient failing a task, especially when the developmental literature predicts a pattern of behaviour different to that which is observed.

At this point I will briefly discuss the regions which I believe are most likely to have caused NB's behavioural pattern.

The angular gyrus is commonly associated with arithmetic problem solving and mental calculation (Cowell *et al*., 2000; Delazer *et al.,* 2003; Prabhakaran *et al.,* 2001; Zago & Tzourio-Mazoyer, 2002). Dehaene *et al.* (1999) specifically linked the angular gyrus with exact, in comparison to approximate, arithmetic. Thus it is possible that NB only fails the choice switching exercise on the basis of a miscalculation. BCoS results demonstrate that NB does indeed have impaired number calculation. As a result it is possible that NB is able to engage in adaptive choice switching but the current task did not allow for him to demonstrate his ability to do so.

This interpretation sheds light on a possible limitation of the presented study; participants should be given simple mathematical sums to calculate in order to establish that they are failing this task on the basis of impaired choice switching and not a calculation error. Combining simple tests of arithmetic and BCoS scores would allow for confident conclusions to be drawn regarding the cause of a patient's difficulties on this task.

However, it should be noted that Venkatraman *et al.,* (2005) suggested that exact arithmetic, and the angular gyrus, is only responsible for retrieval of arithmetic facts, suggesting that the system would not be active during the current experiment. Studies investigating exact arithmetic have shown that multiplication problems are solved from fact retrieval rather than the subtraction and addition which are required in the current experiment (Campbell & Xue, 2001).

I will now discuss how patient performance on the simple regret task (reported in Chapter 6a) relates to the ACS task presented in this chapter. As previously explained, there are three explanations of how regret affects DM and ACS. First, that the experience of regret leads to anticipated regret and it is this anticipation that is at the root of adaptive DM (Coricelli *et al.,* 2005). Second, that the experience of regret creates a negative memory and recollection of the memory that particular choices were poor dictates behaviour modification (supported by O'Connor, McCormack & Feeney., 2014). Third, that the experience of regret is directly responsible for adaptive switching; anticipated regret is not required (O'Connor, McCormack, Beck & Feeney, 2015).

O'Connor, McCormack and Feeney (2014) found that children who participated in a similar experiment demonstrated a relationship between experiencing regret and ACS. Those children who reported experiencing regret in Experiment 1 were able to pass Experiment 2 by switching their box. However, those children who did not report regret in the first experiment were significantly less likely to engage in choice switching. None of the patients in experiment 1 who failed regret trials, RR, LB and MG showed a similar behavioural pattern to the children in O'Connor, McCormack and Feeney's (2014) study who failed initial regret trials and subsequent choice switching in experiment 2. RR, LB and MG were able to engage in ACS despite their lack of experienced regret. Therefore, results from this experiment do not produce evidence for a link between experienced regret and the ability to engage in ACS in the patients who took part in this project.

Patients RR, MG and LB do not report experiencing regret in either the medium or large size condition in Experiment 1, y*et* all three patients pass Experiment 2, demonstrating they have engaged in ACS. It is possible that these patients are able to pass the choice switching exercise due to their memory of the task and not because they previously experienced regret (during ACS part 1). If this is indeed the case, it would suggest that individuals do not directly require regret to change their behaviour in order to build upon past experiences and engage in behavioural modification. This finding is possible support for the notion that memory of regret facilitates ACS (O'Connor, McCormack & Feeney, 2014).

An alternative to the memory account is Coricelli *et al*'s (2005) argument that anticipated regret is the mediating factor between the experience of regret and ACS. Although it is surprising that individuals do not experience regret but do anticipate it. However, evidence from individuals with HFA/AS has shown that participants can make choices in accordance with maximizing expected values and anticipate regret without the ability to experience regret directly (Zalla *et al*., 2014). Thus, patients RR, MG and LB are demonstrating the same response pattern to that of Zalla *et al.'s* HFA/AS individuals and are providing support for Coricelli *et al.'s* (2005) notion that anticipated regret facilitates DM.

The finding that three patients do not require the experience of regret to adaptively switch their behaviour is in line with research conducted by Raeva *et al.* (2011). Indeed, Raeva *et al.* (2011) have argued that the experience of regret itself is not a necessary precursor for altering DM. The authors investigated how feedback on individual DM affected behavioural change. It was shown that participants became regret averse once they received feedback on the obtained outcome (factual outcome) and also on the hypothetical outcome (counterfactual outcome). Regret aversion was observed not only when participants experience regret, but also when no regret was experienced (factual outcomes were equal to counterfactual outcomes). Thus, the findings imply that the effect of behavioural change is, at least in part, due to the transfer of a comparison mind-set which is induced during the prior choice. This claim made by Raeva *et al.* (2011) opposes Coricelli *et al.'s* (2005) suggestion the experience of regret leads to anticipated regret and through this process, individuals choose to make decisions based on avoiding the experience of regret.

In addition, patient GM failed both medium and large size conditions for relief trials, yet passed both regret conditions. GM passes both the memory check and the baseline trial which suggests she understands the task. Based upon O'Connor, McCormack and Feeney's (2014) work one would expect GM to use choice switching in Experiment 2; however this is not the case. GM's pattern of results further indicates that patients after neurological damage does not follow the same pattern of behaviour seen in typically developing children (the experience of regret predicts ACS behaviour), suggesting, in this group of patients, that the experience of regret is not crucial for behavioural modification and possibly regret avoidance.

Overall, this experiment was adapted from O'Connor, McCormack and Feeney's (2014) work that demonstrated that children who experience regret are more likely to engage in ACS behaviour. The aim of this experiment was to examine the relationship of regret and future DM and if the experience of regret underpins adaptive behavioural change in a patient population. Two patients failed the ACS task (GM and NB). Patient GM failed both medium and large size conditions for relief trials in yet passes regret trials in Experiment 1. Patient NB passes all conditions for both regret and relief in Experiment 1. It is possible however that NB's performance on the current task was impacted by impaired number calculation. Patients who do not experience regret in Experiment 1 (RR, MG and LB), do in fact demonstrate ACS in Experiment 2. These results are not in line with the developmental findings described by O'Connor, McCormack and Feeney's (2014), suggesting that, for the patients tested in this experiment, the experience of regret does not underpin the ability to engage in ACS. However, it is not clear whether ACS is facilitated by the memory of regret or anticipated regret. In order to gain a more comprehensive understanding of which account is most likely, it would be necessary to investigate anticipated regret in a patient population. In addition, investigating the effects of memory strategies in patients who are unable to engage in ACS might shed light on the relationship between memory and behavioural modification while also providing an important contribution to rehabilitation programmes for such patients. It is important to note the possibility that the developmental trajectory that binds the experience of regret and ACS together is required for normal development through childhood, but once the ability to adapt ones behaviour is acquired the ability to engage in ACS becomes independent to that of experiencing regret. This possibility also requires further investigation.

Chapter 7

Patients’ with Neurological Damage Performance on a Counterfactual Conditional Questions Task

7.1 Introduction

Counterfactuals are thoughts of what might have been (Epstude & Roese, 2008). For example if an individual is late for work they might think 'If I had not pressed snooze on my alarm, I may not have missed my bus to work and been late'. Previous research has shown that neuropsychological patients, especially those with damage to the OFC, have problems with reporting regret (Camille *et al.,* 2004). However, it has not been investigated if these patients struggle with the reasoning that is thought to underpin regret, CFT. Here I will test neuropsychological patients' ability to answer simple counterfactual conditional questions.

Counterfactual reasoning in Schizophrenia patients has been examined by Hooker, Roese and Park (2000) (see Chapter 1). Results indicated that CFT was impaired in the group with Schizophrenia compared to controls; Schizophrenia patients used less counterfactual language and engaged less frequently in counterfactual thought when prompted. The two groups of participants were not significantly different in tests for general cognitive ability, suggesting that deficits seen in patients was not due to general cognitive declined observed in Schizophrenia. However, CFT was correlated with social functioning. It is possible that the problems faced by Schizophrenia patients in counterfactual reasoning are linked to the frontal lobe dysfunction that causes the disorder.

Further research on CFT has been conducted by McNamara *et al.* (2003) with Parkinson's patients (see Chapter 1 for description of methods). Results indicated that despite demonstrating no difference from controls in a semantic fluency test, Parkinson's patients produced significantly fewer spontaneous counterfactuals. Furthermore, results from the CIT, where participants infer which of two story protagonists feel worse after a negative situation has occurred, provide evidence that Parkinson's patients have impaired

CFT and these deficits correlated with tasks that probe frontal lobe dysfunction. The relationship between impaired performance in counterfactual inference tasks and tests examining frontal lobe dysfunction (EF) are similarly reported in typically developing children (Beck, Riggs, & Gorniak, 2009; Beck, Riggs & Burns, 2011).

These studies of CFT in patient groups have focussed on advanced abilities: such as spontaneous generation of counterfactuals (which developmental psychology suggests is late developing and more challenging than simply considering counterfactual worlds, Guajardo, McNally, & Wright, 2016), and the evaluation of CMEs (at least 2 of 4 questions in the CIT explicitly ask about emotions following from counterfactual thoughts). As mentioned above, studies of neuropsychological patients have also focussed on experience of CMEs (e.g. Coricelli *et al*., 2004) rather than people's competence at thinking about counterfactually, in the first place. This emphasis is particularly interesting when considered in the light of the developmental literature on CFT, which has first tried to analyse children's ability to think about counterfactuals, and only more recently turned to CMEs. In this literature, it suggested that in order to experience CMEs, children must first develop the ability to reason about counterfactual worlds. That is why in this study, I investigated whether simple counterfactual reasoning was impaired in patients with acquired brain damage. We do not yet know whether acquired brain damage can also impair very simple counterfactual reasoning abilities, that emerge early in development. All healthy adults would be expected to have these simple abilities. I now review the developmental literature to identify these specific abilities.

Some argue that children as young as 3 or 4 years old can pass counterfactual tasks (Harris, German & Mills, 1996; Riggs, Peterson, Robinson, & Mitchell, 1996). These studies focused on sequences of events (if A then B) and counterfactual events (in the absence of A, then not B). For example, a character, Carole, walks over a clean floor with muddy shoes. Children are then asked a counterfactual question ''What if Carole had taken her shoes off, would the floor be dirty?' Although there is some dispute over the exact age at which children answer this question correctly (e.g. Riggs *et al.*, 1998), the authors argued that when children pass these tasks they are using counterfactual reasoning abilities.

However, Rafetseder, Cristi-Vargas and Perner (2010) have argued that answering simple counterfactual conditional tasks, such as those described above, does not require counterfactual reasoning and instead children can use Basic Conditional Reasoning (BCR) to answer these questions. BCR involves logical reasoning and general knowledge of the world but not the consideration of a specific alternative world that characterises a counterfactual (Rafetseder *et al.,* 2010). For example, BCR could be used to answer the questions asked in Harris *et al.*'s (1996) study about Carole and her muddy shoes by thinking that typically, if shoes are removed, floors stay clean.

Rafetseder *et al.* (2010) argue that BCR is used when the information about specific events is dismissed and general regularities are relied on instead. In order to think counterfactually, one's reasoning must be within the realm of actual events; creating the nearest possible world. The authors aimed to design a series of experiments that avoided the problem of BCR that Harris *et al.* (1996) encountered (see Chapter 1 for description of methods). In conditions where CFT and BCR would produce the same response, children performed well. However, performance declined in conditions where BCR and counterfactual reasoning produced different answers.

In a further study, Rafetseder and Perner (2010) showed that by 6 years, children used counterfactual reasoning, not BCR, to answer the questions. In support of this, other authors have also argued that children are not thinking counterfactually until they are around 5 or 6 years old, because they fail to see the counterfactual as an alternative that could have replaced the real world (Beck, Robinson, Carroll, & Apperly, 2006, see also Beck & Guthrie, 2011).

Thus, in this study of counterfactual reasoning ability in neurological patients I wanted to use questions that could not be answered using BCR, but rather required genuine counterfactual reasoning, and yet, I did not wish to make the additional demand of asking participants to infer regret. I used a scenario in which events could be singly or doubly determined. Singly determined outcomes have only one cause, whereas doubly determined outcomes could have been the result of either of two causes. For example, if Professor Plum poisons the victim, and then Miss Scarlet, who is ignorant of the poisoning, stabs him, we can describe the victim's murder as doubly determined. If Miss Scarlet had not stabbed the victim, he would still have died. In a singly determined event (where for example no poisoning happens) if Miss Scarlet had not stabbed the victim, the outcome would have been different. Using doubly determined questions allows us to identify patients who are using BCR and those who are thinking counterfactually. BCR-reasoners will answer the question simply by cancelling the stabbing event and asking whether people who have not been stabbed are typically alive or dead. While this gives the same answer for the singly determined event, it leads to the incorrect answer in the doubly determined event (BCR = alive, counterfactual reasoning = dead, because of Professor Plum). Recent developmental research has shown that there is a difference in when children are able to answer singly and doubly determined questions. McCormack *et al.* (2017) showed that while singly determined questions were answered correctly by 4-to-5 year olds, doubly determined questions were not answered correctly until 6-to-7 years. Thus, I aim to investigate how determination affects performance in a patient group. It is possible that patients, like children, find doubly determined questions harder to answer than singly determined questions.

Two different types of counterfactual questions were asked, either subtractive or additive. Subtractive questions require participants to mentally undo an action that has already occurred or remove an element of the stimulus set up that is presented. Additive questions require participants to imagine an additional element to the stimulus set up. In both instances the adding or subtracting of an element/action may or may not affected the outcome. The distinction between additive and subtractive counterfactual questions has been described by Roese, Hur, and Pennington, (1999) and Roese and Olson, (1993). McCormack *et al.* (2017) investigated children's ability to answer additive and subtractive counterfactual questions, although children answered more questions correctly in the subtractive condition the difference did not reach significance. I wish to establish if there is a difference in patients' ability to answer subtractive and additive counterfactual questions.

A further type of temporal conditional is incorporated in this study. Developmental evidence suggests that children find it easier to consider possible worlds in the future compared to the past. While 3-year-olds struggle with past conditionals 'What if Carole had not taken her shoes off, would the floor be clean or dirty?' they perform much better when asked about the future 'What if next time Carole takes her shoes off, will the floor be clean or dirty?' even though both these questions could be answered by BCR, the latter is easier than the former (this may be because ignoring what you know to be true about the past makes additional inhibitory control demands, Beck, Carroll, Brunsden, & Gryg, 2011). In this study I included both singly and doubly determined future conditional questions as well as counterfactual questions, to form a complete picture of the effect of the neurological damage.

The current experiment was conducted to establish if CFT in neurologically damaged patients is impaired on a task that requires patients to ignore current reality and consider an alternative in either the future (future hypothetical) or the past (counterfactual conditional). The questions asked were either singly determined (characterised by only one event causing the outcome in one trial) or doubly determined (characterised by two events causing the same outcome in one trial) and had a subtractive (an element of the apparatus is removed) or an additive component (an extra element is added to the apparatus). Combining neuropsychological research with developmental studies will permit informed claims about the neurological network that supports CFT and DM. A more comprehensive investigation into the developmental processes, which have been reported in the literature, and the neural framework that facilitates CFT will become possible.

7.2 Method

Participants

A total of 17 patients (7 female) aged between 67 and 84 (*M* = 73.8 years, *SD* = 7.02) and 15 controls (12 female) aged between 28 and 74 (*M* = 59.4 years, *SD* = 12.6) completed this test battery. See Table 7.0 for information on the patients who failed, and will be discussed, in this task.

Table 7.0

Description of the patients' information who are discussed in this task

Patient	DOB	Hemisphere	Year of Damage	Lesion affected Anatomy
PW	[redacted]	L	2013	Cerebellar
PS	[redacted]	L	2012	Amygdala. Possible damage to the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule
GM	[redacted]	L	2013	Left sided lingual gyrus and nearby occipital structures including the left intracalcarine cortex and occipital fusiform gyrus
PF	[redacted]	BILAT	1999	Bilateral superior and inferior parietal gyri lesion, left sided lesion extends into the left angular gyrus and the right sided lesion extends slightly into the right caudate. Small left thalamus lesion. Extensive white matter damage to the frontal and parietal cortices
SAR	[redacted]	BILAT	2012	Cerebellar, occipital lobe, frontal lobe, right insula cortex and possible

				damage to the frontal radiation associated with the corpus callosum and the anterior limb of the internal capsule
MP	[redacted]	R	1998	Extensive temporal, frontal and parietal damage. Damage extends to the right insular, middle temporal gyrus (anterior and posterior divisions) as well as the temporo-occipital region and the OFC. Possible damage to the frontal radiation associated with corpus callosum and anterior limb of the internal capsule

Design

The experiment was administered using Power Point. On each trial an image was displayed that consisted of two 'tracks', one red fast (shorter distance) and one blue slow (longer distance). Both tracks ended in the same area, here, a red cylinder block was standing upright. One marble was placed at the top of each track (in its corresponding colour). Half of the trials were in the counterfactual condition; participants watched an animation of the marbles dropping down the tracks. The marbles were dropped down the track, and when one reached the block, it would fall over. In this condition counterfactual questions were asked. The other half of trials were in the future condition; the marbles would stay at the top of the tracks (no animation). In this condition future hypothetical questions were asked. In addition, black pegs -that acted as barriers- were added in or taken away from the tracks, creating additive and subtractive trials. The role of the pegs was to stop the marble half way down the track, thus not allowing that marble to knock over the block.

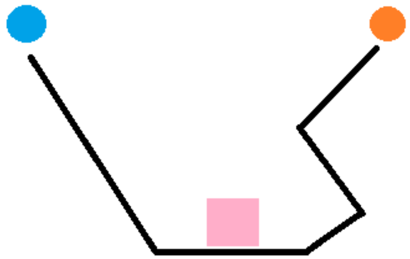
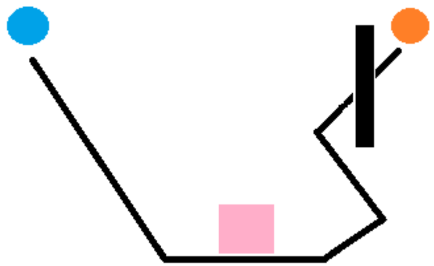
64 trials were administered, 32 in the counterfactual condition and 32 in the future condition. In order to create the stimuli, each of the conditions was split into groups of 4, containing 4 stimuli (16 trials) which had the same set up; i) no pegs. ii) a peg placed on the slow track. iii) a peg placed on the fast track. iv) a peg on both tracks. Each of these images was flipped on the vertical axis to create filler trials. One of each 'type' of question was coupled with each of the 4 stimuli once, for example (see table 7.1 for an example of each type of question coupled with stimuli). The slides were then ordered using a pseudo random trial; an 8x8 Latin Square was used. The trial randomisation limited any sequence effects that may have occurred otherwise.

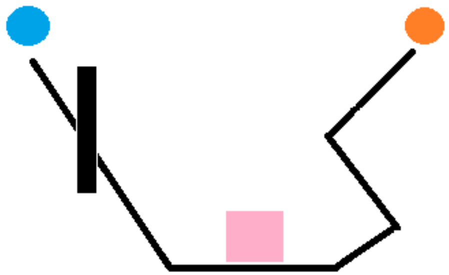
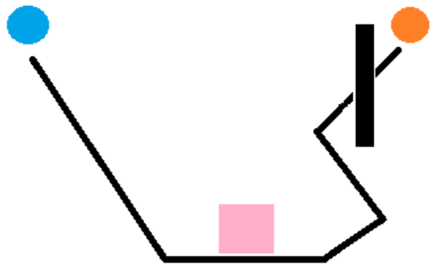
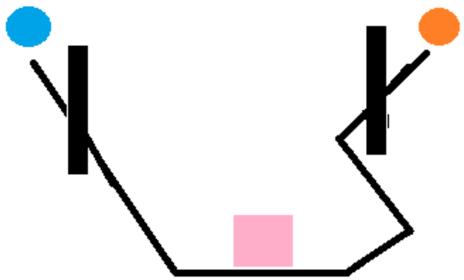
Half of the trials (32) were doubly determined questions. Doubly determined questions are created by the stimulus set up. Two events cause the same outcome in one trial. The blue and orange marble will both knock over the block if the stimuli are not altered (pre-question). When a counterfactual conditional question (counterfactual condition) or a future hypothetical question (future condition) is asked, neither adding nor subtracting a barrier or stopping a marble being dropped will alter the outcome of the trial.

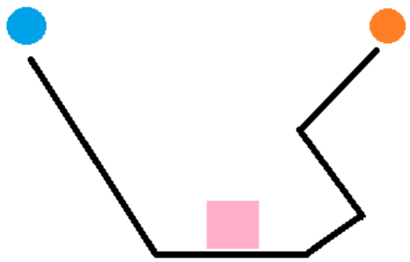
The other half of trials (32) were singly determined. Singly determined trials are characterised by only one event causing the outcome. Either one marble only knocks the block over or two barriers are in place stopping both marbles knocking the block over. If the single marble that will knock the block down is stopped or either of the two barriers are removed then the outcome of the trial will change; this rule applied to both counterfactual and future conditions.

Table 7.1

Example questions for both counterfactual and future trials, including information regarding question type, determination and correct response.

Stimulus	Question	Condition	Additive or Subtractive	Determination	Response
	If I had not rolled the blue marble that time would the block have fallen down?	Counterfactual	Subtractive	Double	Yes
	If I do not drop the orange marble this time will the block fall down?	Future	Subtractive	Single	No

	If I take away the blue peg this time will the block still fall down?	Future	Subtractive	Single	Yes
	If I had put the peg on the blue side as well that time would the block have fallen down?	Counterfactual	Additive	Single	No
	If I take away the orange peg this time will the block fall down?	Future	Subtractive	Double	Yes

	If I had put the peg on the blue side that time would the block have fallen down?	Counterfactual	Additive	Double	Yes

Note. 6 different questions are used as not every question can be paired with every stimulus. For example during trials where the stimuli has no barriers , the question 'If I take away the blue peg this time will the marble still fall down?' cannot be asked.

Procedure

Training: Participants were trained on the rules of the question game. PowerPoint slides were shown depicting small sections of the apparatus accompanied by an explanation. “What you are going to see is a marble at the top of a fast track like this [picture]. The marble is going to drop down the track like this [animation of marble dropping is shown]. As you can see, the marble has knocked over the block [animation of block falling occurs].” This was followed by an explanation of how the peg would be used throughout the task. “In some trials there will be a peg stopping the marble from rolling down the track like this [animation]. This means the block didn’t fall over.” The participants were read the same instructions, accompanied by slides and animation, for the red fast track. The experimenter then showed the two tracks together. “In the experiment there will always be two marbles, dropped down each of the tracks. When the marbles are dropped, only one marble can knock the block over like this [animation].” Finally, the timing conditions were explained; “Sometimes the marble will stay at the top of the track like this [picture]. Other times the marbles will drop down the tracks like this [animation].” It was then explained what the task demanded from the participants; “I am going to ask you questions about the slides, either adding or taking away a peg. You have to say ‘yes’ or ‘no’ to whether the block would have fallen down.” Participants were given the opportunity to ask any questions.

Experimental phase: Participants were shown a 64 slide Powerpoint presentation. Slides were advanced by the experimenter at an appropriate pace. Each slide was accompanied with a single question read by the experimenter live. The order of pseudo random trials was the same for all participants. Participants were asked the questions in the future condition after the animation had taken place. Participants were asked the question in the counterfactual condition while viewing the stationary image. The experimenter read questions from a printed version of the task. Participants' responses of yes/no were recorded by the experimenter on the printed sheet.

Questions that were asked in the future condition were as follows: "If I do not drop the blue marble this time will the block fall down?" "If I put a peg on the blue side this time will the block fall down?" "If I put a peg on the blue side as well this time will the block fall down?" and "If I take away the blue peg this time will the block still fall down?"

Questions that comprised the counterfactual condition were: "If I had not dropped the red marble that time would the block have fallen down?, "If I had taken away the orange peg that time would the block have fallen down?", "If I had put the peg on the orange side that time would the block have fallen down?" and "If I had put the peg on the orange side as well that time would the block have fallen down?"

7.3 Results

Participants' responses were sorted into conditions. Counterfactual and future questions were separated first, followed by additive and subtractive trials, they were then distinguished by determination and finally through the criteria of the questions referring to the marble or the barrier/peg.

On questions which referred to either the addition or subtraction of a peg e.g. 'If I had taken away the orange peg that time would the block have still fallen down?' participants were categorised as failing to meet the criteria for success on a condition if they answered 4 out of 4 questions incorrectly (responding with yes when the answer is no or responding with no when the answer is yes). This criterion shows that patients were systematically answering the question incorrectly. Answering 4out of 4 questions incorrectly has a probability of .06. I used this very strict criterion because performance overall on this task was poor and I wanted to be sure that patients had specific problems with counterfactual questions and because young children make systematic errors on this type of task (Riggs *et al*., 1998).

There were 8 questions in which the counterfactual referred to the addition or subtraction of the marble e.g. 'If I had taken away the orange peg that time would the block have fallen down?' Patients were taken as failing to meet the criteria for success on a condition if they scored equal to or less than 7/8 questions incorrectly. Answering 7 out of 8 questions incorrectly has a probability of .03.

Only two control participants answered a question incorrectly. One incorrect answer was recorded in the 'Counterfactual subtractive doubly determined MARBLE /8' condition and one answer in the 'Counterfactual subtractive doubly determined PEG /4' condition.

Six patients failed during at least one of the 12 conditions (see table 7.2). Each of these six patients failed, at least once, to answer any questions correctly in trials that were doubly determined where the barrier was either added or subtracted. 4 of these were counterfactual doubly determined trials and 3 were future doubly determined trials. Only one patient failed to pass a condition where the question referred to marbles and was a future singly determined trial.

Table 7.2: Responses of patients during the counterfactual conditionals questions task

Condition	Patient																		
	NB	MG	DR	PW	TJ	RR	PS	JB	GM	LB	EL	MP	PF	JH	MB	RP	SAR	Control Average	Overall errors
Past Add Single PEG /4	1			1									3				3		8
Past Add Double PEG/4		1		4			4						2	2			4		17
Past Sub Single MARBLE /8	1	2	1	5			5						3	5			3		25
Past Sub Single PEG /4		2														1	1		4
Past Sub Double MARBLE /8		1		2			3										5	.07	11
Past Sub Double PEG /4	1	1							4			1	4		1		1	.07	13
Future Add Single PEG /4												1	3	1		3	2		10
Future Add Double PEG /4				1			4	1					1				3		10
Future Sub Single MARBLE /8				3									7	3		1	4		18
Future Sub Single PEG /4													2		1		3		6
Future Sub Double Marble /8				1			4						2				3		10
Future Sub Double PEG /4							1		2			4	1	2	1	1	3		15
Overall errors	3	7	1	17	0	0	21	1	6	0	0	6	28	13	3	6	35		147

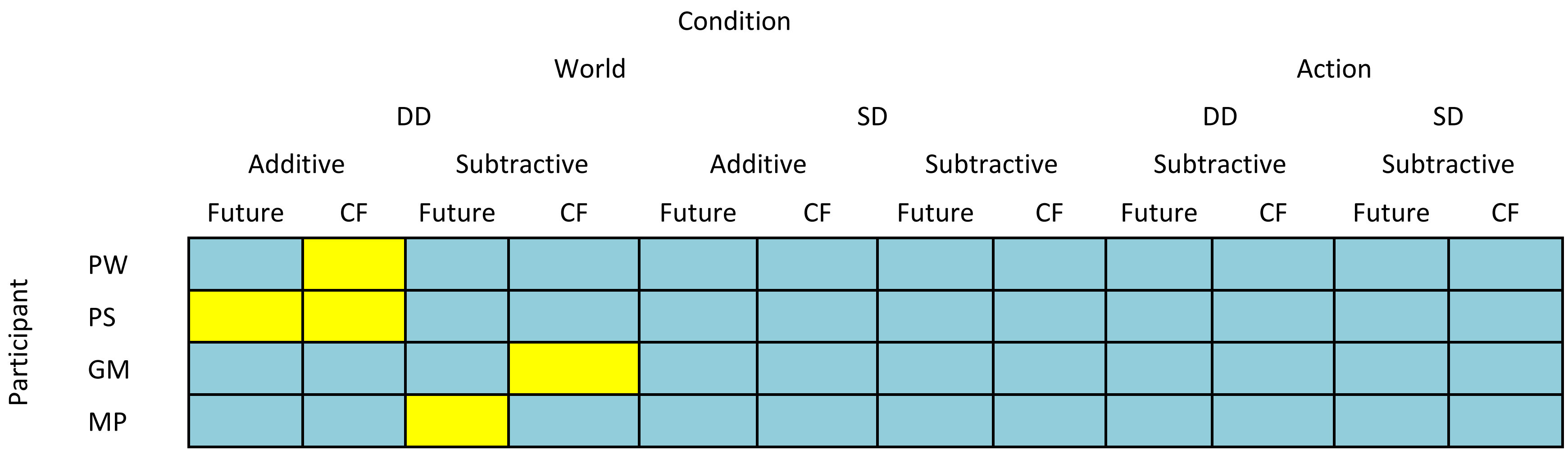
NB: CF stands for counterfactual. The numbers refer to the amount of questions each participant answered incorrectly in that condition. Highlighted in yellow are the conditions where the patient failed. The Control Average refers to the average number of incorrect responses across all 15 controls in each condition respectively.

The table shows the questions broken down into 4 conditions: counterfactual and future conditions were sorted first, followed by additive and subtractive, then by determination and finally by if the question referred to a peg or a marble. This created 12 sub-conditions (which can be seen on the left of the table) for which each participants' answers were recorded. The table shows the number of questions each patient got wrong in each of the 12 sub-conditions. The highlighted numbers signify that that patient has failed the corresponding sub-condition. From the table it is clear that patients PF and SAR answer the most questions incorrectly; PF answers 28/64 questions incorrectly while SAR answers 35/64 questions incorrectly. A binomial test was completed to establish if PF and SAR were answering non-systematically. Results demonstrated that PF's response pattern was no different from chance $p = .382$ additionally, SAR's response pattern was no different from chance $p = .532$. All other patients' cumulative results were different to chance. Therefore PF and SAR were removed from any further analysis. Once PF and SAR were removed, a Mann-Whitney U test was run to establish if the number of questions answered incorrectly was significantly different to controls. There was a significant difference between the number of errors made by patients (*Mdn* = 18.5) and controls (*Mdn* = 6.5); $U = 0$, $p < .001$.

After the results were ordered in the above manner, it became evident that there was a pattern to which sub-conditions were being failed by patients. Thus, the conditions were divided into two further categories; 'world' and 'action'. Questions that referred to a change in the stimuli e.g. 'If I had taken away the blue peg that time would the block have fallen down?' were classified under 'world'. This is the case because the stimuli set up that is presented in front of the participants must be altered in order to answer the question correctly. The participant must create an alternative world, to that of the present, where the stimuli set up is different and compare the current outcome to a hypothetical one. Questions that were categorised as ‘action’ referred to a change in the input to the stimuli e.g. ‘If I had not rolled the blue marble that time would the block have fallen down?’ This type of question does not require a separate counterfactual world to be created. Participants must imagine an alternative outcome using the same stimuli set up that is presented in front of them. To highlight the difference in conditions a heat map was created (see table 7.3). All conditions that were failed by all 4 patients were in the ‘world’ condition.

Table 7.3

Heat map highlighting the difference between world and action conditions for the 6 participants who failed the counterfactual conditionals task.



NB: CF stands for counterfactual. DD refers to doubly determined. SD refers to singly determined. Yellow sections highlight where a participant has answered all questions incorrectly. Blue sections represent a pass.

7.4 Discussion

I set out to explore how neurologically damaged adults answer counterfactual conditional questions. Patients were asked a set of future hypothetical and counterfactual conditional questions. The questions were asked in the future (future hypothetical questions) or the past tense (counterfactual questions). In addition to this, questions were either additive or subtractive and were distinguished by determination (singly or doubly determined). Results indicate that six patients failed during at least one of the 12 conditions. However after inspection of response patterns two patients, PF and SAR, were removed from further investigation due to their responses not being different from chance. Doubly determined trials appear to be harder for patients to answer than singly determined trials. Each of the 4 patients (not including PF and SAR) that failed on one or more sub-condition, failed in the doubly determined condition. Overall, 3 additive and 2 subtractive sub-conditions were failed of which 2 were future and 3 were in the counterfactual sub-conditions. This demonstrates that there was no difference in how hard patients found these sub-conditions.

Singly determined questions were easier to answer than doubly determined questions. It is possible that singly determined trials are easier for patients to pass because BCR can be used to reach the correct response. As only one cause is affects the outcome of the trials, if this is altered in anyway (the marble is not dropped or a peg is placed in the way) then the outcome is changed. Therefore, simply the patient can use ‘general knowledge’ to assume that if the cause changes, then the outcome changes too e.g. no the block would not have fallen down (assuming previously it did). Notably, no patients failed a block of singly determined trials, suggesting that this was within their reasoning capacity.

In contrast, doubly determined questions proved harder for some patients to answer correctly. During doubly determined trials, there are two possible causes that create the outcome. Therefore, BCR cannot be used to correctly answer the question. It is necessary to use counterfactual reasoning to respond correctly. Unexpectedly, all of the trials which proved problematic for patients were not only doubly determined, but also referred to a change in the stimuli itself, the ‘world’, not just the actions which had taken place (e.g. which marble had been dropped).

As discussed in Chapter 4, it is possible that failure in this task could be due to problems with visuo-spatial deficits, and not impairments in CFT. Visuo-spatial perception allows individuals to process visual information regarding the position of objects in space (Pinel, 1993). The visuo-spatial deficits that I will discuss in relation to BCoS scores are neglect and extinction. BCoS scores show that PS, PW and GM do not have deficits in neglect or extinction. However, MP has visuo-spatial deficits in object neglect and visual extinction. This impairment could have resulted in MP failing this task. However, I am reluctant to explain MP’s failure in this task as a result of his visuo-spatial deficits; MP only fails one condition out of a possible 12 and only responds incorrectly throughout the whole experiment 6 times. If visuo-spatial deficits were the cause of MPs failure I would expect him to fail on multiple conditions. Thus, although it is important to note that visuo-spatial deficits could play a vital role in explaining results in this task, I am confident that MP does not fail a condition in this task because of object neglect and visual extinction.

The demands on visual imagery and language also should be considered when discussing this task. Visual imagery is the process of mental simulating an image based on memory and includes processes such as mental rotation (Sirigu &Duhamel, 2001). Demands on visual imagery were reduced in the current experiment by keeping the stimulus image on the screen until the participant had answered the corresponding question during each trial. There was no separate assessment conducted to assess participant's visual imagery abilities, thus I cannot say if any patients who participated in this research had such a deficit. As a result I am not able to determine if patient performance was affected by visual imagery impairments. Future research should focus on establishing if a relationship between visual imagery and counterfactual abilities exists. The current experiment involves a greater language element than other tasks in this thesis, for example complex grammatical structures are involved such as the subjunctive. It is possible that patients with problems with grammatical rules would struggle with this task. However, to express CFT complex language is necessary. A further suggestion for future research is to access this relationship.

The 4 patients who failed this task (PW, PS, GM and MP) were unable to consistently use CFT to predict the outcome of the stimulus set up (the block falling or not). It is clear from the results that some ability to reason counterfactually is preserved as no patients fail more than 2 sub-conditions. However, there is a stark contrast between the number of trials failed by patients (see Table 7.3) compared to that of controls, thus it is evident that reasoning is impairing task performance. It is possible that the explanation behind poor performance is that during the world version of the task participants have to think about the specific events that have happened, such as adding or subtracting a peg. Whereas in the action version participants can simply look at the stimulus set up in front of them and rerun the scenario with a new marble (or not). This would suggest that during the marble version, participants are relying on BCR to respond correctly, whereas the action version requires counterfactual reasoning to pass. If this is indeed true, it is evident that counterfactual reasoning is impaired in the 4 patients who fail this task.

Patients PF and SAR were removed from further investigation do to their responses not being significantly different from chance; throughout the entire experiment PF answered 28/64 questions incorrectly while SAR answers 35/64 questions incorrectly. It is possible that neither PF nor SAR are able to engage in counterfactual reasoning and thus responded with random answers throughout the experiment. However I acknowledge that the cause of their response pattern could be due to a lack of task understanding. In addition, SAR's BCoS scores demonstrate that she suffers from neglect. It is not clear the reasoning for SAR's failure on this task. However an avenue for future research would be to further investigate PF and SAR's ability to reason counterfactually.

The patients that were tested during this experiment had diverse lesion sites. The four patients who failed this task did not have similar neural damage. I suggest that counterfactual reasoning does not depend on one specific brain area. Instead my results suggest that counterfactual reasoning is supported by a large neural network. In support of this argument Van Hoek *et al.* (2015) reviewed the neural networks that support CFT highlighting three systems: the mental simulation network, the cognitive control network, and the reward network (see Chapter 1 for detailed description).

PW has isolated damage in the cerebellar. The cerebellar has been implicated in tasks assessing DM (Guggisberg *et al*., 2008; Rosenbloom *et al.*, 2012). More specifically, Habas *et al.* (2009) used resting state functional connectivity MRI to suggest that damage to the cerebellar system could result in disruption to the cortico-cerebellar loops which may play a role in social cognitive processing, such as CFT, which has directly been investigated in the present experiment.

Additional research that supports this evidence that the cerebellar is involved in counterfactual reasoning comes from Rosenbloom and Schmahman (2012). The authors reviewed the role of connectivity in DM and devised a model of DM that incorporates the PFC (the OFC), ACC, DLPFC and also subcortical structures: the limbic system, striatum, thalamus, and cerebellum. The model defines a cortical area by its neural connections, thus a lesion affecting any of cortical or subcortical areas within the DM network might disrupt the DM process. Therefore the damage to the cerebella that PW and SAR have sustained could have disrupted the decision network and subsequently the processes which are required for counterfactual reasoning.

Of importance is also that NB, MG and DJR have cerebella damage and appear to have no difficulty in this task. It is clear that simply having damage to the cerebella does not result in an inability to think counterfactually for all individuals. It is not clear what factors have dictated that PW's, and possibly SAR's, cerebella damage have led to an impairment in this task while NB, MG and DJR's damage has not resulted in a disruption to counterfactual thinking. As mentioned, BCoS results shed no light on why these patients have different response patterns in this task. Due to the complexity of cerebella connections, it is not possible to rule out the damage to the area as the cause of PW's (and possibly SAR's) counterfactual deficits on the basis that successful patients have damage to the same structure. It is likely that the damage seen in SAR and PW differs to that of NB, MG and DJR in some capacity, for example; proportion of structure affected and the exact location of the damage. My findings would suggest that such differences in the lesions of the discussed patients are the differentiating factors between success and impairment in this task.

The lingual gyrus (the location of GM's primary lesion) has been linked to visual memory; a key component to the current task. Leshikar, Duarte and Hertzog (2012) investigated task selective memory during encoding. Participants viewed pairs of abstract nouns while using visual imagery or sentence generation encoding instructions. Activation in the left middle occipital gyrus, the left precuneus, and the lingual gyrus was observed for memory during visual imagery tasks. The lingual gyrus has also been cited by Blumenfeld *et al.* (2011) and Johnson and Rugg (2007) in studies investigating visual imagery. The link between the lingual gyrus and visual memory could be resulting in GM's failure to pass in one condition that incorporates imagery; Counterfactual subtractive doubly determined PEG. However, GM does pass all other conditions throughout the experiment, suggesting that her counterfactual understanding, even when imagery is necessary, is preserved under certain circumstance.

Due to PF's left angular and supermarginal gyri and superior temporal gyrus damage she is classified as having damage to the left TPJ. MP is also classified as having a right sided fronto-TPJ lesion (see Forti, Humphreys & Watson, 2005). Previous research conducted with left TPJ damaged patients, including PF, has shown that in addition to the frontal lobes, the TPJ is required for reasoning about others' beliefs (Samson, Apperly, Chiavarino & Humphreys, 2004). The three patients tested in the experiment did not perform above chance-level on false-belief tasks which lead the authors to conclude that cognitive processing was impaired. Van Hoeck *et al.* (2012) present findings that demonstrate the theory of mind network and the counterfactual network have commonalities which would go some way to explaining PF's poor performance in tasks requiring patients to reason about others' beliefs and the counterfactual task presented. However, Samson *et al*.'s experiment incorporated a counterfactual task as a control and PF did not make an error. The authors give an example question from the counterfactual task: 'If the object had not moved, then where would it be?' BCR could have been used to pass the control task. It would be fair to assume that BCR was not considered in Samson, Apperly, Chiavarino and Humphreys' (2004) task as the paper proposing this possibility by Rafetseder, Cristi-Vargas and Perner was not published until 2010. Thus, PF's good performance on the counterfactual measure could be questioned in the Samson study.

Further evidence that implicates the TPJ, among other areas, with social cognition comes from Rodrigo *et al.* (2014). Participants read typical scenarios and were asked to make choices under risky or ambiguous circumstances. During RDM, compared to ambiguous, activated occurred in the bilateral TPJ, bilateral middle temporal gyrus, right medial PFC, and the precuneus bilaterally. The authors link this activation to regions associated with social cognition processes, such as ToM.

The amygdala (location of PS' lesion) is routinely cited as a key area for emotional processing, specifically self-blame regret (Nicolle *et al.,* 2011) and regret avoidance (Coricelli *et al.,* 2005). The reason for its involvement in this task could be due to its connectivity with the PFC. The VMPFC has reciprocal connections with the amygdala, hippocampus, temporal visual association areas and dorsolateral PFC (DLPFC) (Barbey *et al.,* 2009). Research has suggested that the VMPFC is recruited when choices and anticipated emotions are considered and consequently is involved in guiding future DM (Levens *et al.,* 2014).

It is important to consider that both PS and MP also have damage to the right frontal lobe. Convincing evidence that right frontal lesions result in inefficient judgments comes from Gomez-Gomez-Beldarrain, Harries, Garcia-Monco, Ballus and Grafman (2004). Patients with right frontal lesions were impaired in reasoning when forecasting oneself into the future; greatly affecting DM. In order to successfully pass the presented task, participants must consider how the outcome of each trial would have been different if the stimulus set up or input had changed. This task therefore requires participants to consider alternative outcomes and answer each question based on the comparison between the actual (stimulus set up/input) and the hypothetical (dependent on the conditional questions asked). Therefore a deficit in forecasting may have caused PS and MP to fail some conditions in this task.

Both PS and MP's damage to the white matter located in the frontal lobe maps onto the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule. As previously explained in Chapter 5, white matter is crucial for relaying information between grey matter areas. If the white matter microstructural integrity becomes affected then the efficiency of information transfer will be reduced (Hagmann *et al*., 2008). Therefore once this damage has occurred it is likely that signal transfer is affected and thus non-typical behaviour may be exhibited.

Despite JH and RP also having frontal damage and responding in line with controls, it is clear from examining their scans that the damage is not in the same position as PS and MP's. JH and RP's frontal lesions are caudal to PS and MP's. Thus, the information transfer discussed above may not be affected in JH and RP, resulting in an intact ability to reason counterfactually in this task.

It has been shown by Zhang *et al*. (2014) that type 2 diabetes patients have white matter disruptions in the corpus callosum and anterior limb of the internal capsule which was positively correlated with cognitive impairments including EF (spatial processing, attention and WM). Previous developmental research has shown that EF abilities are linked to children's success in passing tasks where counterfactual questions are asked (Beck, Riggs, & Gorniak, 2009; Beck, Riggs & Burns, 2011). In addition, McNamara *et al.* (2003) have linked Parkinson's patients' deficits in counterfactual tasks to their EF abilities, which have resulted from the frontal lobe dysfunction that is associated with the condition.

Additionally, fractional anisotropy (a measure of diffusion) reductions in Schizophrenia patients have been demonstrated by Mitelman *et al.* (2007). The anisotropy was detected bilaterally in the corpus callosum and in the anterior and posterior limbs of internal capsule (among other areas). Additionally, anisotropy in the right hemisphere tracts (seen in PS' pathology) was linked to patients experiencing positive symptoms of Schizophrenia. As previously described, Hooker, Roese and Park (2000) showed that Schizophrenia patients with positive symptoms produced less counterfactual language and engaged less frequently in counterfactual thought when prompted.

In line with McNamara *et al.* (2003), Hooker, Roese and Park (2000) suggest that the lack of counterfactual insight in Schizophrenia patients is caused by frontal lobe dysfunction. It is possible that, in both Parkinson's and Schizophrenia, counterfactual production is compromised by the damage to the white matter microstructural integrity between the corpus callosum and the internal capsule. It is not clear if counterfactual reasoning is directly impaired by PS and MP's white matter damage within the frontal lobe or if the information relay indirectly affects her ability to answer counterfactual questions through affecting her EF.

Importantly, 11 patients were able to succeed in this task. Of those 11, 3 patients (TJ, LB and EL) did not answer any questions incorrectly, 2 patients (DJR and JB) answered only one question incorrectly and two patients (NB and MB) answered three questions incorrectly. As this task incorporated doubly determined questions I can infer that the 11 patients who were successful are going beyond BCR and have counterfactual reasoning abilities. This would suggest that simple counterfactual reasoning is resilient to some brain damage in these patients.

The success of 11 patients demonstrates that the majority of patients were successful. Not only does this highlight the usefulness of the presented task to determine which individuals have problems in counterfactual reasoning but also that the aim of the task was communicated effectively. Thus, the two patients whose responses were not different from chance (PF and SAR) were likely failing due to an impairment in counterfactual reasoning and not due to a lack of understanding. .

It is generally accepted that the experience of a CME is dependent on CFT (Roese, 1994). It is interesting to note at this point that although CFT is thought to be a domain general skill; previous research has shown that the experience of a CME, regret, can be linked to specific brain regions. Research conducted with patients has shown that there are key brain areas responsible for regret as a CME. The OFC, middle temporal gyrus, ACC and hippocampus have been implicated in patient and fMRI studies (Camille *et al.*, 2004; Coricelli *et al.*, 2005). Additionally, these findings have been supported through research with healthy adults during fMRI investigations; the VMPFC and anterior insula have been implicated as other key region (Canessa *et al.*, Chua *et al*., 2009; 2009; Nicolle *et al.*, 2011).

Overall, the patients in this experiment showed problems answering counterfactual conditional questions that did not have an emotional component. The 4 patients who were subject to post-hoc investigation were impaired in ‘world’ type questions only, suggesting that BCR had been used to correctly answer ‘action’ type questions. The impaired patients had diverse lesion sites which supports a network theory.

Chapter 8

Discussion

8.1 Summary of experiments

8.1.1 Is the Processing of Regret in Adulthood Effortless?

There are conflicting opinions in the literature about whether CMEs are produced slowly, through deliberative processes, or quickly and effortlessly. In order to answer this question, I devised two experiments based upon Camille *et al.'s* (2004) gambling task that was adapted from Mellers, Schwartz, and Ritov (1999). The task incorporated two wheels that offered differing numbers of points. These were manipulated so that there were different probabilities of winning and losing a high and low number of points. In Experiment 1, we manipulated the length of time that participants were able to view the outcome of the two wheels. In Experiment 2, we manipulated the WM load that participants were exposed to. Results from Experiment 1 showed that the length of time that participants viewed the outcome of the chosen and unchosen wheel did not affect their emotional rating. Results from Experiment 2 indicated that the WM load did not affect participants' ability to process regret. I interpret these results as evidence for fast and effortless CME production.

8.1.2 Exploring the use of The Regret Gambling Task in patients

The task was, as in Chapter 2, adapted from Camille *et al.'s* (2004) RGT that investigated role of the OFC in the experience of regret. The first aim of the experiment was to compare results from the RGT with a sub-set of patients, who have participated throughout my PhD research, with reported patients in the existing literature. The second aim was to use the RGT to widen the search for areas of brain damage that result in patients reporting emotional responses different to controls. Analysis of control data revealed the amplification effect; emotions related to unobtained outcomes are felt more intensely when they were missed by choice (regret and relief) than by chance (disappointment and elation). This was a replication of findings, from control participants, reported in the literature (Camille *et al*., 2004) and findings from Chapter 2. Group analysis of patient responses showed that the amplification effect was not present; there was no difference in emotional ratings for regret and disappointment conditions. Individual analysis revealed that only 1 patient was responding in line with the amplification effect, and thus similarly to controls. 5 patients did not demonstrate the amplification effect. Analysis of memory data showed that controls and patients did not differ in accuracy and thus results cannot be explained by patients having poorer memory for the chosen and alternative outcomes. Results were interpreted to suggest that a wide range of lesions (such as: frontal, parietal, cerebella, insula, lingual gyrus) lead to patients' inability to differentiate between regret and disappointment, which is present in controls. Thus, the RGT has successfully been utilised to extend the search for brain areas that, after damage, affect individuals' emotional responses to regret and disappointment.

8.1.3 A Measure of Risk Taking

Research with healthy adults has shown that behaviour is affected by counterfactual information. This relationship is strengthened when the available counterfactual information provides an insight into a missed opportunity. It has been suggested that a missed opportunity leads to subsequent risk taking (Zeelenberg *et al*., 1996; Brassen *et al*., 2012). This experiment aimed to widen the search for patients with varying lesion sites who displayed a different pattern of risk taking compared to controls. I used a simple task based on Feeney *et al.'s* (2016) research with children in order to reduce executive demands.

Behavioural data on the number of boxes open by each patient showed that, in comparison to controls, two patients, MP and SAR, were riskier (opening more boxes on average) and one patient, GM, was more cautious (opening fewer boxes on average). MP has extensive damage to the temporal, frontal and parietal regions while SAR also has frontal damage and bilateral damage to the cerebellum. Both patients have right insula damage. GM has damage to the left lingual gyrus and surrounding areas.

Data indicating how a previous missed opportunity affected participants' subsequent risk taking showed that after a large missed opportunity, controls were significantly more likely to open more boxes. This replicates the finding by Buchel *et al.* (2011). However, it was not possible to analyse the effect of the missed opportunity for patients. This occurred because there were too few instances where a large missed opportunity was followed by a 'bank' (a requirement to assess the effect of the missed opportunity). Thus, further investigation with patients into RDM should incorporate, where possible, more trials than were used in this experiment.

8.1.4 A Simple Task Assessing Patient's Counterfactual Mediated Emotional Responses

The experience of regret is thought to be beneficial and of significant importance to learning. Due to the experience of regret adults are able to learn from mistakes and make more informed decisions creating desirable outcomes in the future (Roese, 1997). The development of regret has been widely researched in children and healthy adults. However, few studies have been published that examine the experience of regret in brain damaged patients. Therefore, this experiment was designed to establish regret and relief are preserved in individuals who have varying lesion sites as a result of a stroke.

Previous work with brain damaged patients has used complex gambling tasks in order to induce regret and relief. This experiment used a simple task that builds upon Weisberg and Beck's (2010) and O'Connor, McCormack and Feeney's (2010; 2014) work to establish if patients with varying lesion sites can report regret and relief in a simple regret task.

Analysis revealed that controls did not routinely feel sadder in the small regret condition or feel happier in the small relief condition. This was also the case for patients. However, controls did, for medium and large conditions, feel sadder in regret trials and happier in relief trials. However, analysis of patient data revealed 3 interesting patterns of behaviour: 2 patients (LB and RR) failed both medium and large conditions for both regret and relief trials. LB has damage to the amygdala and RR has large left temporal lesions extending into his frontal and parietal cortex. 1 patient, MG with a cerebella lesion, failed both medium and large conditions for regret trials and 1 patient, GM with a lesion in the left lingual region and surrounding structures, failed both medium and large conditions for relief trials. Results are interpreted as lending support to the network theory that supports counterfactual reasoning and emotions.

8.1.5 Exploring the link between the Experience of Regret and Adaptive Choice Switching

The experiment used in this chapter has previously been used by O'Connor, McCormack and Feeney (2014) to demonstrate the relationship between the experience of regret and the ability to engage in ACS. The aim of this experiment was to investigate how the experience of regret directly impacts on future DM and underpins adaptive behavioural change.

Results from Chapter 5 showed that three patients did not experience regret. If the developmental pattern, described by O'Connor, McCormack and Feeney's (2014), was persistent after a brain injury then I would have expected these three patients to not engage in ACS. However, results showed that 2 different patients failed to modify their behaviour in this task. One patient, GM who has damage to the left sided lingual gyrus and the surrounding areas, previously did not report experiencing relief. The other patient, NB who has lesions covering the right angular gyrus, left cerebellum, right inferior occipital lobe and parietal lobe passed both regret and relief conditions in Chapter 5. Thus findings provide support for the concept that memory of the initial task is sufficient to engage in ACS and the experience of regret is not required (O'Connor, McCormack & Feeney, 2014).

8.1.6 Can Patients answer Counterfactual Conditional Questions?

Previous research has shown that neuropsychological patients, especially those with damage to the OFC, have problems with reporting regret (Coricelli *et al*., 2005). In addition, results from Chapter 4 and 6a suggest that a select number of individuals within my patient cohort have problems experiencing regret. However, it has not been investigated if these patients struggle with the reasoning that is thought to underpin regret and relief, CFT. Thus the aim of this experiment was to establish if any patients struggle to answer simple counterfactual conditional questions which incorporated various elements (past/present, additive/subtractive, doubly/singly determined). Using a combination of different question elements, 12 sub-conditions were created.

Analysis of control responses showed that no controls failed this task. Patient analysis of correct responses showed that 4 patients failed in at least one sub-condition. There was no difference in how hard patients found the past/present and additive/subtractive sub-conditions. However, all sub-conditions that were failed were categorised as doubly determined. It is possible that singly determined questions are easier to answer correctly because Basic Conditional Reasoning (BCR) can be used to logically work out the correct answer without using CFT (see Rafetseder, Cristi-Vargas & Perner, 2010). It is not possible to use BCR to answer doubly determined questions.

Post hoc analysis revealed an interesting trend in sub-conditions that proved more difficult for patients. Conditions were split into 'world' (questions that referred to a change in the stimuli) and 'action' (questions that referred to a change in the input to the stimuli). All of the trials which proved problematic for patients were not only doubly determined, but also referred to a change in the stimuli itself; the 'world' category. Therefore, questions that required participants to consider a change to the stimuli were harder for patients to answer correctly compared to questions that referred to a change in the input to the stimuli. This finding provides evidence to suggest that CFT, in patients, is impaired when participants are asked a specific type of question. However, in the same patient group, some counterfactual reasoning is preserved as patients do not fail every trial in the doubly determined world condition.

8.2 How the findings from the thesis relate to the existing literature

The developmental literature suggests that there is a developmental hierarchy in children's counterfactual abilities (see Chapter 1 for description). I aimed to investigate if this trend is present within the patient group who participated in my research. Assuming the developmental structure that has been observed in children's counterfactual abilities is persistent into adulthood, and indeed after brain damage, then I would expect Counterfactual Conditional Questions (Chapter 7) to be the easiest task. As a result of the developmental hierarchy I would expect patients who fail the Counterfactual Conditional Questions to fail the rest of the tasks also.

The rationale behind this claim comes from developmental findings. Children at the age of 3 and 4 begin to correctly answer explicit counterfactual conditional questions (Guajardo & Turley-Ames, 2004; Riggs *et al.,* 1998). Although it should be noted that Perner and Rafeseder (2011) have put forward an argument which claims children do not understand counterfactual questions until the age of 11. Rafetseder, Schwitalla and Perner (2013) suggest that adult like counterfactual reasoning does not develop until 12-14 years.

However, it is evident from research by Beck *et al.* (2006), Perner *et al.* (2004) and Robinson and Beck (2000) that there are different 'types' of counterfactual questions that are passed at different ages. Results have been consistent with Riggs *et al.* (1998); simple counterfactual conditionals are answered at approximately 4 years, although there are claims that 'true' CFT does not emerge until 5-to-6 years of age (Beck *et al.*, 2006). Therefore, different 'types' of counterfactual questions were incorporated into Chapter 7.

The majority of developmental evidence points to the suggestion that children answer counterfactual questions between the ages of 3 and 6. Evidence for children experiencing CMEs has suggested that this occurs later than children's counterfactual reasoning abilities. Amsel and Smalley (2000) found no evidence that 3 or 5 year old children understood regret or relief.

The task devised by Weisberg and Beck (2010), which was modified for the purpose of my research (Chapter 6a), was administered to children aged: 5-6, 6-7 and 7-8. All age groups reported regret with no significant difference separating the age groups. However, only 7-8 year olds reported the feeling of relief. This finings indicates that developmentally relief is a more complex emotion to experience.

Further to this, O'Connor *et al.* (2014) built on Weisberg and Beck's (2010) 'boxes task' adding an element to investigate behavioural modification. Authors found that children's ability to engage in ACS was dependent on an initial experience of regret. Although children who did not initially demonstrate behaviour modification were more likely to do so if reminded of their prior negative experience, suggesting that memory is a component factor in this relationship.

Overall, it appears that there is a developmental trajectory in which children pass the discussed tasks. Children seem to pass future hypothetical questions first, followed by counterfactual conditional questions. CMEs appear to develop after counterfactual reasoning, with the experience of regret preceding the experience of relief. Behaviour modification and ACS occurs after the experience of regret and thus is last in the developmental chain. Therefore, developmentally, the experience of regret is dependent on CFT and behavioural modification is dependent on experiencing regret. Thus, it is reasonable to suggest that if the developmental relationship between counterfactual reasoning and CMEs is persistent after brain injury, then a task examining counterfactual conditional understanding (Chapter 7) would underpin success in tasks examining regret and relief and adaptive choice switching.

However, results from my investigation into counterfactual understanding and CMEs in brain damaged patients do not support the developmental pattern. Table 8.0 is presented as an overview of individual patient performance across all tasks used in my investigation and also as a comparison of patient performance between tasks. It is clear from table 8.0

that a different behavioural pattern is present in brain injured patients compared to typically developing children; 2 of the 4 patients who fail in a task assessing simple counterfactual questions demonstrate that they do experience regret and relief. These patients are also able to successfully engage in ACS. Interestingly, of the patients who do not experience problems answering counterfactual conditional questions, 3 are impaired in their ability to experience regret (2 are impaired in experiencing relief also) and 1 does not engage in ACS. This would suggest that, for some patients, their basic counterfactual reasoning is preserved while they appear to struggle experiencing CME’s. In other words tasks higher up in the hierarchy are failed yet the basics remain intact. This pattern of behaviour could be interpreted as evidence for the developmental hierarchy in some patients.

Table 8.0

Patient performance across all tasks

Patient	**Battery 1**			**Battery 2**		**Statistics**		
	Counterfactual Conditional Questions	Simple Regret	Adaptive Choice Switching	Regret Gambling Task	Risky Decision Making	No. Fails	No. Tests	Perc. Fail
EL						0	3	0%
TJ						0	3	0%
MB						0	3	0%
RP						0	3	0%
NB						1	3	33%
MG		Regret				1	3	33%
LB		Regret Relief				1	3	33%
RR		Regret Relief				1	3	33%
PS						1	3	33%
PF						1	5	20%
SAR					Risky	1	5	20%
DJR						1	5	20%
PW			Memory			1	5	20%
JB						1	5	33%
JH					Risky	2	5	40%
MP		Baseline	Memory	No Analysis	Risky	2	5	40%
GM		Relief			Cautious	5	5	100%

NB: Words written in cells are labelling the specific condition which that patient failed, for example 'Regret' indicates that regret is impaired, 'Risky' indicates that that patient has a behavioural profile which suggests they engage in riskier DM compared to controls. MP has various experiments highlighted in orange with 'baseline', 'memory' and 'no analysis' written in the cells. Each description written in the cells refers to the reason why I am unsure if MP is classified as failing that particular experiment. For example, 'no analysis' has occurred because too few responses were recorded. Thus, this task is highlighted in orange as 'unclear' due to ambiguity resulting from an absence in analysis. Additionally 'memory' is present due to a failure to pass the memory test. Finally, 'baseline' is recorded as MP was the only patient to fail the baseline condition during this task.

8.3 BCoS Review

As described in Chapter 1b, the cognitive profile of each patient was derived 6 months post-stroke using the Birmingham Cognitive Screen (BCoS; Humphreys, Bickerton, Samson, & Riddoch, 2012). It is important to consider which, if any, cognitive impairments individual patients have as these losses in cognition may directly affect task performance. One of the aims of my project was to establish if there is a link between lesion site and behavioral profile in a cohort of patients with varying lesion sites. Therefore it is essential to establish if task failure can be explained by general cognitive impairment or if task performance is directly caused by a brain injury. Each patients' graphical report is presented in Chapter 1b. I will discuss domains, tested during a BCoS assessment, that I believe may affect task performance. In the next section I will then discuss individual patient's performance in the light of their BCoS results.

8.3.1 *Language*

Comprehension: Each task is verbally explained to participants before the task begins, thus language comprehension is required to understand the instructions. It is therefore plausible that if an individual is inhibited in language comprehension then the aim of the task will not be translated. This possibility was taken into consideration when designing the tasks used in this project. Language demands were kept to a minimum and written instructions were provided along with examples demonstrated by the experimenter and also completed by the participants. Written instructions were included as their use has been shown to improve task performance (Eiriksdottir & Catrambone, 2011). Demonstrations were used as it has been shown that participant understanding is increased as a result of experimental examples (LeFevre & Dixon, 1986).

In my opinion, difficulties in language comprehension would have the greatest effect on task performance during Counterfactual Conditional Questions. During Chapter 7 participants are read questions for each trial. The use of verbal questions is required in this task as it would be impractical to ask patients to read each question in the testing time slot. Additionally, there is an equal chance that patients would have problems in language reading.

BCoS results demonstrate that only one patient, RR, has a language comprehension impairment. RR's performance on the Counterfactual Conditional Questions task is in line with controls. This suggests that impairments in language comprehension do not affect task performance in Chapter 7.

8.3.2 *Attention and Memory*

Controlled auditory WM: As described above, the tasks used in this project use verbalized instructions. Thus, WM for auditory information is required for participants to hold in mind the instructions throughout each experiment and carry out the aim of the experiment as explained by the experimenter. For this reason, short term verbal memory both delayed and immediate would be considered important also. In order to minimize the effects of memory impairments participants are reminded on several occasions that they are permitted to ask questions regarding the 'rules' of a task to ensure that they clearly understand what the task requires.

BCoS results demonstrate that only three patients have a controlled auditory WM impairment, one of which passed every experiment (patient EL). NB and PF's BCoS scores also highlight a problem with controlled auditory WM. NB performance on the Adaptive

Choice Switching task is different from controls whereas PF's performance on the RGT is different from controls. The fact that these two patients fail different tasks with the battery suggest that there is no relationship between controlled auditory WM and general patient ability in the presented experiments.

Controlled auditory sustained attention: Auditory sustained attention is required when instructions are read to participants. This skill becomes progressively important when the amount of auditory information increases. During Counterfactual Conditional Questions, each question is one sentence long. Questions were designed to be short and easy to compute, thus limiting the probability that deficits in both controlled auditory WM and controlled auditory sustained attention would affect task performance.

Three out of the four patients who failed the Counterfactual Conditional Questions task (PS, GM and MP) have impairments in auditory sustained attention. This impairment could result in failure in the Counterfactual Conditional Questions task due to the high language demands of the task. However as explained in Chapter 7, complex language is required to express counterfactual thoughts. In addition, four patients (TJ, MB, DJR and LB) who took part in this experiment and were unimpaired also have impairments in auditory sustained attention. Thus, the relationship between success on the Counterfactual Conditional Questions task and auditory sustained attention is not clear and requires further research to fully understood.

WM and attention are crucial for patients to engage in CFT generally. Beck, Riggs, and Burns (2011) discuss how CFT and EF skills are linked in children. The authors highlight several stages in childhood that possibly lead to successful CFT. Two of these stages are: representing multiple possible events and comparing these multiple possibilities. These particular abilities require individuals to have WM skills to recall possible outcomes of a counterfactual alternative and attention to switch between the multiple possibilities in order to establish a CME (regret when the alternative is deemed more desirable). As a result, patients who have very limited WM and attention capacity may struggle on all aspects of this project. Therefore, for patients who produce a set of results that are consistently different to controls, across all experiments, I will examine if their WM and attention has been highlighted in their BCOS assessment as impaired.

Spatial Attention: It is important to consider all aspects of spatial attention when interpreting patient performance on every task in this project. If a patient suffered from extinction or spatial neglect this could result in skewed emotional responses caused by a patient's failure to attend to the whole stimulus set up. For example, during Chapter 4 participants are presented with two wheels of fortune, one wheel is presented on the left and one wheel on the right side of space. Visual extinction or page asymmetry neglect could dictate that a participant ignored the wheel in the contralesional side of space (for example always choosing the wheel on the right side). This would cause the patient to not incorporate the counterfactual information provided in the full feedback condition (this information would be provided by the wheel in the ignored visual field). This patient would therefore present as though they did not differentiate between regret and disappointment. Additionally, object neglect would dictate that an individual would only attend to one side of an object. This would lead to the patient ignoring the outcome on left or right of the chosen and unchosen wheel, affecting their emotional responses to regret and disappointment conditions due to limited information processing.

BCoS scores for the patients who have responded differently to controls are discussed in Chapter 4; MP has visuo-spatial deficits in object neglect and visual extinction while SAR has page neglect. It is not possible to rule out MP's visuo-spatial deficits as the cause of his impairment in this task. However, it is interesting to note that the only patient whose responses in this task are in line with controls also has a visuo-spatial deficit in page neglect. SAR's success in this task demonstrates that her visuo-spatial deficits has not impeded her performance and sheds light on her abilities despite her neglect.

The effects of spatial attention impairments during the Counterfactual Conditional Questions task are discussed in Chapter 7. As described above, MP has visuo-spatial deficits and also is impaired in the Counterfactual Conditional Questions. However, MP only fails one condition out of a possible 12 and only responds incorrectly throughout the whole experiment 6 times. If visuo-spatial deficits were the cause of MPs failure in this task then I would expect him to fail on multiple conditions.

8.4 Patients demonstrating interesting patterns of results

GM is the only patient who failed every task during this project. A review of BCoS scores suggest that the only area that GM is impaired in is 'sustained auditory attention' (the ability to respond to specific words and ignore others, for example tapping the table when the words 'please, hello and no' are said and not taping the table when the words 'thanks, goodbye and yes' are said). This could account for GM's failure during Counterfactual Conditional Questions, due to the auditory language demands placed on participants. However during a task assessing understanding of counterfactual conditional questions, it is necessary to have a language element.

Throughout this project I have tried to keep verbal instructions to a minimum. Participants are given written instructions to accompany verbal instructions. Participants watch example trials and also engage in practice trials during each experiment in attempt to consolidate the aim of each experiment. Therefore I do not believe that GM's impairment in sustained auditory attention is an explanation for her behavioural pattern of consistency failing tasks in this project.

It is very unlikely that GM has failed the tasks due to misunderstanding. GM reports responses that are in line with controls to regret situations in the Simple Regret task. If GM did not understand this task then she would have also failed to report relief and additionally failed the baseline test. GM also successfully answered the memory questions during the ACS task implying that her lack of choice switching was not due to memory for the unobtained monetary reward. In addition, GM's memory data during the RGT does not lead me to believe that memory is a consideration when interpreting GM's results.

Therefore, it is likely that GM's brain damage is the cause of her inability to engage in counterfactual tasks and experience relief. This would suggest that there are separate processes for experiencing regret and relief, of which regret processing is preserved after damage to the left lingual gyrus and surrounding areas. This suggestion is in line with the finding that GM is more cautious than all other patients and also controls. GM does not report experiencing relief during the Simple Regret task, thus it is possible that her actions are guided solely on her experience of regret. This may have resulted in a reluctance to lose during the RDM Task which as a result manifested in cautious DM during this task.

MP also appears to fail multiple tasks within both test batteries. It is unclear if MP fails 3 of the tasks. Analysis was not possible during the RGT due to too few responses in a one condition required for analysis. Although, visual inspection of MP's graph did not imply that there are any obvious patterns to his emotional ratings. MP also fails the memory questions in the ACS task which implies that impaired memory should be taken into consideration when interpreting his results.

MP seems to understand the aim of certain tasks, for example he reports feeling regret and relief in line with controls, yet is the only patient who fails the baseline condition in the Simple Regret task. Although, as discussed previously, this can be explained through a different method of logical thinking than what is regularly demonstrated. Additionally, MP answers enough questions correctly, during the Counterfactual Conditional Questions task, to have a performance significantly different to chance, suggesting he understands the task instructions.

MP's BCoS results do not highlight any particular cause for concern that would imply he should fail the current tasks. The only aspect of MP's memory which is deemed, via BCoS, as impaired is personal information which would not impact on task performance. MP's auditory attention, like GM, is considered impaired. As described, this could explain MP's performance on Counterfactual Conditional Questions, however this does not explain MP's risky behaviour identified in Chapter 5. Other cognitive domains that are impaired (as indicated with BCoS results) would also not affect counterfactual ability and CME responses.

PS fails Counterfactual Conditional Questions only. As previously described when linking the findings from this project to the developmental literature, this is the first task that developmentally would be passed. Thus, PS demonstrates the exact opposite pattern that would be expect if the developmental hierarchy was persistent after brain injury.

PS has an amygdala lesion. An amygdala lesion could go some way to explain an individual's inability to express emotion due to the area's involvement in emotional and evaluative judgments (Berntson *et al.,* 2011) and also its limbic connections to the OFC (Barbas, 2007; Zald & Rauch, 2006) and ACC (Allman, 2001). However, PS does not demonstrate inhibited emotional responses yet is impaired in answering counterfactual conditional questions. Thus, it is possible that damage to the PFC (including the OFC) can cause problems in counterfactual reasoning without affecting emotional processing.

However, PS also has damage to the white matter located in the frontal lobe. The right frontal lobe has been implicated during an economic DM task which demonstrated that damage to this area causes patients to struggle with incorporating advice/information and impacts their forecasting and DM as a result (Hooker, Roese & Park, 2000). The damage which maps onto the frontal radiation associated with the corpus callosum and anterior limb of the internal capsule could indirectly affect PS' counterfactual reasoning due to the fractional anisotropy that could disrupt normal EF abilities.

On review of PS' BCoS data, she also has impaired auditory attention. As previously explained this impairment would not be considered a factor for various tasks used throughout this project, however it must be highlighted as a possible reason for PS' results during Counterfactual Conditional Questions. This task requires a high level of sustained auditory attention. Although patients were regularly offered breaks, and indeed asked clarification questions throughout the experiment, it is possible that the demands on PS' auditory attention were too great for her to demonstrate her counterfactual understanding. However, I would argue that if this was the case then PS would fail more than 2/12 conditions. In addition, PS fails in the same conditions (doubly determined 'world') as the other 3 patients who also fail this task. This suggests that her failure is systematic and is not a result of attentional demands. Thus, it is more likely that her brain injury is the cause of her failure during this task.

It should be noted that EL, TJ, MB and RP do not fail any of the tasks used throughout my research project. This would suggest that the tasks used were suitable for a patient population and the aim of each experiment was communicated effectively. These patients have performed in line with controls across all experiments and thus demonstrate that their brain damage does not affected their counterfactual reasoning, CME processing and DM. However, as previously discussed, it is not possible to rule out the brain areas affected in EL, TJ, MB and RP purely on the basis that these patients perform well. The extent to which the structures damaged are affected by a stroke is likely to be an influencing factor when considering counterfactual abilities, including CME and DM. For example, RP has damage to the right insula. The insula has been cited as important for counterfactual reasoning in multiple investigations (Berntson *et al.,* 2011; Canessa *et al*., 2009; Chua *et al*., 2009; Clark *et al.,* 2008; Nicolle *et al*., 2011; O'Doherty *et al*., 2003; Palminteri *et al.,* 2012). In addition, SAR, JB and JH have insula damage and are all inhibited in at least one task in this research project. Thus, evidence clearly points to the insula playing a role in counterfactual processes, yet RP does not appear to be impaired. This would suggest that the insula damage RP has sustained does not affect the whole structure and the spared sections of the structure are those that are important for counterfactual abilities.

8.5 Neural Specialisation vs Neural Network

The overall findings from this project lead me to support the idea that DM, CFT and CME production is supported by various neural connections, which if damaged, affect the

DM process, counterfactual production, and the experience of CMEs. Previous work by Rosenbloom and Schmahman (2012) has suggested that a cortical area is defined by its neural connections (see Figure 1.0 for visual representation of the DM Network model). In addition, Van Hoek *et al.* (2015) reviewed how neural connectivity influences CFT. Three systems work together to produce counterfactuals and CMEs; the mental simulation network, the cognitive control network and the reward network. Network arguments imply that damage to any of cortical or subcortical areas within the networks might disrupt their ultimate goal of successful DM or appropriate emotional responses.

Research with brain lesioned patients has implicated specific brain regions that are important for the production of regret as a CME. Famously, Camille *et al.* (2004) used the RGT to demonstrate that OFC lesioned patients did not experience regret over disappointment. Coricelli *et al.* (2005) also used the RGT to show that activity in the medial OFC and amygdala is related to initial regret and also cumulative regret whereas dorsolateral prefrontal cortex activity is a result of the immediate regret experienced caused by the gamble outcome. Research with healthy controls have shown that the VMPFC, ACC and hippocampus are active when experiencing regret and also when imagining a third party's regret (Canessa *et al.,* 2009).

In addition to region specificity during the experience of CMEs, specific brain areas have been linked to CFT and DM. Gomez-Gomez-Beldarrain *et al.'s.* (2004) research highlighted the role of the right frontal cortex in reasoning when forecasting oneself into the future. The VMPFC has routinely been cited as an important region for DM (Canessa *et al.*, 2009; Nicolle *et al.*, 2011; Studer *et al*., 2015)

I do not question that specific brain regions are crucial for the production of CMEs, in particular regret (such as the OFC). It is worth noting that the patients who participated in this research who have OFC damage show different patterns of behaviour. MP does not demonstrate a clear behavioural profile in that 3 out of 5 experiments cannot be analysed due to varying reasons such as limited data, failure in memory or baseline conditions. MP also has extensive damage so it is unclear what directly causes his responses throughout this research. However, JB fails the RGT only. It is possible that the OFC has a more refined role in regret than is previously discussed in the literature. I would suggest that the role of the OFC needs further research to accurately understand how damage to the area affects counterfactual abilities in general.

The results from my investigation lead me to believe that after damage to multiple brain areas the experience of regret and effective DM can be compromised. It is possible that wider brain regions are directly involved in the production of CFT and regret (such as the lingual gyrus and immediate surrounding areas), however I think it is more likely that it is the neural connections from these regions to specialised areas that cause the behavioural profile seen in my patients. I therefore suggest that damage to a seemingly unimportant region can inhibit an individual's emotional experience and choices significantly. This reason for this disruption, in my opinion, can be underpinned by neural connectivity.

This concept is supported by Clausi *et al.* (2015) who showed that patients with cerebella lesions were able to make choices that minimise regret but were impaired in reporting regret during the RGT. Importantly, the authors consider the cerebellum's connectivity with the PFC, limbic system and basal ganglia when interpreting this finding. Thus, when interpreting the findings from experiments with brain injured participants it is essential to consider if the damaged region is directly responsible for the measured variable or if neural connectivity is a factor.

During my project I have worked with 5 patients with cerebellar damage; SAR, NB, PW, MG and DJR. The latter of the 3 patients have isolated damage. All 5 patients fail in at least one task used within my investigation. However, there is no pattern between the tasks failed. In addition, SAR is the only patient to perform in line with control responses during the RGT. Thus, cerebellar damage can lead to inhibited DM, CMEs and CFT but does not always. It is likely that a more fine grained understanding of the cerebellar and its neural connections is needed to fully appreciate its role in these tasks.

In addition to the cerebellum, I believe that further investigation into the lingual gyrus and the immediate surrounding areas is required. GM fails each task used within my project. This is, to my knowledge, the first piece of research that suggests that either the lingual gyrus (and surrounding areas) is directly linked to CFT, CMEs and DM or is connected to specialised brain regions that support individuals successfully passing these tasks.

8.6 Future Considerations and limitations

While discussing the experiments I have used in different chapters, I have already highlighted possible task adaptions and specific brain regions that warrant further investigation. Therefore I will now consider more speculative directions for future research.

A possible influential factor which I did not initially consider when collecting my data was the possibility that some participants were recreational gamblers. It is possible that individuals who more regularly engage in gambling activity are less sensitive to adverse outcomes. Research has shown that pathological gamblers, compared to controls, respond in an addictive manner during the Iowa Gambling Task, significantly affecting their DM capabilities (Petry, 2001). A sense of loss of awareness is one possible explanation for altered gambling behaviour; a factor which would be influential in the interpretation of my results, specifically on tasks requiring a self-report of regret experience (Langham et al., 2006).

There is little discrimination between gambling platforms, for example casino gamblers versus slot machine gamblers (Sharpe, 2002). However, it is clear that persistent gambling behaviour affects performance on the type of DM tasks used within my research (see Goudriaan *et al.,* 2005).

The use of group analysis for control data would more than likely average out a participant who responded differently due to a preference for gambling. However, this would not be the case for patients; patient data was analysed on an individual basis. Thus it is possible that patients' results appear less risk averse or desensitised to regret due to gambling behaviour. Thus, future work conducted with DM and regret should look to measure pre-morbid gambling behaviour as a possible exclusion factor.

Throughout this thesis I have opted for a strategy of comparing individuals patients' responses to a control mean. I chose to do this as I did not want to lose differences in patient behaviour by grouping patients for analysis. It is possible to perform group analysis with patients, as seen in Camille *et al*. (2004). However, the patients participating in my research did not have similar lesion sites and thus I had no justification for grouping them. Additionally, through analysing each patient separately I have been able to discuss each patient individually and assess the most likely cause for their task performance, in turn highlighting new areas that are possibly involved in the counterfactual network (such as the lingual gyrus). However, I would suggest that future research consider using more sophisticated analysis to test for differences between a single individual and a control group (see Hulleman & Humphreys, 2007 for discussion of the modified F test).

A further consideration for future work would consist of using voxel-based morphometric (VBM) analysis. Through using VBM, a precise relationship can be draw between patients' lesion sites and behavioural profile. Although I have aimed to relate patient lesion sites to task performance, I believe that using VBM could facilitate a greater level of accuracy when assessing a patient's lesion site. The process of lesion identification would have been more efficient and more accurate using VMB. Thus, I would urge future research conducted with patients to use this technique.

A general limitation of the tasks I have used throughout my research is the influence visuo-spatial deficits could have on task performance. As discussed in Chapter 7 the spatial configuration of my tasks could lead to visuo-spatial deficits, namely neglect and extinction, causing patients to appear as though they have deficits in CFT, CME production and DM, when in fact these patients are merely unable to demonstrate their understanding due to their inability to engage in the task. I suspect that the effects of visuo-spatial deficits would be most detrimental during the counterfactual questions task, the simple regret task and the RGT. I suggest this as these are the three tasks that require participants to track two separate stimuli in opposite visual fields. I have already discussed the possibility of neglect and extinction affecting task performance for the counterfactual questions task in Chapter 7 and I am confident that visuo-spatial deficits of the patients who failed this task did not interfere with task performance. In addition, all patients who I am confident understood the RGT demonstrated an effect of the unobtained outcome. The unobtained outcome on complete feedback trials is representative of the outcome on the unchosen wheel, thus this result indicates that all patients were attending to the unchosen wheel, signifying that visuo-spatial deficits were probably not affecting response patterns. However, during the simple regret experiment I did not record if patients' consistently chose the box on the right or the left. Thus, I cannot be certain that visuo-spatial deficits did not affect patient choices and thus affect their ratings on this task. Moving forward I would suggest that all experiments conducted with patients record this information. However, it should be noted that effort was made to minimise the effects of neglect and extinction on patients' responses. This was done by using a vertical response scale over a horizontal response scale.

A further limitation of my work is the effect of patient mood on task performance. It is possible that mood fluctuation could affect patients' emotional self-ratings of regret. Mood disturbances are commonly reported post-stroke. It has been documented that mood disturbances are highly complex and are affected by multiple factors, such as depression, sex, age, and condition comorbidity (Hackett *et al.*, 2006). It is possible that mood disturbances fluctuate day-to-day. It would have been possible to establish if the mood affected task performance by giving each patient a simple mood questionnaire to fill out before the start of each testing period. This would have allowed me to establish if there were any trends in task performance and mood. The Stroke Association advise that patients are assessed using any of the following standardised measures (or a combination of): Hospital Anxiety and Depression Scale (HADS), General Health Questionnaire (GHQ- 12), Patient Health Questionnaire (PHQ9) and brief assessment schedule depression cards (BASDEC). Future research conducted with stroke patients should use a standardised measure to assess mood before each testing session to ensure that results are not affected by a variable that can otherwise not be accounted for.

8.7 Conclusion

There were three general aims of this research that were set out in Chapter 1b. First, to explore the component processes of CMEs, namely regret, and widen the search for the brain areas that support these. Second, to establish if regret or its alleged component processes are experienced in brain damaged individuals. Third, to conduct research that points to how the experience of regret directly impacts on future DM and underpins adaptive behavioural change.

The first aim of the project has been investigated in two ways. I have conducted research with undergraduate students to further our understanding of how CMEs are experienced. Results from this study have shed light on the speed and ease that healthy adults produce CMEs. Additionally I have widened the search for the brain areas that support CMEs by testing a wide range of brain damaged patients on varying tasks that require CFT, DM and CMEs. I have established that damage to varying neurological areas, some of which are infrequently cited in the literature (such as the cerebellum and lingual gyrus) can cause impaired performance on such tasks.

The second aim of the project has been investigated through establishing if regret itself is experienced in brain-damaged individuals during two experiments. It would appear that several patients have a different emotional response compared to controls during these experiments. The Simple Regret task demonstrates that regret and relief is equally impaired in some patients whereas either regret or relief is impaired in others. However, the RGT sheds light on how the differentiation between regret and disappointment is not made by the majority of patients tested. It is possible that specific brain regions that have been damaged as a result of a stroke have caused this pattern.

To complete the second aim of this project I have also included varying tasks adapted from the literature and tasks developed by myself. The developmental literature has suggested that counterfactual reasoning is necessary for the production of CMEs. Thus I included a task assessing patients' ability to answer counterfactual questions and compared the results to multiple tasks that include a measure of regret and relief. Additionally, I included a task which measured RDM; an indirect measure of counterfactual consideration. Research with healthy adults has shown that counterfactual information regarding a missed opportunity affects risk taking behaviour (Zeelenberg *et al.,* 1996). Finally the RGT was used in attempt to compare the group of patients tested throughout this project with OFC patients described by Camille *et al.* (2004). Therefore, a comprehensive assessment of the components of CMEs with brain injured patients has been completed and thus my results have shed light on the relationship between damaged brain regions and counterfactual capacity.

The final aim of this project is addressed in Chapter 6, ACS. Through adapting O'Connor *et al.'s* (2014) experimental procedure I have investigated the link between patients' experience of regret and their ACS behaviour. Results demonstrated that for the patients tested in this experiment, the experience of regret does not underpin the ability to engage in adaptive choice switching. It is possible that memory of regret or anticipated regret underpins patients' ability to engage in behavioural modification without reporting the experience of regret initially.

To conclude, the three aims set out at the start of this project have been investigated through a series of six experiments. The main findings from my research are as follows: I have ascertained that healthy controls experience CMEs quickly and effortlessly. I have established that, in the group of patients who took my part in my research, the developmental hierarchy is not persistent after brain damage. In addition it would appear that damage to a number of neurological areas interferes with the experience of CMEs and successful DM. When considering the range of neurological damage that my patients present with, paired with their task performance, it is reasonable to argue that my results support a network theory that facilitates counterfactual reasoning and emotions.

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