TEMPORAL DYNAMICS OF SOCIAL AND AFFECTIVE DECISION-MAKING PROCESSES.

by

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This thesis is dedicated to my beloved father,

Kyriakos Kyriakopoulos

Father, thank you for giving me the opportunities you did not have in life, thank you for the encouragement in pursuit of excellence and for your generosity. Your constant showings of love have helped to keep my moral high.

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Abstract

This thesis will establish the influence of social saliency and affect on perceptual decision-making. Although the study of the neural basis of human decision-making has inspired great attention, much of the literature has employed fMRI to explore complex decision-making in the brain which has great advantages in providing spatial information about the underlying neural activation. But, there is a lack of studies on the temporal dynamics of simple perceptual decision-making. It is important to focus on simple perceptual decision-making because people tend to make decisions rapidely based on the presented information which varies in sociality. However, despite research that has highlighted the importance of social saliency in simple perceptual decision-making tasks (Gutnik et al., 2006) the influence of social saliency on the temporal dynamics is understudied. It is crucial to examine the influence of social saliency on decision-making because humans are bombarded with various socially salient information/stimuli which impacts subsequent behaviour. Another influence on decision-making is the affective nature of information/stimuli. Emotions are the dominant driver of the most meaningful decisions in life (Keltner & Lerner 2010; Keltner et al 2014) but the impact of affect on the temporal dynamics of simple perceptual decision-making tasks, in particular, remains to be established.

The current thesis addressed those gaps in the literature by examining the influence of social saliency and affect on the temporal dynamics of simple perceptual decision-making. Three conceptually similar studies were designed involving simple perceptual decision-making tasks in which social saliency (e.g. task stimuli, word primes and context) and affect (e.g. positive and negative) were manipulated to contrast differences in amplitudes in certain processing stages dependent on social saliency and affect. The first study was a systematic review which synthesised existing neurophysiological evidence from studies that manipulated social saliency across different neuroimaging paradigms and task designs. The systematic review highlighted the scarcity of temporal examination of the influence of social saliency on decision-making and the limited use of simple perceptual decision-making tasks in that literature.

The second study investigated the influence of social saliency of task stimuli on behavioural performance and temporal dynamics in a preference choice task involving two conditions: 1) choosing between faces that varied in affect - social condition and 2) choosing between landscapes that varied in affect – non-social condition. In both conditions, one happy and one sad image was presented in a pair. Results demonstrated that the sensory processing and attentional focus stages had higher amplitudes for faces, whereas the affective evaluation stage was sensitive to landscapes. During the late processing stage,

social saliency did not influence the decision-related stage (i.e. there was no difference in processing based on social saliency).

The third study investigated the impact of social saliency on unconscious influences using a simple perceptual decision-making task involving trustworthiness ratings about neutral faces in two conditions: 1) primed with social words and 2) primed with non-social words. To examine the contributions of affect on decision-making, in both conditions word primes varied in affective nature (positive and negative). Social saliency and affect influenced behavioural performance and trustworthiness ratings of neutral faces: reaction times were faster in trials preceded by non-social primes than social word primes and faces preceded by social word primes were rated as more trustworthy compared to non-social word primes. There was no effect of social saliency on temporal dynamics, but negatively-valenced words elicited higher ERP amplitudes during the affective evaluation and decision-related stages.

The fourth study moved from manipulating the social saliency and affective nature of the task stimuli and word primes to manipulating the social context. The influence of social context on the temporal dynamics of performance monitoring was investigated while participants performed a visual discrimination task in two conditions: 1) in the presence of a passive observer – social condition and 2) alone – non-social condition. The influence of affect was examined by giving participants performance feedback (i.e. via the computer) that varied in affect (i.e. neutral, negative and positive). The findings revealed an effect of social saliency at the behavioural level: reaction times were faster during the non-social condition compared to the social condition. There was no effect of social saliency on temporal dynamics, but negative and neutral feedback elicited higher ERP amplitudes during the feedback-related stage and the mid-range stage. There was an interaction between social saliency and affect with higher amplitudes for non-social trials where negative feedback was given during the mid-range stages.

Overall, the current thesis contributes to the literature by providing electrophysiological evidence that both social saliency and affect of stimuli or feedback moderate the process of decision-making at different stages dependenting on the type of stimuli and task used. Early components (less than <200ms after stimulus onset) are sensitive to the social saliency, but this effect is stimuli dependent: faces as a form of social stimuli demonstrated an influence on early temporal dynamics. Mid-range and late components (around 300-600ms) are sensitive to non-social information and modulated by the affect of stimuli/feedback with sensitivity towards negatively-valenced stimuli. Finally, the electrophysiological findings show that when social saliency interacts with affect, it elicits greater ERP amplitudes (i.e. activation) during the later processing stages that decision-making evaluative judgements take place.

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Abbreviations

(Alphabetically)

ACC	Anterior Cingulate Cortex
ANOVA	Analysis of Variance
BOLD	Blood-Oxygen-Level Dependent
DG	Dictator Game
dlPFC	dorsolateral Prefrontal Cortex
EEG	Electroencephalography
EOG	Electrooculogram
ERP	Event-Related Potentials
FFA	Fusiform gyrus of Temporal Cortex
FRN	Feedback-related negativity
fMRI	functional Magnetic Resonance Imaging
Hz	Hertz
IPL	Inferior Parietal Cortex
KDEF	Karolinska Directed Emotional Faces
lOFC	lateral Orbitofrontal cortex
LPP	Late Positive Potential
M	Mean
MEG	Magnetoencephalography
mPFC	Medial Prefrontal Cortex
vmPFC	Ventromedial Prefrontal Cortex
MRI	Magnetic Resonance Imaging
MVPA	Multivoxel Pattern Analysis
MS	Milli-seconds
NAcc	Nucleus accumbens
OFC	Orbitofrontal Cortex
PCC	Posterior Cingulate Cortex
PET	Positron Emission Tomography
PD	Prisoner’s dilemma
PFC	Prefrontal Cortex
RT	Reaction Time
rTMS	repetitive Transcranial Magnetic Stimulation
ROI	Region Of Interest
SD	Standard Deviation

SNR	Signal to Noise Ratio
STS	Superior Temporal Sulcus
TMS	Transcranial Magnetic Stimulation
ToM	Theory of Mind
TPJ	Temporoparietal Junction
UG	Ultimatum Game
μV	Milli-volt

Chapter 1. Introduction and Overview of the thesis

1.1 Introduction

Our everyday lives involve an immeasurable number of decisions. Decision-making is a complex cognitive process which involves the integration of available information to make a choice amongst possible alternatives (Resulaj, Roozbeh, Wolpert, & Shadlen, 2009). Decision-making involves various processes including, preference judgement and performance monitoring (van den Boss et al., 2013). As opposed to decision-making in general, perceptual decision-making in particular, emphasises the role of available sensory information in choosing one option from a set of alternatives (Hauser & Salinas 2014). Over the past two decades, understanding how perceptual decisions are made has become a central theme in the neurosciences (Hanks & Summereld 2017).

The literature suggests that there are at least four main cognitive processes underlying perceptual decision-making: an initial process related to the encoding of sensory information, a second process related to allocation of attentional resources to each stimulus, a mid-range process associated with accumulating the evidence required to make a decision and the motivational/affective processing of sensory information and a later process related to decision-making, evaluation and final choice (Sternberg, 1969). It has been suggested that these underlying cognitive processes act in a hierarchical manner and function as a succession of steps from sensory processing to decision formation (Ratcliff et al., 2007; van Rullen & Thorpe, 2001).

The use of electroencephalography (EEG) recordings has provided evidence for the existence of these discrete processing stages between presentation of stimulus and response. The EEG measures the dynamics of perceptual processing in the brain by analysing the sequence of event-related potential (ERP) components (Woodman, 2010). The ERP components are deflections related to the presented events. The ability of ERPs to show the progression of information processing in the brain has established this technique for testing theories of perception, attention, and cognition. Using ERPs, brain activity is recorded whilst participants complete perceptual tasks, as reflected by the different interacting stages of information processing.

Over the years a number of ERP studies have provided electrophysiological markers of these four main cognitive processes underlying perceptual decision-making in humans using diverse paradigms (Philiastides, Ratcliff, & Sajda, 2006; Philiastides & Sajda, 2007; Ratcliff et al., 2009; O’Connell et al., 2012; Wyart et al., 2012; de Lange et al., 2013; Kelly et al., 2013; Heekeren et al., 2008; Fleming et al., 2012; Posner, 1980). The four distinct perceptual processing stages relating to specific ERP waveforms are: 1) sensory processing stage: the first stage occurs around 100ms to approximately 200ms post stimulus as manifested in the N1/P1 component and it is associated with encoding of sensory information of the physical stimulus; 2) attentional focus stage: the second stage occurs around 200ms to approximately 300ms post stimulus as reflected in the N2/FRN component and it is associated with the attentional resources allocated to each stimulus. If the task involves feedback, outcome evaluation takes place at this stage; 3) motivational/affective processing stage: the mid-range stage occurs around 300ms to approximately 600ms post stimulus as manifested in the P3 component and it is associated with accumulating evidence to make a decision and it is sensitive to motivational/affective evaluation of sensory information; 4) decision-related stage: the late stage occurs around 600ms to approximately 800ms as reflected in LPP component, it becomes more pronounced over time, it is associated with decision-related neural processes, evaluation and final choice. Each of these ERP components does not represent a single neuronal source, but instead an aggregation of parallel implemented processing stages (Heekeren et al., 2008; Engelmann et al., 2009; Cisek & Kalaska, 2010; Otto & Mamassian, 2012) associated with the respective dimension of interest (e.g., sensory processing and attentional focus). Figure 1-1 outlines the stages of decision-making process from the initial registration of the stimuli till the final decision.

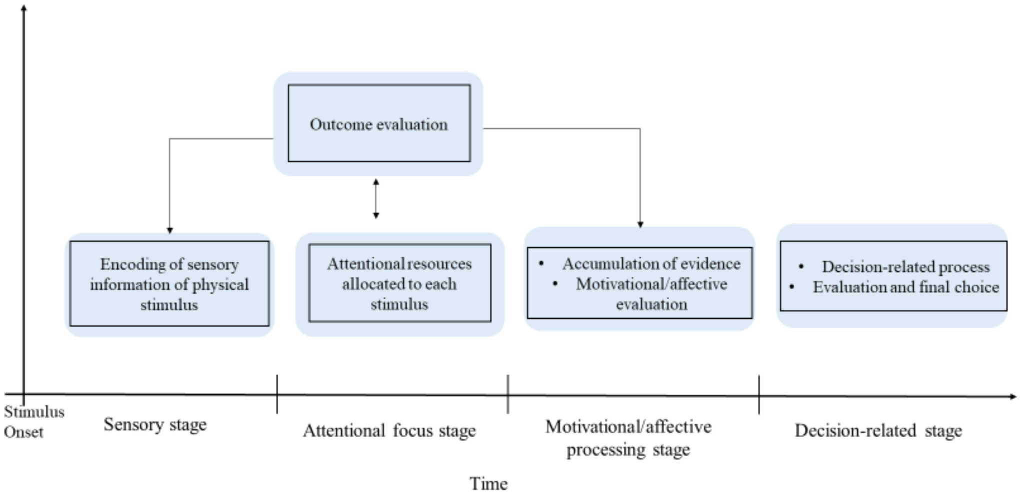


Figure 1-1. Schematic representation of the four main cognitive processes underlying perceptual decision-making stages from the initial registration of the stimuli till the final decision.

Researchers have highlighted the importance of social saliency and affect in simple perceptual decision-making tasks (Gutnik et al., 2006). Humans as social animals are increasingly bombarded with various socially salient information/stimuli such as socially salient cues which vary in affect, faces, actions, emoticons, socially relevant pieces of text, and social rewards. In this thesis, social saliency is given a broader term and is defined as any type of information that vary in sociality (i.e. social stimuli, social decisions, social presence, social influence or priming) that captures the attention, and influences subsequent processing, decisions and behavioural performance. Therefore, social saliency of information may impact humans' behaviour through unconscious influences or social context and affective nature of this information. However, the exact impact of social saliency on the temporal dynamics of simple perceptual decisions is not clearly established. Hence, it is important to examine the effect of social saliency on simple perceptual decision-making to establish potential differences/similarities between social and non-social decision-making depending on the social saliency manipulation.

In this thesis, the impact of social saliency and affect on simple perceptual decision-making will be examined using EEG and specifically using ERP methodology. It has been argued that future research examining perceptual decision-making should focus on using EEG (Hanks & Summereld 2017; Wyart, Gardelle, Scholl et al., 2012) and especially ERP methodology. This is important because ERPs provide chronological insights about the exact influence of social saliency and affect at the underlying processes involved in decision-making which will contribute to better temporal characterisation of perceptual decisions.

Existing empirical studies have shown that social information, such as emotional expressions displayed on a person’s face, descriptions of a person, and the presence of another person elicit higher ERP amplitudes compared to non-social information (diFilipo & Groser-Fifer, 2016; Groen, Wijers, Tucha et al., 2013; Hobson & Inzlicht, 2016; Simon et al., 2014; Tian et al., 2015). But, studies that explore the impact of social saliency on simple perceptual decision-making tasks to establish potential differences/similarities between social and non-social decision-making depending on the social saliency manipulation are lacking.

Although there is some existing evidence that show discrete temporal processing for social and non-social decision-making, there are limitations in the extant literature. The effect of social saliency has been demonstrated mainly in tasks that involve co-action (Nawa et al., 2008), strategic interaction (Lee, 2008), cooperation with fictional partners (Chen et al., 2012) and gambling games (Fukushima & Hiraki, 2006; Leng & Zhou, 2014; Tian et al., 2015) in which one’s performance could influence the other’s (Koban, Pourtois, Bediou, Vuilleumier, 2012; de Bruijn, Miedl, & Bekkering, 2011). However, perceptual decisions are fundamentally different to more complex decisions and although there is sufficient literature on the impact of social saliency on complex decisions (Mavrodiev, Tessone & Schweitzer, 2013) a gap exists in the literature for an examination of social saliency on simple perceptual decision-making. Hence, this thesis will address this gap in existing knowledge and examine how social saliency impacts the underlying process of perceptual decision-making.

Other studies have examined the effect of social saliency on the neural and temporal dynamics using passive viewing tasks (Heekeren et al., 2005; Philiastides et al., 2009). Findings of these studies show that early (170 ms) and late (300 ms) ERP components discriminate between viewing a social and a non-social stimuli (Philiastides et al., 2009) and implicated dorsolateral prefrontal cortex (DLPFC) in the decision process (Heekeren et al., 2005). Findings from other ERP studies that have used passive viewing tasks have shown larger ERP amplitudes during the sensory processing stages in response to pictures with humans compared to pictures with visual scenes, such as landscapes (diFilipo & Groser-Fifer, 2016; Groen, Wijers, Tucha et al., 2013; Proverbio et al., 2009; Proverbio, Zani, & Adorni, 2008). This suggests that there is a prioritised processing of socially relevant information when passive viewing task is used which may be due to the relevance of social information to humans compared to non-social information. A problem with relying on this literature alone to explain temporal dynamics of perceptual decision-making is that passive viewing does not inolve an overt judgement or decision being made. Therefore, a gap exists in the literature about the exact influence of social saliency at the different temporal stages of perceptual decision-making.

Another limitation in the extant literature is that despite the impact of sociality being demonstrated in different tasks, as described above, the effect of social saliency of unconscious influences (i.e. primes) on decision-making is completely unexplored. It is important to examine the impact of social saliency on priming effects because unconscious influences are embedded in humans' everyday choices for example, social exchange, TV adverts, social media and political campaigns and influence our behaviour. No study to date has compared the effect of social and non-social primes on decision-making. Therefore, in one of the studies in this thesis the influence of social saliency of primes on the temporal dynamics of decision-making using a simple perceptual decision-making task is examined.

A further limitation in the current literature is that despite the impact of social presence being demonstrated in traditional social psychology experiments (Crisp & Turner, 2010; Fiske, 2010; Hogg & Cooper, 2007; Klehe, Anderson, & Hoefnagels, 2007; Wagstaff et al., 2008), relatively little attention has been paid to the effect that social saliency has on perceptual decision-making and performance monitoring. Existing literature has mainly focused on the impact of implied social presence (i.e. perception of being watched or actions being evaluated by others) in complex tasks, rather than examining the impact of actual social presence (i.e. being watched by another person). It is important to examine the impact of social presence on decision-making and performance monitoring because decisions in real-life are often influenced by social presence and involve direct and indirect feedback. Currently there is a scarcity of empirical studies that have investigated the impact of social presence on the neural and temporal basis of decision-making and performance monitoring (Hobson & Inzlicht, 2016; Simon et al., 2014; Tian et al., 2015). Therefore, in one study in this thesis the influence of social presence on the temporal dynamics of decision-making and performance monitoring using a simple perceptual decision-making task is examined.

Another influence on decision-making is the affective nature of stimuli (Gutnik et al., 2006). Emotions are the dominant driver of most meaningful decisions in life (Ekman 2007; Keltner & Lerner 2010; Keltner et al 2014;

Loewenstein et al 2001). Affect, such as happiness or sadness, has been related to different antecedent appraisals (Smith & Ellsworth, 1985), depths of processing (Bodenhausen et al., 1994), brain hemispheric activation (Harmon-Jones & Sigelman, 2001) and facial expressions (Ekman, 2007). But the impact of affect on simple perceptual decision-making tasks, remains to be established. Therefore, the current thesis will address this gap by exploring the influence of affect on simple decision-making tasks.

Another limitation in the extant literature is that despite the impact of affective face-primes being demonstrated in different tasks (Dijksterhuis & Aarts, 2003; Hsu, et al., 2008; Li, et al., 2008; Lu et al., 2011; Marcos & Redondo, 2005), the impact of word-primes that vary in affective nature on the temporal dynamics on decision-making remains to be established. More importantly, no study to date has examined the influence of word-primes that vary in social saliency and affect on the temporal dynamics of perceptual decision-making. This thesis will fill this gap and examine the effect of social saliency and affect of word primes on temporal dynamics of decision-making using a simple perceptual decision-making task.

In addition, in performance monitoring studies where the affective nature of feedback is highly important for the subsequent decision, studies have mainly manipulated positive and negative feedback. Therefore, the effect of neutral feedback on decision-making and performance monitoring is yet to be established. It is important to examine all three affective feedback outcomes because differences in the monitoring of the different dimensions of feedback outcomes is instrumental for guiding our performance and adjust future behaviours (Holroyd & Coles, 2002; Cohen & Ranganath, 2007).

Hence, the last study of this thesis will explore the effect of social presence on the temporal dynamics of decision-making and feedback monitoring using three different types of feedback outcome in a simple perceptual decision-making task.

Hence, to address the gaps in the existing literature, throughout this thesis a novel investigation is achieved by manipulating both social saliency and affect in a series of empirical studies. It is important to combine an examination of both social saliency and affect because they might have a direct impact on decision-making but also there might be an interaction between social saliency and affect which leads to differential temporal processing. Also, this is important to explore because it might have an impact on how to influence social behavior through marketing or how to motivate learning in teaching.

So, to investigate the influence of social saliency and affect on the temporal dynamics, three conceptually similar studies were undertaken in the thesis involving simple perceptual decision-making tasks in which both the social saliency and affect (e.g. positive and negative) were manipulated to contrast differences in amplitudes in certain processing stages dependent on social saliency. Thus, in each of the studies in the thesis social saliency is manipulated: social saliency of the task stimuli (Study 2), social saliency of word primes (Study 3) and social context (i.e. an observer was included, Study 4). In addition, the affective nature was also manipulated in each of the studies: affective nature of stimuli (Study 2), affective nature of the primes (Study 3) and affective nature of feedback outcome (Study 4).

Given the lack of reviews that combine existing evidence from studies that explicitly examined social and non-social decision-making across different methodologies (i.e. fMRI and EEG), tasks (i.e. perceptual, passive viewing, discrimination, gambling etc) and social saliency manipulation (i.e. stimuli type, reward type and social presence), the work in this thesis commenced with a systematic review (Chapter 4 -Study 1). The systematic review helped to draw conclusions about current knowledge about the influence of social saliency on temporal dynamics of decision-making the systematic review synthesised existing neurophysiological evidence from studies that directly compared the neural basis of decisions across a wide variety of tasks, social saliency manipulation employed (i.e stimuli type, reward-type and social presence) and neuroimaging paradigms to highlight similarities and differences in decision-making and establish gaps in the literature. Study 2 (Chapter 5) investigated the influence of social saliency on temporal dynamics of decision-making for faces and landscapes with either happy or sad affect. Study 3 (Chapter 6) investigated the influence of social saliency and affect of word primes on behavioural performance and temporal dynamics using a simple perceptual decision-making task involving trustworthiness judgements of neutral faces. Study 4 extends findings from previous studies in the thesis and moves from manipulating the social salience and affect of the task stimuli or word primes to manipulating social presence and affect of feedback (given by the computer). In this last study, social presence was manipulated, and participants performed a simple perceptual decision-making task in the presence of passive observer, as well as, alone, to examine differences/similarities in behavioural performance and temporal dynamics. The research findings across all studies are summarised and combined in a general discussion at the end of the thesis in Chapter 8.

Research Aims of the thesis

Building on existing evidence, this thesis, examines the temporal information reflected in the EEG signals bounded to an event as well as measures performance and speed of decision-making to provide an examination of the influence of social saliency and affect on the temporal dynamics of decision-making. Electroencephalogram was chosen as the main methodology for this research due to its high temporal resolution which allows for comparison between the different neural stages (Luck, 2005). An event-related potential analysis provides an understanding of the chronology of information processing related to the underlying processes involved in perceptual decision-making with millisecond precision.

By understanding how social saliency influences temporal dynamics of simple perceptual decisions the thesis will contribute to the limited electrophysiological insights into the neural representation of social decisions in the human brain. Thus, building a coherent picture of how social saliency impacts on decision-making.

The thesis had the following aim:

- examine the influence of social saliency and affect on temporal dynamics of perceptual decision-making.

The thesis had the following objectives, to:

- Review the literature that directly examines the impact of social saliency on decision-making across different neuroimaging methodologies and task paradigms to synthesise existing findings and highlight gaps in the extant literature
- Address the gaps in the literature by focusing on the influence of social saliency on behavioural performance and temporal dynamics of simple perceptual decision-making tasks.
- Provide temporal insights on the impact of both social saliency and affect on the underlying processing of decision-making.

Structure of the thesis

The thesis comprises of a literature review chapter (Chapter 2), a methodology chapter (Chapter 3), a systematic literature review (Chapter 4), and three empirical studies (Chapter 5, 6, and 7) followed by a general discussion chapter (Chapter 8).

Chapter 2 provides a general introduction to the field of decision-making and outlines literature relating to the influence of social saliency on decision-making. The chapter discusses current findings on the differences between decisions dependent on social saliency to better understand the process of perceptual decision-making. Also, literature on the influence of affect on perceptual decision-making is discussed in detail. Chapter 3 provides information about the different methodologies and techniques used in social neuroscience, rationale for employing EEG/ERPs methodology in this thesis and an overview of the ERP components in relation to perceptual decision-making.

The thesis commences with a systematic review of the extant literature (Chapter 4 – Study 1) which synthesises existing neurophysiological evidence that directly compares the neural basis of social and non-social decision-making in studies that manipulated social saliency involving all neuroimaging paradigms and task designs to examine patterns in brain correlates and temporal dynamics relating to social saliency. The systematic review highlighted the scarce electrophysiological literature examining differences between social and non-social decision-making and the limited use of simple perceptual decision-making tasks in that literature. Building on the findings of this review, three empirical studies were conducted, each of which manipulate social saliency in perceptual decision-making tasks.

Study 2 (Chapter 5) investigates the influence of social saliency on the behavioural performance and temporal dynamics in a preference choice task, involving two conditions: 1) choosing between faces that vary in affect - social condition and 2) choosing between landscapes that vary in affect – non-social condition. In both conditions, one happy and one sad image was presented in each pair. Results demonstrated the effect of social saliency on processing with higher amplitudes in the sensory processing, attentional focus and affective evaluation stages, with no differences based on social saliency observed in the decision-related stage.

Study 3 (Chapter 6) investigates the impact of social saliency on unconscious influences using a simple perceptual decision-making task involving trustworthiness ratings about neutral faces. In Study 3 instead of manipulating the task stimuli as in Study 2, the social saliency and affect of prime words was manipulated so the focus for examination was on unconscious influences on decision-making. Participants performed a trustworthiness task in two conditions: 1) rate the trustworthiness of neutral faces when primed with social words that vary in affect and 2) rate the trustworthiness of neutral faces when primed with non-social words that vary in affect. To examine the contributions of affect on decision-making, in both conditions word primes varied in affective nature (positive and negative). The influence of social saliency was evident in the behavioral results; reaction times were faster in trials preceded by non-social primes than social word primes and faces preceded by social word primes were rated as more trustworthy compared to non-social word primes. There was no effect of social saliency on temporal dynamics. Negatively-valenced words elicited higher ERP amplitudes during the affective evaluation and decision-related stages.

Study 4 (Chapter 7) builds on the previous empirical studies in the thesis by examining the influence of a passive observer on behavioural performance and temporal dynamics of perceptual decision-making. This final study extends findings from Studies 2 and 3 by moving from manipulating the social saliency and affective nature of the task stimuli and word primes to manipulating social presence. In Study 4 affect was also manipulated by giving participants performance feedback through the task itself (i.e. via the computer) that varied in valence (i.e. neutral, negative and positive). Participants performed a visual discrimination task in two conditions: 1) in the presence of a passive observer – social condition and 2) alone – non-social condition. Findings of Study 4 demonstrate that social presence and feedback valence elicited higher amplitudes during the affective evaluation and decision-related stages with higher amplitudes for non-social trials where negative feedback was given.

Taken together, the results of this thesis further support the proposition made in the systematic review that both the task type used and the social saliency manipulation influence the underlying temporal processing of decisions. Given that social saliency only influenced the temporal dynamics in Study 2 results indicate that early sensory processing is sensitive to social stimuli compared to non-social stimuli when faces are used as physical stimuli. But, findings of Study 3 show that the manipulation of social saliency of word primes has an effect on higher cognitive processing stages during the mid-range and late more evaluative stages. The findings of Study 4 are in line with Study 2 that found an effect of social saliency during the P3 stage with higher amplitudes for non-social images but in contrast to Study 3 that did not report any effect of social saliency. These apparent differences could be due to the variability in the social saliency manipulation; in Study 2 the social saliency of the stimuli was manipulated, in Study 3 the social saliency of the word primes was manipulated and in Study 4 the social saliency of the context was manipulated.

A synthesis of the findings across all studies of this thesis is outlined in Chapter 8. That chapter analyses findings from a more general perspective and discusses findings of individual studies and overall contributions of the thesis. In addition, that chapter examines the findings in relation to existing theoretical models. The chapter also examines applications of the findings and suggests avenues for future research.

Findings, propositions or new discoveries in the thesis

The review of the literature revealed the diversity in stimuli and tasks used in the selected studies which informed the design of the individual studies in each of the experimental chapter of this thesis. Also, the systematic review highlighted the scarce electrophysiological literature examining differences between social and non-social stimuli and the limited use of simple perceptual decision-making tasks in the extant literature.

The thesis examined the influence of social saliency and affect on the underlying temporal dynamics of simple perceptual decision-making tasks. In Study 2 the sensory processing and attentional focus stages were sensitive to social stimuli, whereas affective evaluation stage was found sensitive to non-social stimuli. During the late processing, social saliency did not influence the decision-related stage (i.e. there was no difference in processing based on social saliency).

In study 3, social saliency of word primes did not influence the temporal dynamics of decision-making. Social saliency influenced the trustworthiness ratings: neutral faces were rated as more trustworthy when they were preceded by social word primes than non-social word primes. Also, social saliency influenced reaction times which were slower following social primes than non-social primes indicating that social information might have been more complex than non-social information and influenced the speed at which participants respond. Affect of word primes influenced reaction times and trustworthiness ratings, with faster responses preceding positive word primes and higher trustworthiness ratings for neutral faces preceded by positive primes. Both mid-range evaluative and encoding stages as well as decision-related stages were influenced by the affective nature of the word primes with larger amplitudes for negatively-valenced primes compared to positive primes.

In Study 4, the social context (i.e. being watched by a passive observer) influenced mainly the affective evaluation and decision-related stages, with higher amplitudes for the negative feedback outcome only and larger amplitudes for non-social context. In Study 4 there was also an interaction of social saliency and valence: the affective evaluation stages were found more sensitive to the content of non-social trials where negative feedback was given.

Overall, the effect of social saliency on decision-making was demonstrated during the early sensory components in Study 2 (outlined in Chapter 5) when the social saliency of target stimuli was manipulated and found differences in the temporal dynamics of preference choices specifically in the early sensory processing ERP components and the mid-range ERP component but not the late decision-related components. But, in both Study 3 (outlined in Chapter 6) and Study 4 (outlined in Chapter 7) there was an effect of social saliency at behavioural level but not in the temporal dynamics. This result indicates that both word primes and social presence were not motivationally salient enough for participants to influence their decisions.

In Study 3, there was a trend for an influence of social saliency of the primes on the LPP amplitude, with greater ERP amplitudes for social word primes compared to non-social word primes, but this trend did not reach statistical significance in the analysis. Overall, social saliency influenced different temporal stages of decision-making depending on the type of stimuli and task type used in each of the empirical studies of this thesis. From the findings it was evident that faces because they possess physical characteristics and emotional properties (a happy and sad face have different characteristics which can be distinguished visually), are efficient in inducing effects on early sensory processing ERP components as seen in Study 2. Whereas social saliency manipulation of word primes and context did not have an effect on the decision process as seen in Study 3 and Study 4. Finally, social saliency did not influence the late processing stages which reflect decision-related activity across all studies in the current thesis which indicates that there were no differences in the decision-related stage based on social information.

In terms of the influence of affect on the temporal dynamics of decision-making, the affective nature of stimuli was found to modulate the neural underpinnings of trustworthiness judgements in Study 3 (outlined in Chapter 6), and the neural underpinning of performance monitoring in Study 4 (outlined in Chapter 7). In Study 3, negative word primes elicited larger mid-range and late processing amplitudes whereas in Study 4 neutral and negative feedback outcomes elicited larger feedback-related and mid-range processing amplitudes. Hence, the results across Studies 3 and 4 indicate that mid-range processing stages are sensitive to affect across a range of task stimuli (words of feedback).

The findings of this thesis demonstrate that both social saliency and affect of stimuli or feedback moderate the process of decision-making at different stages and are dependent on the type of stimuli and task used. Early components (less than <200ms after stimulus onset) are sensitive to the social saliency but this is stimuli dependent: faces as a form of social stimuli demonstrated an influence on early temporal charactertistics. Mid-range and late components (around 300-600ms) are sensitive to non-social information and modulated by the affect of stimuli/feedback with sensitivity towards negatively-valenced stimuli. The findings also establish links between social saliency and affect and their impact on decision-making, which as a novel approach in this research area, provides valuable information regarding the temporal dynamics of decision-making. Overall the findings of the current thesis provide electrophysiological evidence that both social saliency and affect of stimuli/context moderate temporal dynamics of processing decisions in the brain.

Impact and Further Research

An important finding of the current thesis is that both social saliency and affect influence the underlying temporal processing of simple perceptual decision-making. The research findings outlined in this thesis address the lack of ERP studies that contrast social and non-social decision-making by manipulating both social saliency and affect. The research conducted in this thesis adds to the theoretical understanding of this area, in two ways: 1) the results illustrate the impact of social saliency on behaviour and on the temporal dynamics of perceptual decision-making tasks relating to early and late processing stages, 2) the findings highlight that affect of stimuli or feedback moderates the decision-making process during the mid-range and late processing stages. The results demonstrated the influence of social saliency on the different temporal stages of decision-making and highlighted in the brain. More specifically, the findings in this thesis indicate that temporal dynamics are dependent on several different pieces of information when making a decision including, social saliency and affective nature of the task stimuli in order for a person to make a decision among alternatives. For example, when face-stimuli is manipulated (Study 2) the effect of social saliency was evident in the sensory, attention allocation and affective evaluation stages, when prime words are used (Study 3), social saliency did not influence the temporal dynamics of perceptual processing and when social presence is manipulated (Study 4), an interaction between sociality and affect was found in the affective evaluation stages. This finding indicates that when social saliency of stimuli interacts with affect require greater focus during the higher cognitive levels that evaluative judgements take place in order to establish how they both modulate decision-making.

Hence, a major contribution of this thesis is that it adds to the limited literature that examines the effect of social saliency and affect on the temporal dynamics of simple perceptual decision-making by manipulating different aspects of social saliency on decision-making. Thus, providing electrophysiological insights into the neural representation of social decisions in the human brain. Overall, the findings in this thesis will advance the neurophysiological understanding of decision-making by providing electrophysiological insights into the underlying temporal differences between social and non-social decision-making.

The findings of the current thesis indicate that future research should focus on unique ways of providing a more global view of the brain function in relation to decision-making. A combination of fMRI and EEG technique offers an informative way to investigate simultaneously distinct levels of temporal processing and interactions between brain areas. This is important to provide a more wholistic approach towards elucidating the underlying process of decision-making at spatiotemporal level.

Chapter 2. Literature Review

2.1 Introduction

This Chapter reviews the literature related to the process of decision-making generally and then moves onto discussing perceptual decision-making in particular. In this Chapter the literature relating to the influence of social saliency on decision-making is outlined and evidence on the differences/similarities between decisions dependent on social saliency are discussed. Also, literature on the influence of affect on perceptual decision-making is reviewed. Finally, directions for future research are outlined.

2.2 The process of decision-making

Decision-making is a process, which has been given numerous definitions over the years and can be broken down into various components. A decision is an action, a choice amongst alternatives, based on prior experiences and evidence, upon considering the advantages and disadvantages of each option (Resulaj, Roozbeh, Wolpert, & Shadlen, 2009). Decision-making is a long, deliberate process, in which one must choose an optimal action (Rilling & Sanfey, 2011) that is expected to produce the most desirable outcome (Lee, Seo, & Jung, 2012). Decision-making spans a vast range of different decision types and complexity, from deciding the next move in a chess game, to choosing a partner, deciding in which restaurant to make a reservation or choosing whether to gamble. Decision-making in everyday life requires individuals to consider information about the environment and others, as well as, weigh the value and uncertainty of outcomes prior to making a decision (Sanfey, 2007).

In contrast to decision-making in general, perceptual decision-making emphasises the role of available sensory information in choosing one option from a set of alternatives (Hauser & Salinas 2014). Perceptual decision-making often involves choosing one option from a set of alternatives based on available sensory information (Sterzer, 2016). Over the past two decades, understanding the underlying cognitive and neural processing behind perceptual decision-making has become a central theme in the neurosciences (Hanks & Summereld 2017). This thesis will focus on simple perceptual decision-making.

Theoretical frameworks posit that perceptual decisions arise from a sequence of functionally distinct processes (Ratcliff et al., 2007). More specifically, in traditional models of information processing, information proceeds from the sensory processing stage into the decision stage with no interaction between these different processing stages (Glezer, Jiang, & Riesenhuber, 2009; Pylyshyn, 1999; Riesenhuber & Poggio, 2000). These frameworks distinguish the sensory process, where the physical stimulus is encoded into internal sensory evidence, from the decision process, that integrates this sensory evidence over time into a decision variable. Recent advances in electrophysiology can add insights into the processes leading towards perceptual decisions. Specifically, in the classic framework of information processing, perceptual decision-making is the product of a succession of steps from sensory processing to decision formation and, if necessary, motor execution.

Evidence from ERP literature suggests that there are four distinct components to perceptual decision-making relating to specific ERP waveforms: 1) sensory processing stage: the first stage occurs around 100ms to approximately 200ms post stimulus as manifested in the N1/P1 component and it is associated with encoding of sensory information of the physical stimulus; 2) attentional focus stage: the second stage occurs around 200ms to approximately 300ms post stimulus as reflected in the N2/FRN component and it is associated with the attentional resources allocated to each stimulus. If the task involves feedback, outcome evaluation takes place at this stage; 3) motivational/affective processing stage: the mid-range stage occurs around 300ms to approximately 600ms post stimulus as manifested in the P3 component and it is associated with accumulating evidence to make a decision and it is sensitive to motivational/affective evaluation of sensory information; 4) decision-related stage: the late stage occurs around 600ms to approximately 800ms as reflected in LPP component, it becomes more pronounced over time, associated with decision-related neural processes, evaluation and final choice (Philiastides, Ratcliff, & Sajda, 2006; Philiastides & Sajda, 2007; Ratcliff et al., 2009; O'Connell et al., 2012; Wyart et al., 2012; de Lange et al., 2013; Kelly et al., 2013; Heekeren et al., 2008; Fleming et al., 2012; Posner, 1980). The different ERP components outlined refer to the underlying cognitive processes and brain activity when making a decision (Luck, 2004; Rugg & Coles, 1995). These ERP components are examined in the decision-making literature and emphasise different aspects of the defining features of perceptual processing.

Researchers have highlighted the importance of social saliency and affect in simple perceptual decision-making tasks (Gutnik et al., 2006). Various disciplines (e.g. psychology, neuroscience) have tried to shed light into this sophisticated human ability to make decisions (Frith & Frith, 2010). However, although there is increasing literature on the neural basis of decision-making, the complexity and diversity of its neural basis has not allowed scientists so far to accurately establish the exact impact of social saliency on the neural and temporal dynamics of simple perceptual decision-making. Therefore, it is essential to summarise current theoretical knowledge in relation to the influence of social saliency on decision-making and evidence about differences/similarities between social and non-social decision-making. This is important to better understand the underlying neural association between decisions in different domains and highlight the gaps in the literature that need addressing.

Many of our most important decisions take place in the social context. Decisions in social contexts require people to encode emotion depicted through expressions on other peoples' faces, react to unconscious influences, act and perform in front of other unfamiliar individuals. But, delineating the underlying neural basis and temporal dynamics of social decision-making is a great challenge because social decisions are vulnerable to a number of factors including, affective properties of the choices, presence of other individuals, monetary incentives and social influence that impact differently the decision process. In this thesis, social decision-making is given a broader term and is defined as both decisions made in a social context (i.e social presence, implied social presence, with another person – cooperation and competition) and those made under social influence (i.e. priming). Whereas, non-social decision-making is defined as those decisions not made in a social context or under social influence. The focus of the current thesis is on the impact of social saliency on decision-making in order to investigate differences and similarities between social and non-social decision-making.

The effect of social saliency on human decision-making, performance and behaviour has been found in social psychology studies (Aiello & Douthitt, 2001; Bredart, Delchambre & Laureys, 2006; Zajonc, 1965) and in more recent studies that involve interactive games and value-based decisions (Mojzich & Krug, 2008). The effect of social saliency in interactive environments has been demonstrated mainly in tasks that involve co-action (Nawa et al., 2008), strategic interaction (Lee, 2008), cooperation with fictional partners (Chen et al., 2012) and gambling games (Fukushima & Hiraki, 2006; Leng & Zhou, 2014; Tian et al., 2015) in which one's performance could influence the other's (Koban, Pourtois, Bediou, Vuilleumier, 2012; de Bruijn, Miedl, & Bekkering, 2011). However, in the absence of interactions, the degree to which the social presence affects one's decision-making remains unclear. The effect of social saliency in value-based decisions has been demonstrated mainly in tasks that compare non-economic (e.g., social) rewards with monetary rewards to investigate differences/similarities in the way the brain encodes social and non-social decision-making (Izuma et al., 2008; Lin, Adolphs, & Rangel, 2012; Rademacher, Krach, Kohls, et al., 2010; Rademacher, Salama, Grunder, et al., 2014; Smith, Hayden, Truong, et al., 2010; Spreckelmeyer, Krach, Kohls, et al., 2009; Zink, Chen, Bassett, et al., 2008). However, perceptual decisions are fundamentally different to more complex decisions and although there is sufficient literature on the impact of social saliency on complex decisions (Mavrodiev, Tessone & Schweitzer, 2013) a gap exists in the literature for an examination of social saliency on perceptual decision-making. Hence, the influence of social saliency on simple perceptual decisions will be the focus of this thesis.

There is some existing evidence of the influence of social saliency on temporal dynamics of decision-making using more simple perceptual tasks, but that evidence is limited because studies have mainly focused on passive viewing, without an overt judgement (or decision) made. Therefore, there is little information about the neurocognitive mechanisms and temporal dynamics of simple perceptual decision (Gold & Shadlen, 2007; Smith & Ratcliff, 2004). It is important to understand the influence of social saliency and affect on temporal dynamics of decision-making to accurately establish the impact of both social saliency and affect on each of the underlying temporal stages of human decision-making. This thesis builds on existing literature relating to the stages of processing for perceptual decision-making using EEG/ERPs.

2.3 Decision-making and Social Neuroscience

Decision-making has attracted great attention in research and has been examined by psychologists, economists (Loewenstein et al 2001; Slovic et al 2002; Tversky & Kahneman 1975), neurologists, neuropsychologists (Bechara 2004a; Clark et al., 2003; Damasio et al 1996; Lhermitte et al 1986; Shallice & Burgess 1991), psychiatrists (Paulus et al 2003) and neuroscientists (Clark et al 2004; Ernst & Paulus, 2005; Gold & Shadlen 2001; Platt & Glimcher 1999). Research on decision-making commenced when researchers started exploring the decision-making abilities of patients with ventromedial prefrontal cortex (vmPFC) lesions (Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, & Damasio, 2000). Alterations in social behaviour after injury to the prefrontal cortex enabled neuropsychological observations and encouraged attempts to link social behaviour to a specific brain circuit which fostered the research on the neural systems underlying decision-making. The efforts to model and predict social behaviour were enriched when neuroscience research joined the endeavour to understand the neural processes associated with decision-making. By 1990s the interest shifted to using advanced non-invasive neuroimaging techniques to tap into social processes.

In the 21st century, scientists highlighted the need for a discipline that could accommodate diverge backgrounds that examine the social brain. This new discipline that combines methods from psychology (cognitive and social) and neuroimaging techniques from neuroscience (cognitive neuroscience mainly) to understand and explain the biological underpinnings of social behaviour and human cognition in diverse situations was named Social Neuroscience (Cacioppo & Bernston, 1992).

In recent years, research into the neural basis of decision-making ranges from animal neurophysiology, computational neuroscience, affective science, behavioural neuroscience, social neuroscience, game theory, behavioural decision-making, behavioural economics, neuroeconomics, neurology and psychiatry (Heekeren & Phillips, 2010). All of these subdisciplines investigate how decision makers acquire perceptual or other information about decisions in a social or non-social context, and further process this information to reach a decision. Research on human decision-making has mainly focused on building a neurobiological model of decision-making and the field of Social Neuroscience is now playing a crucial role in our understanding of the neural and temporal underpinnings of decision-making. Therefore, a substantial part of social neuroscience is devoted to the question of how the brain translates physical stimulation into behavioural decisions - an operation known as perceptual decision-making (Gold & Shadlen, 2007; Heekeren et al., 2008; Smith & Ratcliff, 2004).

Social Neuroscience approach allows an exploration of the underlying neurobiological networks of social cognition and effects of social saliency on neural level and social behaviour (Cacioppo & Decety, 2011). In this thesis, social saliency is given a broader term and is defined as any type of information that vary in sociality (i.e. social stimuli, social decisions, social presence, social influence or priming) that captures the attention, and influences subsequent processing, decisions and behavioural performance.

Evolutionarily, humans, have evolved specific neural networks in the brain, the “social brain”, to process social information on perceptual level which are associated with generating social as well as non-social signals to guide behavior and social adaptation (Chang et al., 2013). So, humans, have the remarkable function of social cognition which allows them to complete diverse cognitive abilities in the social domain including communication and other prosocial behavior. Social cognition refers to how people think about others’ intentions and goals (i.e., theory of mental state tasks), identify social others (i.e., faces and bodily movement), moral judgements, social scripts, and making trait inferences (Lee & Harris, 2013).

A distinctive advantage of humans compared to animals is the ability to think about the mental states of another person (Lee & Harris, 2013). These processes are explained by the “social brain hypothesis” which includes social cognition and theory of mind (ToM). The “social brain hypothesis” proposes a set of brain regions that specialise only in human social behavior, problem solving, and social information processing (Adolphs, 2009; Dunbar 1998; Whiten & Byrne 1997). Considerable research indicates that such information processing is primarily mediated by a specific collection of neural regions also known as neural network of social cognition. Neuroscientific studies that employed tasks on social cognition and theory of mind to compare social to non-social decision-making are included in the systematic review, outlined in Chapter 4.

Social Neuroscience approach provides the tools to investigate decision-making and it is a new, promising research area that deepens our understanding of emotional, social and cognitive phenomena (Cacioppo & Decety, 2011). Scientists have long highlighted the need for biological data to inform judgement and decision-making research in order to elucidate the cognitive and emotional processes (Sanfey, 2007). The emergence of Social Neuroscience adds to the examination of decision-making and will be employed to examine decision-making in this thesis. Given that extant literature has yet to establish the exact impact of social saliency on simple perceptual decision-making tasks, the current thesis utilises a Social Neuroscience approach to fill this gap.

It should be noted that the investigation of the neural basis of social decision-making is a relatively recent development within the field of cognitive neuroscience and it is only in the last several years that there has been a critical mass of studies allowing inferences to be made about the brain organisation of decision processes (Sanfey & Rilling, 2011). The most commonly used neuroscientific techniques employed to investigate how the brain processes social decisions are functional magnetic resonance imaging (fMRI), EEG/ERP and transcranial magnetic stimulation (TMS). These neurophysiological measures are used because they provide a wealth of information regarding the underlying cognitive and brain systems and temporal dynamics. These techniques are discussed in detail in the methodology chapter (outlined in Chapter 3) along with the rationale for using the EEG/ERP methodology approach in this thesis. As the work outlined in this thesis focuses on examining the role of social saliency in decision-making, the literature relating to the impact of social saliency on decisions will be discussed in the next sections.

2.4 Research Contexts to Investigate Social Decision-Making

To better understand the neural basis of social decision-making, the behavioural paradigms from cognitive psychology have been combined with a variety of neuroscience methods, most notably neuroimaging. Empirical work in the social decision-making field has examined differences between social and non-social decision-making using either interactive or non-interactive paradigms. Interactive tasks involve decisions made with others in the context of competition or collaboration, whereas non-interactive tasks are mainly perceptual decision-making tasks which involve either manipulation of social saliency of the task stimuli or decisions made in the presence of another person, either mere presence or implied (i.e. through video-camera) (Lee & Harris, 2013). One important difference between interactive and non-interactive paradigms is that, interactive decisions require individuals involved in the task to make careful estimations of others' mental state in order to predict their behaviour. Also, interactive task scenarios are often challenging to replicate in a laboratory setting.

The studies involving an interactive context depend critically on the behaviour or actions of the individuals involved (Utevksy & Huettel, 2014). Two commonly used tasks to examine interactive decision-making include the Ultimatum Game (UG; Sanfey, Rilling, & Aronson et al., 2003) and the Dictator Game (DG). In the UG, the proposer has to take into account the desires and intentions of the responder and predict whether the responder will view the offer as fair, so as to increase the likelihood of acceptance and pay out for both the proposer and the responder. Whereas in the DG, one player proposes how to divide an amount of money between themselves and the second player has to passively accept it. A set of questions regarding moral decisions such as sacrificing one life to save many others (Shenhav & Greene, 2014) and third-party punishment, such as choosing to punish another who has violated social norms are asked to the players (Bolton & Ockenfels, 1998; Camerer & Fehr, 2004; Fehr & Fischbacher, 2004). Other interactive task is the Public Good Game in which participants are asked to decide how much of some resource to contribute to the creation of a public good and how much to spend on private goods (Fischbacher, Gachter, & Fehr, 2001). The focus of this thesis is simple perceptual decision-making tasks hence, all experimental studies will take place in non-interactive contexts. Relevant literature which examined the influence of social saliency on simple perceptual decision-making tasks in non-interactive environments is discussed below in much detail.

In non-interactive contexts, a well-established paradigm within cognitive psychology to examine social decision-making is the manipulation of social saliency of the task stimuli. The studies that have varied the sociality of task stimuli have mainly used tasks that involve passive receipt of social and non-social stimuli and incentive delay, or decision-making tasks that involve preference choice or visual discrimination (diFilipo & Groser-Fifer, 2016; Flores et al., 2015; Groen, Wijers, Tucha et al., 2013; Pegors et al., 2015; Proverbio et al., 2009; Philiastides et al., 2006; Heekeren et al., 2004; Zeng et al., 2012). These tasks contrast social information including mainly faces, words-adjectives or images of attractive/sexy women to non-social information which includes, money, cars, houses, or urban scenes that do not involve humans. Current research has yet to establish the exact impact of social saliency on simple perceptual decision-making tasks because there are limited electrophysiological insights on the effect of social saliency on temporal dynamics. Hence, this is the gap that will fill the current thesis. It is very important to understand how social saliency of the task stimuli can affect simple perceptual decision-making tasks in the constantly changing environment.

Another widely used experimental paradigm in the non-interactive context involves decisions made in the presence of another person or else social presence. Two commonly used manipulations in the neuroimaging field to examine decision-making in the presence of another person is mere presence (i.e. passive observation; Hobson et al., 2016; Tian et al., 2015) and implied presence mainly through a video-camera (Simon et al., 2014).

Social presence has been found to influence performance in decision-making tasks (Crisp & Turner, 2010; Fiske, 2010). Findings of the studies involving social presence are mainly discussed in the context of social facilitation theory and have focused on individual’s performance on a variety of simple and complex tasks (Allport, 1924). Social presence can improve an individual’s performance if a task is simple – social facilitation, and/or well-practised but, reduces performance when the task is novel or difficult – social inhibition (Hogg & Cooper, 2007; Klehe, Anderson, & Hoefnagels, 2007; Wagstaff et al., 2008). The impact of social presence on decision-making appears to be an innate process because both social facilitation and inhibition have been documented in insects (Baumeister & Finkel, 2010), animals (Monfardini, Redoute, Hadj-Bouziane et al., 2015), children (Arteberry, Cain, & Chopko, 2007), and adults (Simon et al., 2014; Tian et al., 2015; Hobson et al., 2016).

A recent fMRI study that examined the effect of implied presence (through video-camera) on decision-making and neural processing of feedback monitoring found activation at the ventral striatum during the implied social presence condition compared to playing alone (Simon et al., 2014). Another study used EEG to examine the effect of the presence of an unfamiliar person and a familiar person to the participant in the temporal dynamics of feedback monitoring (Hobson & Inzlicht, 2016). This study found increased ERP amplitudes in the attentional focus stage whilst being observed by the familiar person, highlighting the effect of familiarity on the ERP amplitudes. Only one EEG study has explored the effect of social presence to the temporal dynamics of feedback monitoring and used a gambling game whilst being observed by an unfamiliar peer than when playing alone (Tian, Feng, Gu, et al., 2015). Findings of this study show an effect of social presence at both attentional focus stage and motivational evaluation stage with larger amplitudes in the social condition. Overall, social saliency of stimuli and context influence differently the temporal and neural processing of decision-making based on the task used and the nature of the paradigm. Existing research has mainly used complex tasks such as gambling to examine the impact of social presence on decision-making. Hence, research has yet to establish the impact of social presence on perceptual decision-making and this is the gap that will fill the current thesis. It is important to understand how social presence affects simple perceptual decision-making because social decisions in the presence of other (often unfamiliar) people are an integral part of everyday life and may influence both complex and simple perceptual decisions.

2.5 Existing Empirical Work Investigating Social Decision-Making

In our daily life we constantly make decisions based on the available information and therefore human behaviour is influenced through social saliency of information (i.e. faces) (van den Boss et al., 2013) and unconscious influences (Nomura et al., 2004), promoted or enhanced through social facilitation (Zajonc, 1965). Humans, as social species interact with other people and the environment and as consequence encounter various socially salient stimuli: faces, gestures, emoticons, and socially relevant pieces of text. Hence, humans are influenced by others without the direct involvement in the decision, by sensing their presence, judgement, or disapproval or by being watched (van den Boss et al., 2013). This influence has a direct impact on subsequent health decisions, feelings of rejection or approval and could be effectively manipulated through marketing and social media campaigns. In order to examine social influence on perceptual decision-making it is important to understand the role of social saliency across all the above tasks.

Social saliency (i.e. task stimuli, unconscious influences, social presence) influences both performance and temporal dynamics of individual perceptual decision-making (Delgado, 2007). Social saliency has been shown to impact decision-making and performance monitoring in studies where it is manipulated. An increasing number of studies report that social information is incorporated into the guidance of attention during decision-making (Anderson, 2016; Tallat, 2011). A number of brain areas including vmPFC and orbitofrontal cortex (OFC) have been found sensitive to social information compared to non-social information when it is embedded in reward and feedback tasks (Bault et al., 2011; Harris et al., 2007; Kringelbach & Rolls, 2003; Amft et al., 2014). Also, social cues appear to modulate greater collaborative behaviour of co-players compared to non-social cues (Delgado et al., 2005; Le Bouc & Pessiglione, 2013). Other fMRI studies on feedback monitoring, show that the striatum is preferentially activated in response to social context during feedback processing (Simon et al., 2014).

A number of ERP studies have explored the influence of social saliency on decision-making by demonstrating temporal differences between social and non-social decisions. These ERP studies that have examined the temporal dynamics of social versus non-social stimuli using passive viewing of social (visual scenes involving people) and non-social scenes (Proverbio, Zani, & Adorni, 2008; Proverbio, Adorni, Zani et al., 2009) have shown higher amplitudes during the early sensory processing in response to social stimuli than non-social stimuli (P1, N2) (Proverbio et al., 2008; 2009). Specifically, the N1 component was strongly affected by the presence of persons, being larger to scenes with people than to scenes without people. In fact, many ERP studies have shown a brain’s response to human faces as early as 120–150ms after the stimulus (Batty & Taylor, 2003; Halgren, Raij, Marinkovic, Jousmaki, & Hari, 2000; Junghöfer, Bradley, Elbert, & Lang, 2001; Pizzagalli et al., 2002). Recent studies have also reported greater attentional focus, as reflected in the P2 component, when viewing pictures featuring humans to pictures with scenes (Groen, Wijers, Tucha et al., 2013; uck, 2005; Griffin et al., 2002; Proverbio et al., 2008; 2009). In another study participants preferred to view the images of attractive females compared to receiving money (Flores et al., 2015). Taken together, this evidence suggests that humans have a preference towards attending to social information than non-social one. These findings indicate that humans have an innate bias towards social information over non-social information which leads to discrete temporal processing stages between social and non-social decision-making as social cues are processed faster than non-social ones (Cacioppo & Hawkley, 2009; Shintel, Nusbaum, & Cacioppo, 2006). However, a limitation of the studies mentioned above is that they have mainly used passive viewing of images rather than asking participants to make overt judgement (i.e. choice or rating).

A recent fMRI study compared people's attractiveness judgements of social to non-social stimuli in humans (Pegors et al., 2015). When mean neural responses were examined, common activity at vmPFC was evident for both faces and places, but when multivoxel pattern analysis (MVPA) was used, differentiated activity in posterior and ventral portions in the right hemisphere of the frontal cortex was observed. There are no existing ERP studies that provide electrophysiological insights into the neural basis of decision-making by manipulating the sociality of the stimuli (social vs. non-social) using a preference judgement task so, little is known about the influence of social saliency on temporal dynamics of perceptual decision-making when an overt judgement is required. It is important to include overt judgement in the examination of temporal dynamics of perceptual decision-making because without over judgement a decision is not taking place.

Successful interaction with our environment requires humans to constantly monitor their behaviour and adapt it accordingly in case of errors or unfavourable events. Humans have a need to fit in socially and avoid rejection. Hence, monitoring social feedback is crucial for guiding performance evaluations and future decision-making. Studies that examined the impact of social saliency on decision-making have shown that social feedback causes attentional biases in associative learning tasks (Anderson, 2016) and that social information is better attended than non-social information in cognitive tasks (Brédart, Delchambre, & Laureys, 2006). Other studies have shown that negative social information is attended more from lonely adults compared to negative non-social information (Cacioppo & Hawkley, 2009; Shintel, Nusbaum, & Cacioppo, 2006), indicating that social words are more distracting. Thus, recent research argues that social factors are highly relevant during the monitoring stages in the decision-making processes (Koban & Pourtois, 2014). Also, a recent EEG study that examined the effect of mere presence of an unfamiliar person and a familiar person to the participant in the temporal dynamics of feedback monitoring showed that social presence of a friendly person influences more decision-making and performance monitoring compared to playing a game independently or in front of an unfamiliar person (Hobson & Inzlicht, 2016). Overall, these findings show that neural and temporal processing is influenced by social cues indicating a prioritised processing of social information, which is critical for evolutionary fitness (Chang et al., 2013). Although the impact of social saliency on the neural and temporal dynamics of decision-making has been studied (Rilling & Sanfey, 2011), there are limited studies that have examined the impact of the social context in modulating the temporal response to perceptual decision-making and feedback monitoring. To bridge that gap in the literature, the current thesis will examine the temporal dynamics of decision-making and feedback monitoring when social presence is manipulated in non-interactive environments.

The literature discussed above shows that the underlying differences between social and non-social information processing have been studied in a variety of diverse research fields and highlight the effect of social saliency in information processing. Despite the research, on the neural dynamics of perceptual decision (Gold & Shadlen, 2007; Smith & Ratcliff, 2004), current research has yet to establish the effect of the social saliency on the temporal dynamics of simple perceptual decision-making. This is the gap that the present thesis will address through a series of three conceptually similar ERP studies. The work in this thesis is unique because it adds to the limited literature that examines simple perceptual decision-making using an overt judgement rather than passive viewing tasks and provides electrophysiological insights into the neural representation of social decisions in the human brain.

2.6 The impact of affect on social decision-making

It has long been assumed that affective stimuli elicit emotion in a rapid, uncontrolled, and perhaps unconscious, fashion (Zajonc, 1980). Affect is an independent, primary and dominant influence of people's responses to social situations (Zajonc, 2000). However, it can have indirect effects on people's behavior through implicitly shaping attitudes and judgements (cognitive representations of the world). In addition, emotion may have different effects depending on the negative or positive valence of the emotion (Forgas, 2000), such as anger, fear, happiness or pleasure (Lerner & Keltner, 2000). There have been a number of attempts to measure these effects, both in the social cognitive literature (Schwarz & Clore 1983) and in modern neuroscience (Bechara et al. 1994), all of which suggest that the affective nature of presented information influences (harness or enhances) the way people make decisions and monitor performance outcomes. Recently it was suggested that affect influences people's attitudes and judgements, thus also influences subsequent decisions (Gutnik et al., 2006). Therefore, evidence suggests that decision-making is modulated by different emotional variables (i.e. positive vs. negative information; Liu, Hsieh, Hsu & Lai, 2015).

The literature suggests that there is differential processing of negative and positive stimuli, possibly due to differential activation in brain structures (Cacioppo, Crites, Berntson, & Coles, 1993; Ito, Larsen, Smith, & Cacioppo, 1998; LeDoux, 1996; Öhman & Wiens, 2001). It has been suggested that the right hemisphere is more involved in emotional processing than the left hemisphere (Borod et al., 2002). An ERP study that examined evaluative priming using faces that varied in affect (happy vs fearful) showed activation in mid-range processing stages at P3 amplitudes in response to happy faces over the right hemisphere than fearful faces (Li et al., 2008). Another ERP study that looked at the impact of word primes on preference judgements showed that positively-valenced words elicit larger ERP amplitudes during the evaluative stages, over the right hemisphere than the left hemisphere (Gibbons, 2009). These findings explain why physically identical stimuli that have different affective properties may receive differential processing in the brain resulting in different judgements. However, the exact impact of affect on simple perceptual decision-making tasks has not been established clearly. This thesis will address this gap by manipulating affect in each of the studies in the thesis in order to investigate the impact on behaviour and/or temporal dynamics of decision-making.

Two of the most commonly used tasks to investigate the contributions of emotions on decision-making are, affective priming and performance monitoring tasks. Studies in these fields have varied the degree of affective information given to decision-makers (e.g. positive vs. negative) and examined the influence of affect mainly at behavioural and more recently at neural levels.

Priming refers to a form of perception in which a stimulus is presented unconsciously (Jacobs & Sack, 2012). Priming is the ideal way of examining the influence of affect on decision-making because it is efficient in eliciting transient emotional responses that impact subsequent choices (Breitmeyer, Ogmen, & Chen, 2004; Eimer & Schlaghecken, 2003; Neumann, Esselamnn, & Klotz, 1993). Affective priming is achieved by manipulating the affective states of unconscious stimuli. In affective priming, participants are subliminally presented with emotion-laden stimuli, such as happy, angry and neutral faces or affective words (Phelps, Lempert, & Sokol-Hessner, 2014). Most priming studies have employed complex tasks to examine how affective primes influence judgements of neutral or social stimuli (e.g., Nomura et al., 2004). Findings suggest that affective information influences subsequent decisions. For example, when participants were primed with angry, happy and neutral faces (Winkielman et al., 2005) and asked to pour, consume, rate and indicate their willingness to pay for a non-alcoholic beverage, results revealed that those who had been exposed to happy faces poured and consumed more of the beverage. Whereas, those presented with angry faces showed the opposite effect. These findings are particularly noteworthy because participants were unaware of the experimental manipulation and did not report any changes in affect during the study. This is important as it provides evidence that the emotional primes served as cues that generated subtle emotional reactions which influenced subsequent judgements (Phelps, Lempert, & Sokol-Hessner, 2014). In another study, participants were presented with either positive or negative words while they made choices between different types of rewards in a temporal discounting paradigm (Augustine & Larsen, 2011). That is, those who were more likely to experience negative affect regularly were more impatient when they were experiencing a negative affective state. This study suggests that subtle changes in baseline emotional state may have a substantial impact on decisions. However, there is little evidence of how affective priming influences processing in simple perceptual decision-making tasks (Phelps, Lempert, & Sokol-Hessner, 2014) and this will be the gap that the current thesis will fill.

Affective nature of primes has been found to influence performance during decision-making tasks in which socially salient primes were used. More specifically, in affective priming literature, the sensory processing stages have been associated with the detection of expression-specific facial configurations (Werheid et al., 2005). For example, an ERP study reported larger P1 amplitudes in response to fearful face primes than happy face primes whereas P3 amplitudes were enhanced with happy face primes compared to fearful face primes (Li et al., 2008). These findings may indicate a sensitivity to threat and reflect differential attentional orienting but also show that sensory processing stages are associated with the processing of human faces. Other ERP studies that have used word primes instead of face primes, did not report any sensory processing activation rather late positive components were found enlarged in response to word primes (Knost et al., 1997; Naumann et al., 1992; Williamson, Harpur, & Hare, 1991). This finding of enhanced amplitude during late processing stages for word primes is considered an index of enhanced elaborative processing (Paller, Kutas, & McIsaac, 1995).

Although there is an increasing literature on the impact of affect on decision-making, only limited studies have manipulated both social saliency and affect of prime stimuli to explore the combined effect on decision-making. This is important to examine as social saliency and affect might have a direct impact on decision-making but might also interact with each other and influence differently the decision process. This thesis will fill this gap by manipulating both social saliency and affect in a series of experimental studies to investiage the temporal dynamics of decision-making. Determining the interaction between sociality and affect is crucial for establishing the neural basis of social decision-making as affect might e a potential moderator of the decision-making process.

Another method to manipulate affect in decision-making tasks is through the feedback given. Studies manipulate the affect of feedback in performance monitoring tasks that require participants to evaluate the consequences of a choice embedded in the decision process. In order for human's performance to be precise, the neural monitoring system relies on feedback either given by someone else or through action planning (Villuendas-Gonzalez & Gonzalez-Garrido, 2016). So, performance monitoring is important for people to guide their future decisions. Performance monitoring is ideal for studying the influence of affect in decision-making by manipulating the affective nature of feedback outcome during a perceptual decision-making task (Tian et al., 2015; Simon et al., 2014). Monitoring and evaluating the consequences of our behaviour is important for future action selection. In performance monitoring tasks, participants are presented with outcome feedback that varies in affective nature such as positive and negative feedback (Hobson & Inzlicht, 2016; Tian et al., 2015). Crucially, evidence suggests that these different valence outcomes (positive vs. negative feedback) influence differently performance monitoring and future decisions (Ferdinand & Opitz, 2014). The influence of the affective nature of outcome feedback on performance monitoring and decision-making has been typically examined in the context of social facilitation/inhibition theory. Studies that have used experimental paradigms where outcome feedback is given have shown that neural feedback monitoring is modulated by affect of feedback outcome (Hobson & Inzlicht, 2016; Simon et al., 2014; Tian et al., 2015). Empirical evidence highlights the importance of considering multiple dimensions of affect in studying reactions to feedback (Ratner & Herbst 2005). It is important to understand how different feedback outcomes influence perceptual decision-making and feedback monitoring because feedback monitoring is instrumental for guiding our performance and help us guide future behaviours (Holroyd & Coles, 2002; Cohen & Ranganath, 2007).

Previous research indicates that outcome feedback influences subsequent performance on a variety of tasks. For example, observers rate people as better thinkers, more competent, when their decisions have a favourable outcome compared to a negative outcome (Alicke, Davis, & Pezzo, 1994; Allison, Mackie, & Messick, 1996; Baron & Hershey, 1988). Specific ERP components have been associated with neural activation 200–500ms following task feedback and are thought to reflect the neural reactivity to external feedback (Holroyd & Coles, 2002; Hajcak et al., 2005).

At the same time, influences of social information on feedback related activity of the human brain have mainly been investigated in passive viewing tasks or using implied mere presence. For example, in behavioural experiments the presence of observers or just the mere presentation of images of others is frequently associated with enhanced performance and increased frequency of overt behaviours across many species (Zajonc, 1965). However, only a few electrophysiological studies have investigated how the affective nature of feedback outcome influences the temporal dynamics in simple perceptual decision-making tasks (Hobson & Inzlicht, 2016; Tian et al., 2015). Therefore, it remains unclear if the presence of an observer who is not explicitly engaging in social interaction may modulate processing of positive and negative performance feedback and decision-making. This is important to examine because decisions in real-life are often influenced by social presence and involve direct and indirect feedback.

One EEG study that examined the effect of being observed by an unfamiliar person (non-social condition) in comparison to a familiar person (social condition) when completing a monetary task demonstrated higher ERP amplitudes in the attentional focus stage when participants were observed by a familiar person than a non-familiar person (Hobson & Inzlicht, 2016). But this study did not examine the role of social saliency on the temporal dynamics of perceptual decision-making. Another EEG study explored the effect of social presence to the temporal dynamics of feedback monitoring when playing a gambling game whilst being observed by an unfamiliar peer (social condition) than when playing alone (non-social condition) (Tian, Feng, Gu, et al., 2015). Findings of this study show an effect of social presence at both attentional focus and motivational evaluation stages with larger amplitudes when observed by an unfamiliar peer (social condition) than when playing alone (non-social condition). Hence, there is a scarcity of empirical studies that have investigated the impact of social presence on the neural and temporal basis of simple perceptual decision-making and performance monitoring. It is important to understand how social presence affects decision-making because social decisions in the presence of other (often unfamiliar) people are an integral part of everyday life. This thesis addresses the gap in the literature for an examination of the influence of affect of feedback outcome in perceptual decision-making tasks by including a study (Study 4) that investigates the influence of both social saliency and affect of outcome feedback on the temporal dynamics of perceptual decision-making.

Based on the reviewed evidence in Chapter 2, there are indications that humans have an innate bias to attend preferentially to social information compared to non-social information. Also, reviewing the literature around affective priming and performance monitoring, it is evident that affect influences greatly subsequent decisions and judgements. However, it has not clearly established yet, how social saliency and affect impact the different temporal stages of perceptual decision-making. Most importantly, literature has not examined how both social saliency and affect of prime stimuli together could influence subsequent decision processes. Social information is often linked to affective information (i.e. angry face, happy face). This means that affect is embedded in social information and is often interrelated. Affect has been argued to be a valuable and adaptive tool in informing the decision process (Kahneman, 2003) hence it is crucial to establish its impact on decision-making. This is the gap that this thesis will fill.

In all three experimental studies of this thesis, both social saliency and affect are manipulated. Specifically, in Study 2 (outlined in Chapter 5), an examination of the influence of social saliency on temporal dynamics of simple perceptual decision-making is conducted using stimuli that vary in sociality (social vs. non-social) and in affect (positive vs. negative) to investigate the underlying neural processing of preference choice. Study 3 (outlined in Chapter 6) examines the impact of affective priming on decision-making using primes that vary in sociality (social vs. non-social) and in affect (positive vs. negative) to investigate the underlying temporal dynamics of unconscious influences on perceptual decision-making. In Study 4 (outlined in Chapter 7) the social saliency of the context (social presence vs. alone) and affect of feedback (positive vs. negative vs. neutral) are manipulated to identify how social saliency and affect of feedback outcome influence decision-making.

Gaps in research literature

In the previous sections of this chapter, literature demonstrating the influence of social saliency on decision-making leading to temporal differences between social and non-social decision-making was outlined. It was evident, from the studies reviewed that the temporal dynamics of social saliency of perceptual decision-making remain understudied, especially in relation to the behavioural and neural processing of simple perceptual decision-making tasks. Therefore, the work in this thesis addresses that gap by focusing on temporal dynamics of perceptual decision-making. For this reason, a series of studies were designed to manipulate social saliency of: 1) the target stimuli, 2) the primes and 3) the context through social presence. The similarity between the three studies is that they all examine the impact of social saliency on behavioural and temporal processing using simple perceptual decision-making tasks and differ only in the way in which social saliency is manipulated.

In addition, there are currently only a few electrophysiological studies that have investigated the effect of the presence of an observer and affect of outcome feedback on decision-making (Hobson & Inzlicht, 2016; Tian et al., 2015; Simon et al., 2014). So, there is limited evidence on the effect of social presence on performance monitoring and decision-making. Therefore, it is important to accurately establish the impact of social context on the temporal dynamics of decision-making to establish differences on how humans make decisions in social and non-social contexts. This is a gap that the current thesis will fill.

Research Aims of studies

The thesis aims to explore the temporal dynamics of social saliency of perceptual decision-making to generate a more complete model of how people make decisions. In order to fill the gaps identified in the existing literature that examines social decision-making this thesis will use electrophysiological methods to examine the influence of social saliency on the temporal dynamics of simple perceptual decision-making tasks. This is important to build a coherent picture of how social saliency influences decision-making and understand how social saliency and affect modulate decision-making in the brain.

This will be achieved by reviewing the literature that directly examines differences and similarities between social and non-social decisions across different task paradigms to synthesise existing findings and highlight gaps in the extant literature. Then, gaps in the literature will be addressed by focusing on the influence of social saliency on behavioural performance and temporal dynamics of perceptual decision-making tasks. Hence, this thesis will advance the theoretical understanding of the impact of both social saliency and affect on perceptual decision-making by systematically reviewing existing literature and providing novel electrophysiological evidence.

Outline of studies in the thesis

Study 1 (Chapter 4) reports the results of a systematic review and summarises existing empirical evidence that directly compare the neural basis of social (those involving social saliency and those influencing decisions made with others or specifically relating to other people) and non-social decision-making and also identify gaps in the current knowledge on the influence of social saliency and social context on neural and temporal dynamics of decision-making and suggest areas of focus for future research.

Study 2 (Chapter 5) examines the influence of social saliency on behavioural and neural processing of perceptual decision-making by manipulating the social saliency of the task stimuli in a preference choice task. The ERP is employed to measure temporal dynamics while participants engage in a preference choice decision using stimuli that vary in sociality and affect.

Study 3 (Chapter 6) examines the temporal dynamics of affective priming using primes that vary in social saliency (social vs. non-social) and in affect (positive vs. negative) to examine the temporal dynamics of trustworthiness judgements about neutral faces. In contrast to Study 2, in Study 3 the target stimuli was not manipulated (which are the same across conditions) but social saliency and affect were manipulated through prime words.

Study 4 (Chapter 7) was conducted to investigate the effects of social presence on decision-making and performance monitoring. In this final study, social saliency of context was manipulated and participants performed the task in two conditions: 1) with a passive observer, and 2) alone. Affect of feedback outcome (positive vs. negative vs. neutral) was also manipulated.

Contribution to Knowledge

This thesis adds to the limited studies in the literature that examine the effect of social saliency and affect on the temporal dynamics of decision process using tasks that require an overt judgement (i.e. decision) rather than passive viewing. Using EEG/ERPs this thesis will investigate the influence of social saliency on temporal dynamics for perceptual decision-making by conducting a series of simple perception tasks.

The work in this thesis is unique because it examines different aspects social saliency on decision-making to provide a better understanding of the social influences at each temporal stage of decision processing. At the same time, by examining the contribution of affect on the temporal dynamics of decision-making, this thesis will add to the literature by providing evidence on the interaction of affect with social saliency and their influence on perceptual decisions during the different temporal processing stages.

Given the prevalence and complexity of social decisions in peoples' lives this thesis will make an important contribution to existing knowledge about social decision-making by extending existing findings in two ways: 1) the influence of social saliency on temporal dynamics of perceptual decision-making, and 2) the influence of affect on social decisions. This thesis is an attempt to combine information from different social decision-making studies to provide empirical evidence about how people make choices and decisions.

Chapter 3. Methodology

This chapter describes the most commonly used social neuroscience techniques to explore human decision-making, outlines the main reasons for choosing EEG as the main methodology for this thesis and provides a background on the origin and function of EEG as well as the acquisition and analysis of EEG data.

3.1 Social Neuroscience techniques

The combination of neuroscience methods with theories from social psychology enables a more complete understanding of the underlying biological, chemical and neural processes and helps researchers to untangle psychological and behavioural processes related to social information processing (Harmon-Jones & Beer, 2009). Neurophysiological measures provide a wealth of information regarding the underlying cognitive and brain systems and temporal dynamics.

In order to better understand the reasons for choosing EEG as the main methodology for this thesis, it is useful to outline the most widely used neuroscientific methods that have been employed from scholars investigating questions of how the brain processes social decisions.

Psychologists and neuroscientists have used a variety of methods to examine the neural basis of social decision-making. These can be categorised based on their different physical principles including: (i) studies that examine the consequences of abnormal brain function on decision-making on brain-damaged patients (ii) experiments applying repetitive transcranial magnetic stimulation (rTMS) to disrupt temporally the activity within the brain, (iii) electroencephalography (EEG) studies which measure the electrical signals of neuronal firing at the scalp, (iv) genetic studies looking at the correlation between individual differences in the expression of certain genes and behavior, (v) pharmacological research to examine the effects of drug administration and neurotransmitters, and (vi) functional magnetic resonance imaging (fMRI) studies which measure neural activity reflected in changes in cerebral blood flow of subjects. But the most commonly used neuroscience techniques with adults in decision-making research are fMRI, TMS and EEG/ERP. It is of particular interest to outline methods for elucidating brain mechanisms underlying decision-making in social contexts for two main reasons; first, some of aspects of social decisions have already been studied in humans with behavioural and neuroimaging methods which make it easier to compare activation in different brain sites. Second, to outline the contribution of each of the neuroscientific methods in decision-making research and outline the reasons for choosing EEG/ERP as the main methodological approach in this thesis.

Ward (2012) argues that neuroimaging methods used in social neuroscience can be placed into four broad categories based on their resolution, invasiveness, type of data acquisition and what they measure in the brain (Table 3-1).

Table 3-1. Neuroscientific methods.

Method	**Measurement**	**Invasiveness**	**Type of data acquisition**
fMRI	Hemodynamic changes	Non-invasive	Recording
PET	Hemodynamic changes	Invasive	Recording
EEG/ERP	Electrical activity	Non-invasive	Recording
TMS	Electromagnetic activity	Non-invasive	Stimulation

Resolution: Methods with good temporal resolution measure *when* an event is occurring and include electroencephalography/event-related potentials (EEG/ERP) and TMS. In contrast, methods with good spatial resolution, such as fMRI, measure *where* an event is occurring (Figure 3-1).

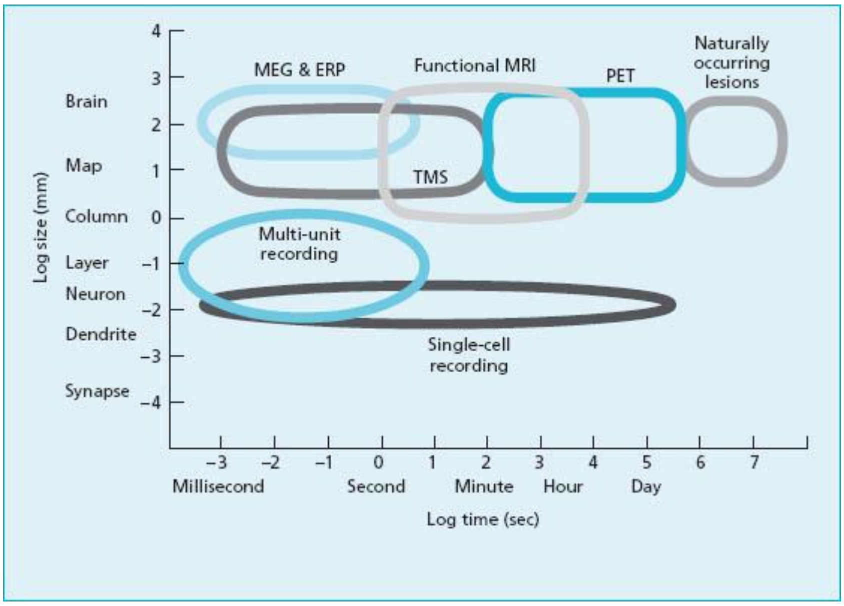


Figure 3-1. Categorization of methods of cognitive neuroscience based on their spatial and temporal resolution (Taken from Ward, 2012).

Invasiveness refers to whether or not equipment is placed internally or externally. In this category falls only Positorn Emission Tomography (PET) because an injection of radio-labeled isotope is required. It is still debatable whether TMS is considered invasive because although the coil is placed only outside of the body it results to stimulation of the brain (Ward, 2012). Almost all methods, PET, fMRI, EEG/ERP, are tools to record brain activity but only TMS is a method to stimulate the brain.

fMRI

The most dominant approach in cognitive neuroscience since the 1990s is fMRI. The fMRI is a variant of the Magnetic Resonance Imaging (MRI) technique used frequently for medical purposes to depict the body internally. It is a hemodynamic method and has been used extensively to examine cognitive processes. The fMRI measures the result of neural activity relating to changes in blood flow/blood oxygen to meet the metabolic needs of neurons. It is considered an indirect measure of neural activity because it measures changes in the concentration of oxygen in the local blood supply rather than the neural activity directly.

The fMRI takes place inside a magnetic scanner. A strong magnetic field is applied constantly during the scanning process (e.g. 1.5 or 3 Tesla). This magnetic field disrupts the orientation of magnetic molecules in the human body and brain, such as water and haemoglobin, and causes a detectable change in the magnetisation of these molecules that is recorded by the MRI scanner (Sanfey & Stallen, 2016). It is a measurement sensitive to the concentration of oxygen in the blood. More specifically, the amount of deoxyhemoglobin in the blood in different regions of the brain effects the magnetic resonance signal in the brain which is measured during fMRI. The difference in magnetic characteristics of oxygenised and deoxygenised haemoglobin causes a signal that is also known as the Blood Oxygenation

Level Dependent (BOLD) signal. The BOLD signal is used to study human brain function in fMRI experiments.

Because fMRI is not a direct measure of brain activity the results are not considered a causal link between brain activation and behaviour. Moreover, the BOLD signal appears a few seconds later than the underlying neural activity so the fMRI signal is slow. Therefore, fMRI is not recommended when measuring fast occurring events or examining temporal dynamics.

Because of the temporal limitations of fMRI, decision-making studies using fMRI tend to use static stimuli such as pictures of human faces and instruct participants to either passively view them or judge their attractiveness or age (Winston, Strange, O'Doherty, & Dolan, 2002). Other stimuli presentation methods used in fMRI studies are instructing participants to read stories or look at cartoons and then either evaluate the scenarios, such as in moral decision-making (Greene, Sommerville, Nystrom, Darley, & Cohen, 2001) or evaluate the mental state of another individual (Gallagher, Happe, Brunswick, Fletcher, Frith, & Frith, 2000). But techniques are getting more sophiscated and recent fMRI studies have focused on cooperation and competition to employ real life social interaction paradigms (McCabe, Houser, Ryan, Smith, & Trouad, 2001; Rilling, Gutman, Zeh, Pagnoni, Berns, & Kilts, 2002).

Transcranial Magnetic Stimulation (TMS)

The TMS is based on the principle of electromagnetic induction. It uses portable equipment in contrast to fMRI or PET and

Magnetoencephalography (MEG) which uses static equipment. The TMS equipment consists of a magnetic coil which when placed over a specific area of a participant’s scalp and creates a brief magnetic field which leads to neural interference that temporarily disrupts performance. It causes a “virtual lesion” when applied which affects the neurons involved in performing an important cognitive function and as a result it disrupts that function. The TMS pulse is very brief (less than 1ms) but effects on the cortex may last for several tens of milliseconds. Barker, Jalinous and Freeston, (1985) were the first to use a TMS approach. Since then, TMS has been used to examine the timing and location of cognition (Ward, 2012).

Transcranial Magnetic Stimulation has a series of advantages compared to the traditional lesion methods (Pascual-Leone, 1999). Firstly, the effects of TMS are temporarily and do not jeopardise the reorganisation of the cognitive system which allows for within-subjects designs. Secondly, TMS is a flexible technique in comparison with organic lesions, which means that the site under stimulation can change based on the requirements. The TMS offers direct examination of the brain’s areas involved in social decisions (Vant Wout, Kahn, Sanfey, & Aleman, 2005).

Electroencephalography (EEG)

Electroencephalography is a non-invasive technique to measure electrical activity at the scalp of the brain. It is widely used because it has a temporal resolution of milliseconds and electrical activity is generated from action potentials and postsynaptic potentials, as well as, electrical signals from scalp muscles and skin (Carter & Shieh, 2010). Another advantage with EEG is that it is relatively inexpensive compared to other techniques (Vespa, Nenov, & Nuwer, 1999). As EEG has a high temporal resolution, it is particularly important for examining the decision-making process because it provides information on the underlying neural changes occurring with millisecond precision thus enabling examinations of each of the temporal stages/processes involved in making a decision (i.e. perception, encoding, decision, evaluation). However, EEG is inferior to fMRI in terms of signal's source estimation because it has poorer spatial resolution (Srinivasan, 1999).

In order to extract time-locked information from the EEG data, a method called Event-Related Potentials (ERPs) is used. The ERPs are time-locked to certain events or visual stimuli thus provide insights on information processing with millisecond precision, starting with the initial registration of a stimulus followed by the preparation and execution of a response (Coles & Rugg, 1995). In the current thesis, ERPs are used to examine the temporal dynamics of social decision-making.

3.2 EEG and the Current Thesis

There are currently only a few EEG studies that directly contrasted the temporal dynamics of social and non-social decision-making (Flores et al., 2015; Proverbio et al., 2008; 2009; Philiastides et al., 2006) and therefore the current thesis will fill this gap using EEG/ERPs to shed light into differences/similarities between the temporal dynamics of social and non-social decision-making.

The EEG was chosen because it has a high temporal resolution compared to other widely used social neuroscience techniques mentioned in Section 3.1 of this chapter. The distinctive ability of EEG compared to the other neuroscientific methods that were discussed in section 3.1 is, to measure the dynamics of perceptual processing in the brain through the sequence of ERP components (Woodman, 2010). The high temporal resolution that ERP technique offers is particularly efficient in isolating distinct processing stages intervening between stimulus and response and disentangling their individual contributions to reaction time (Woodworth, 1938, Hillyard & Kutas, 1987). These features make ERP technique a vital tool for testing the impact of social saliency on simple perceptual decision-making tasks and thus will be the main methodology used in this thesis.

The ERP components used in this thesis are commonly examined in the decision-making literature emphasising different stages of processing of decision-making including, sensory processing, attention allocation, motivational-affective evaluation and decision-related activity. These ERP components refer to the underlying cognitive processes and brain activity indexed by the potential (Luck, 2004; Rugg & Coles, 1995). The neural activity originating from the brain related to each of the processing stages reflects the progression of information processing in the brain (Woodman, 2010). In this thesis an examination of the temporal dynamics was the main focus hence, the ERP technique is the most appropriate tool to examine the temporal dynamics and generate a view of coordinated activity in the brain with milliseconds accuracy. Also, by examining the temporal dynamics in the decision process will allow us to establish how social saliency and affect influence each processing stages of human decision-making.

The next sections of this chapter will provide background knowledge on the origin of the EEG, technical aspects of the EEG equipments, data acquisition and analysis process.

3.3 Current knowledge on EEG

The EEG was invented in 1924, however there was an understanding of electrical activity in the brain from around 1875. The EEG is a neurophysiological technique that measures voltage differences across the scalp that represents electrical activity in the brain. EEG was first used to record electrical activity from the neocortex of rabbits and monkeys and formerly introduced for research and clinical purposes in 1924, when the German psychiatrist Hans Berger successfully recorded electrical activity from human brain using an EEG. The EEG represents summated activity of post-synaptic potentials over time.

It is widely used for intracranial investigations and measures the electrical communication between numerous, synchronously active neural populations, which allows for precise time estimation of cognitive function in the brain by scalp recordings (Andreassi, 2000; Hugdahl, 1995).

3.4 The Origin of the EEG

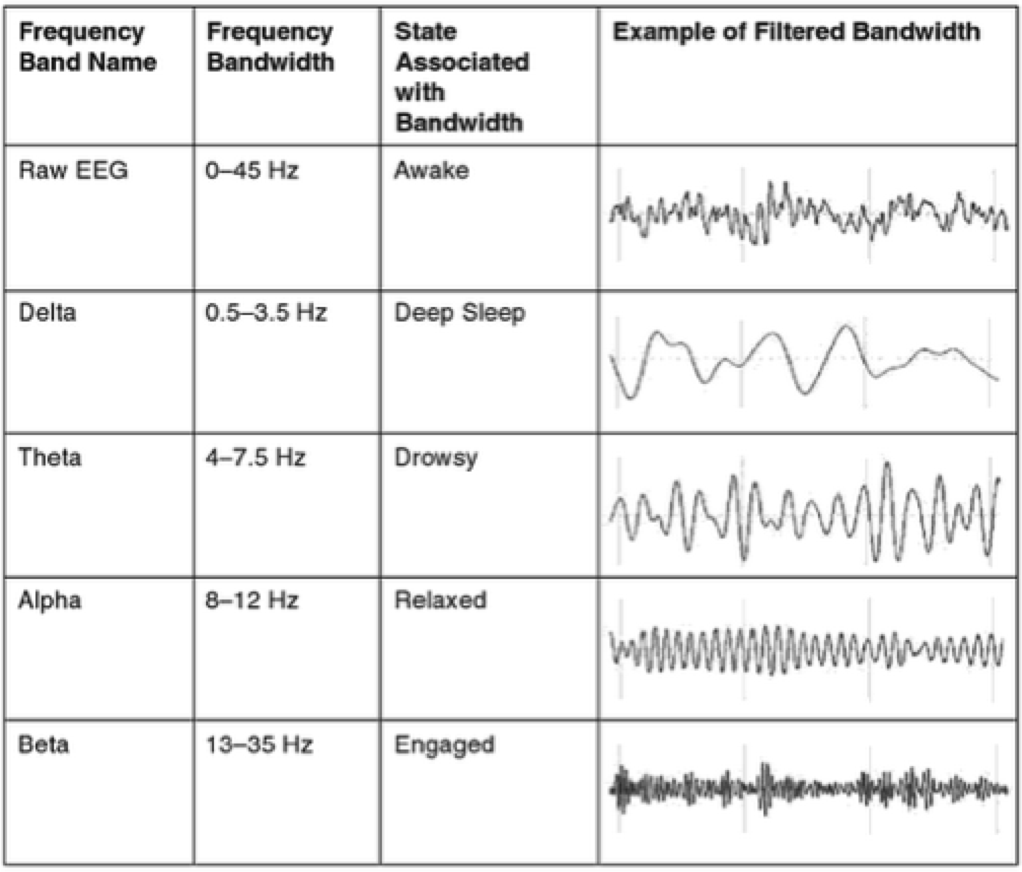
Neurons are electrically polarised so that their interior sustains a negative electrical potential approximately around -70mV with respect to the outside of the cell membrane which is 0 (Speckmann & Elgar, 1987; Schaul, 1998; De Clercq, 2005). This potential difference, called the resting potential, is due to an unequal distribution of mainly Na+, K+ and Cl− ions across the cell membrane. Cells communicate with each other by releasing chemicals at the synaptic terminals, from presynaptic to postsynaptic regions that disturb this resting potential. The postsynaptic potentials alter the neuronal membrane potential by several millivolts. This change in potential lasts over 10 ms and both depolarisation and hyperpolarisation are possible. As every neuron has many synapses connecting to different neurons, the action potential over a cell membrane is given by the spatial and/or temporal summation of the postsynaptic potentials. When the neuronal cell is depolarised beyond a critical level or threshold, an action potential is generated that proliferates along the axon. When such an action potential arrives at a synapse, it is able to release neurotransmitters to communicate with other neurons. If the potential is excitatory, the chance that an action potential will be triggered, will increase in the postsynaptic cell. When it is inhibitory, the generation of action potentials will be suppressed. This very complex network of chemical and electrical signals controls, in a detailed way, normal brain function, which is depicted in the EEG waveform.

The EEG signal reflects the aggregation of aligned post-synaptic currents of millions of neurons (Xue, et al., 2010). Neurons generate currents which are aggregated in the extracellular space and are then attenuated can still be detected though through meningeal coverings, spinal fluid and scalp. When cortical neurons are simultaneously active, the sum of these potentials will be between 10 to 150 µV on the human scalp. The potential difference in signals, measured between two electrodes constitute the EEG.

The EEG produces several waveforms which reflect neural activity from all parts of the brain. When a participant is engaged in a task while measuring EEG, some of this activity is associated with the presented task. To gain these waveforms the voltage between two or more different sites is compared. This method allows for investigation of the basic neural processes that generate complex higher-order cognitive functions and posits a fundamental tool for both cognitive and social neuroscience (Light, et al., 2010).

The EEG is commonly subdivided in 4 frequency f bands in relation to changes in a person's state of arousal, from being awake and alert to deeply asleep (Fish, 1999). Table 3-2 shows the distribution of the 4 frequency bands.

Table 3-2. Typical analysed EEG frequency bands. (Taken from Molina et al., 2012).



Frequency Band Name	Frequency Bandwidth	State Associated with Bandwidth	Example of Filtered Bandwidth
Raw EEG	0–45 Hz	Awake	
Delta	0.5–3.5 Hz	Deep Sleep	
Theta	4–7.5 Hz	Drowsy	
Alpha	8–12 Hz	Relaxed	
Beta	13–35 Hz	Engaged	

3.4.1. Recording the EEG

Having described the basic information about the EEG, in the next section technical aspects of the EEG equipment will be discussed.

Active Electrodes and Reference Electrodes

Scalp electrodes are typically made from small discs of conductive metal. Conductive gel is inserted between the electrodes and the surface of the scalp to maintain recording integrity over prolonged periods. Because the electrical current takes the path of least resistance, it is important that the impedance (impediment to current flow) between the scalp and the electrodes is kept stable and to a minimum. Reducing the impedance minimises the risk of contamination by low frequency noise (caused by electrode and environmental artefacts) and can be done by gently abrading the skin to remove the outer layer of dead skin cells (e.g. using a hair brush).

A reference site that remains uninfluenced by the variable under investigation is selected. The most commonly used are the common average reference and the linked-ears reference (Fisch, 1999). With an average reference, all potentials are displayed with respect to the average value of all electrodes. In linked-ears reference, the EEG is displayed with respect to the average of the potentials at the ear lobes (which should be ideally zero). Both are good for visualising widespread coherent waveforms.

3.4.2. Electrode Placement

The EEG signal is collected from a number of electrodes, mounted on caps at different locations on the scalp, ranging from 32 to 256. To ensure clarity in recordings and create a general electrode placement system, electrodes are placed in pre-defined positions on the recording cap. The international 10-20 system is the most commonly used system for positioning the electrodes (Nuwer, et al. 1998).

This standard International system (International 10-20 System) (Figure 3-2) was developed by Jasper (1958) detects that electrodes are positioned at points 10 and 20 percent of the distance between the nasion to the ion and from the left to the right pre-auricular points. Electrode placements are labelled by a letter and a number. The letter refers to the lobe, for instance F, T, C, P, and O stand for frontal, temporal, central, parietal and occipital respectively. The number next to the letter stands for the recording site. Electrode sites on the left hemisphere have been assigned an odd number while the right even numbers. The smaller the number the closer the site is to the midline. Electrodes which are placed on the actual midline are assigned the letter ‘z’.

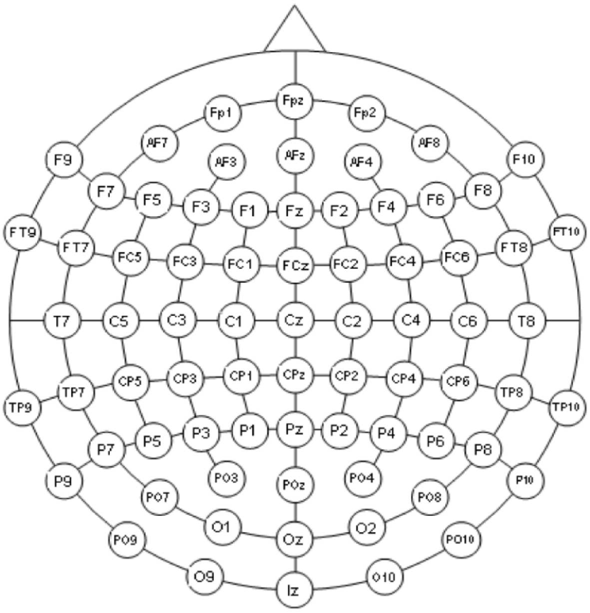


Figure 3-2. Names and places of electrodes.

The recorded EEG signal reflects spontaneous or event-related activities (Gui Chuansheng, Zhong-Lin, & Qi, 2010). Spontaneous EEG is associated with neural activity in the absence of any identifiable stimuli, whereas event-related activity EEG is mainly used to assess seizures and has been extensively used in social neuroscience research.

3.4.3. From EEG to ERPs

The changes in electrical variation in the scalp can be observed in specific time-windows, locked to a stimulus event and after averaging the brain’s activity to a series of stimuli presentations (Jones & Amodio, 2011). The aggregated brain activity which is consistently associated with the event of interest constitutes the event-related potential (ERP) (Coles & Rugg, 1995). ERPs record precisely the time (in ms) of electrophysiological activity at the scalp as a result of synchronous firing of several neural subpopulations (Hillyard & Picton, 1987; Luck, 2005).

The ERPs provide a variety of advantages as opposed to other neuroimaging methods regarding the investigations of sequences of cerebral events. The most important is the high temporal resolution which allows researchers to track information processing with millisecond precision, starting with the initial registration of a stimulus followed by the preparation and execution of a response (Coles & Rugg, 1995). The ERPs are components, theoretically associated with specific stimuli or thoughts. The amplitudes of ERPs tend to be low, ranging from less than a microvolt to several microvolts, compared to tens of microvolts for spontaneous EEG.

In order to extract time-locked information from EEG data, certain steps should be followed to minimise the effect of random or systematic artefacts (Rowan & Tolunsky, 2003). Artefacts vary from muscular tension to electrical interference from the surrounding environment which can be reduced by ensuring the participants are comfortably seated and that any unnecessary electrical equipment is switched off. Other types of artefacts include eye movement and eye blinks which could be removed whilst offline (i.e. not during the actual recording time) from the recorded data by applying specific filtering.

All experiments discussed in the thesis took place in a dim lit, experimental chamber as shown in Figure 3-3.

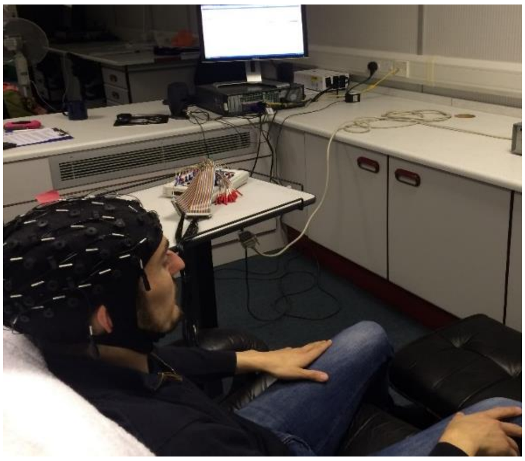


Figure 3-3. Laboratory set up for all studies in the thesis.

In the current thesis, acquisition in CURRY 7.09 was enhanced with tools of on-line data processing, with either 40 or 64 channels (Figure 3-4, 3.5). NuAmps amplifier was used for Study 2 (in Chapter 5) which is a 40-channel digital EEG amplifier of 22 bit sampling at 1000HZ, measuring signal from Direct Current (DC) to 260HZ. NuAmps is monopolar amplifier which produces real time scalp impedance measurements.

Figure 3-4. Nuamps 40-channel EEG/ERP Amplifier.

For study 3 and study 4, SynAmps 2/RT was used. SynAmps 2/RT is a 70-channel EEG/ERP amplifier, consisting of 64 monopolar, 4 bipolar and 2 high-level input channels (for receiving voltage outputs from other equipment) per headbox (Figure 3-5). Each channel has a dedicated 24 bit Analog to Digit (A-to-D) converter, allowing high signal fidelity with low gain and a broad dynamic range. Both amplifiers include a 12-bit trigger input port that synchronises external stimulator Stim2 system that is used for the purposes of the ERP measurements in studies in this thesis. Stim2 4.0 is Compumedics Neuroscan's stimulus presentation and experimental design system.

Figure 3-5. Synamps 2/RT 64-channel EEG/ERP.

3.5 EEG Data Pre-processing

In all the studies outlined in this thesis the CURRY 7 Neuroimaging Suite software has been used to acquire and analyse data (see Figure 3-6 for Analysis steps). Figure 3.6 outlines the analysis steps taken.

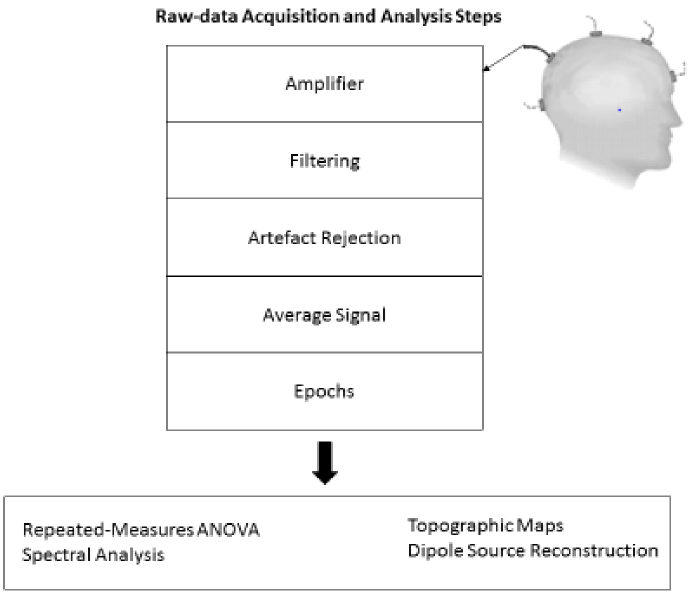


Figure 3-6. Schematic representation of EEG/ERP Analysis Process.

Prior to pre-processing, the data are viewed in the “Functional Data” window which displays the single sweep data file for each participant. Then the data pre-processing takes place including artefact removal, baseline correction, filtering, and event detection.

The first step is to specify the Reference Channel. The most commonly used reference channel is the <CAR>, Common Average Reference, which is required for source reconstruction (with EEG data). For EEG measurements it is typical to select the CAR. Then a method for handling data within bad blocks should be selected. At this stage, baseline correction option is used to remove a constant or linear DC offset from the data.

The bad block removal is done by defining a bad block within the data file. Once the bad block is defined there are several ways that could be treated. Either by taking no action and then the bad block will be excluded from epoching, by using the function constant in which flat lines (zero slope) connect the last data point before the bad block to the first data point after the block by using the Linear function in which Sloping lines will connect the last data point before the bad block to the first data point after the block or by using the function zero which will set the bad blocks to 0mVs (similar to Constant above, except that the flat lines with constant are not necessarily at 0mV).

There are different parameters which allow for control over the filter characteristics. In the bandpass filter, the user defined option allows users to select the desired cut offs and slopes. User defined sets the slopes automatically. Ripples and fast ripples select faster frequency bands to focus on high frequency oscillations that have been associated with epilepsy. Then a notch filter, centered at either 50Hz or 60Hz may be applied to attenuate line noise. A bandstop filter is the opposite of a Bandpass filter. Rather than passing frequencies between the high and low pass limits, the bandstop filter attenuates frequencies about a selected frequency (similar to a notch filter, but broader).

To reduce artefact reduction in the data there are five different methods that could be used: Bad Blocks, Threshold, QRS Detection and Event-Codes. The bad block method allows for rejection bad sections in the data file on the basis of a voltage threshold set to the lower and upper threshold of the monitored data from each channel. The threshold will scan for voltages in excess of the defined values and mark these values. QRS Detection is designed primarily for reduction of heart beat artefact.

Finally, the process of averaging could be performed using minimum and maximum voltage threshold criteria, frequency interval thresholds, or the signal to noise ratio (SNR) or noise estimates of each sweep as the criteria for accepting/rejecting the epochs. After epochs are averaged, time averaged data are extracted to be used for the statistical analysis.

3.6 Data Analysis

For all EEG studies in this thesis, a similar data analysis process was followed. First, EEG data were re-referenced to the common average. Then, baseline correction was done using the constant option. Following this, a bandpass filter was applied in the data using the User defined filter option as suggested from the manufacturers of CURRY 7. Ocular artefacts were corrected by excluding trials with any EEG artefacts exceeding ± 70 µV. After filtering, the EEG epochs were segmented typically from 200 ms pre-stimulus (serving as baseline) to 1000 ms post-stimulus and separate average waveforms were created for each condition time-locked to the stimuli of interest. Finally, separate average waveforms for each condition were generated time-locked to the stimuli of interest.

The extracted time averaged data for each component were exported to IBM SPSS Statistics for Windows (Version 20.0). Differences in the ERP amplitude values were analysed using a repeated-measures analysis of variance (ANOVA) separately for each ERP component. In this thesis, typically a 3-way ANOVA was performed in Chapters 5, 6 and 7. The within subject factors in each ANOVA were: cerebral hemisphere (left and right), sociality (social and non-social), and electrode location (depending on the electrodes of interest). The sample sizes used in studies 2, 3 and 4 were based on existing empirical studies in the decision-making research area (Proverbio, Zani, & Adorni, 2008; Proverbio et al., 2009; Tian et al., 2015; Zhang et al., 2012; Yeung & Sanfey, 2014) which have typically used 20-25 participants in their experiments.

3.7 Perceptual decision-making and stages of ERP processing in the current thesis

This section describes the stages of processing involved in perceptual decision-making and maps these into the ERP components identified in the literature as they relate to the stages of decision.

The EEG was used in the current thesis in Studies 2, 3 and 4 outlined in Chapters 5, 6 and 7 respectively, to directly examine the influence of social saliency on brain activity as reflected by the different interacting stages of information processing at four-time windows. The ERP components that will be examined in each of the studies of this thesis are: N1/P1, P2/FRN, P3 and LPP components. These components have been previously associated in the literature with the temporal dynamics of social and non-social stimuli (Hofel & Jacobsen, 2007; Jacobsen & Hofel, 2003; Proverbio et al., 2008; 2009).

Sensory processing

Two ERP components have been associated with sensory processing of information, the N1 and the P1. The N1 component is consistent with a negative deflection prominent over anterior part of the brain peaking in the occipital-temporal scalp regions (particularly on the right side) appearing around 120-200ms after stimulus onset. The P1 component is a positive deflection peaking in the posterior part of the brain appearing around 90-

150ms after stimulus presentation. These two components differ because P1 is a visual component modulated by the task whereas the N1 component is associated with visual registration (Luck, 2005; Griffin et al., 2002; Proverbio et al., 2008; 2009) and stimulus encoding (Jeffreys, 1996; Halgren et al., 2000; Liu et al., 2000; Rossion et al., 2003; Philiastides and Sajda, 2006a, b; Philiastides et al., 2006). Both of the sensory components (N1 and P1) have been associated with encoding of faces in visual perception tasks (Bentin et al., 1996; Eimer, 2000). Literature on decision-making has found differentiated processing for social and non-social stimuli during the sensory processing components with increased amplitudes for social scenes compared to non-social scenes (Luck, 2005; Griffin et al., 2002; Proverbio et al., 2008; 2009). Thus, these sensory components are of special interest to social behaviour because the increased amplitude for faces in the P1 and N1 conponents indicates the preferential processing of faces during the sensory stage.

This is consistent with evidence from affective priming tasks that found larger N1 and P1 amplitudes when faces were used as primes compared to when words were used as primes (Comesana et al., 2013). Studies have shown differential processing of pictures and words with face-primes inducing greater influence during the sensory components relative to word primes (Herbert et al., 2006; Liu et al., 2010; Zhang, Lawson, Guo, & Jiang, 2006). This finding might indicate that pictures may lead to a more direct access to meaning representations than word stimuli hence processed faster than words during the early sensory stages.

In the current thesis, sensory components will be examined in all studies as they relate specifically to processing of sensory information. More specifically, in Study 2 (Chapter 5) it is expected that social saliency would influence this stage with social pictures eliciting disproportionately larger (more negative) N1/P1 amplitudes than non-social pictures. However, as sensory ERP components have been associated more with processing of physical characteristics of stimuli such as faces (Bradley, Hamby, Low, & Lang, 2007), in Study 3 (Chapter 6) and in Study 4 (Chapter 7) there should not be an effect of social saliency on the sensory components as these studies involve words and feedback outcome as stimuli. This prediction is based on evidence suggesting that word primes and social presence elicit greater ERP amplitudes during the mid-range and late time windows mainly (Gibbons, 2009).

Attentional focus stage

A second processign stage, the attentional focus stage, includes two evidence-induced components typically occurring around 180 – 270ms, the N2 component, manifested as a P2 component as well. The P2 component is a positive ERP deflection, whereas the N2 is a negative ERP deflection, peaking at frontocentral electrode locations after stimulus onset (Polezzi, Lotto, Daume et al., 2008). The P2 and N2 components are attention-related potentials, believed to reflect an early assessment of outcomes (Rigoni et al., 2010). The amplitude of the P2 and N2 components has been associated with attention allocation (Carretié, Mercado, Tapia, & Hinojosa, 2001; Potts, Liotti, Tucker,

& Posner, 1996). These components have been argued to reflect attention capture and have been associated with affective significance of target stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Potts, 2004; Potts, Martin, Burton, & Montague, 2006; Jeffreys, 1996; Halgren et al., 2000; Liu et al., 2000; Rossion et al., 2003). The amplitude of N2/P2 ERP components has been associated with sensitivity towards social stimuli compared to non-social stimuli with greater attentional focus towards pictures featuring humans (Luck, 2005; Griffin et al., 2002; Proverbio et al., 2008; 2009). Therefore, it is expected that in Study 2 (Chapter 5), there would an effect of social saliency in the temporal dynamics of decision-making with larger N2 or P2 amplitudes for social stimuli compared to non-social stimuli.

In affective priming studies, word-primes do not affect the attentional focus components. Literature suggests that word primes elicit greater ERP amplitudes during the mid-range and late time windows mainly (Gibbons, 2009) possibly because word stimuli does not lead to a fast, direct access to meaning representations (de Houwer & Hermans, 1994; Kouider & Dehaene, 2007) as face-primes do. This evidence is supported by a recent study that compared priming effect from words and emoticons (Comesana et al., 2013). The study showed that attentional focus ERP components have been associated with the presentation of emoticons rather than emotional words (Comesana et al., 2013). These findings suggest that larger amplitudes at this processing stage for affective processing are specifically associated to the processing of human faces, but not of words. Therefore, in Study 3 (Chapter 6), word-primes are not expected to influence this stage of processing.

Another ERP component that is examined in the present thesis is the Feedback-Related Negativity (FRN) at the attentional focus stage. The FRN appears as a negative deflection in the ERP waveform following performance feedback, when it is given in a task, typically occurring between 200 - 300ms after feedback stimuli (Gruendler, Ullsperger, Huster, 2011) at frontocentral recording sites (Gehring & Willoughby, 2002; van Veen, Holroyd, Cohen, et al., 2004). The FRN has been associated with motivational relevance of feedback (Wu & Zhou, 2009), indicating that an ongoing evaluation of events and predictions of future events in terms of favourable or unfavourable outcomes is taking place (Rigoni et al., 2010).

Also, the FRN amplitude is associated with the degree to which the feedback was unexpected by the participant (i.e. not in line with their expectations based on their performance; Hajcak, Moser, Holroyd, & Simons, 2007). The FRN amplitude has been found enlarged in response to mainly negative and neutral feedback (Hewig, Trippe, & Hecht, et al., 2007; Holroyd, Nieuwenhuis, & Yeung, 2004; Holroyd, Hajcak, Larsen et al., 2006; Gehring & Willoughby, 2002; Goyer, Woldorff, & Hettel, 2008; Leng & Zhou, 2010; Nieuwenhuis et al., 2004; Villuendas- Gonzalez & Gonzalez-Gorriado, 2016; Yeung & Sanfey, 2004) and has been influenced by the sociality of the context (Hobson & Inzlicht, 2016; Simon et al., 2014). This component will be examined only in Study 4 as it is specifically related to performance monitoring and this is the only study in the thesis where feedback about performance is given to participants. In Study 4 it is expected that the FRN component will have higher amplitude mainly for negative and neutral feedback compared to positive feedback and that social saliency will influence the neural feedback monitoring.

Mid-range activity

An additional ERP component that is examined in this thesis is the P3 which appears as a positive-going inflection between 300 - 600ms after stimulus onset (Nieuwenhuis et al., 2005). It is a mid-range component, reflecting the allocation of attention (Benning, et al., 2016; Gray et al., 2004; Linden, 2005; Weinberg, Hilgard, Bartholow et al., 2012) and motivational/affective evaluation of stimuli and decision-making (Yeung & Sanfey, 2004; Nieuwenhuis et al., 2005). The P3 component is influenced by the available sensory evidence (Philiastides & Sajda, 2006b, 2007; Philiastides et al., 2006; Ratcliff et al., 2009) representing postsensory processing reflecting the quality of decision evidence. Hence, in both Study 2 and Study 3 it is expected that P3 amplitude will reflect motivational/affective evaluation of stimuli.

In relation to performance monitoring, P3 component amplitude varies with the magnitude of feedback outcome (Rigoni et al., 2010). The P3 amplitude variation is assumed to reflect more elaborate stimulus processing reflecting motivational saliency and context updating in working memory (Bellebaum & Daum, 2008; Nieuwenhuis, Aston-Jones, & Cohen, 2005). The P3 component has been found to be influenced by the valence of the feedback stimuli, with larger P3 amplitude in response to positive feedback (Hajcak et al., 2005, 2007; Wu & Zhou, 2009). Given that the P3 is widely believed to be related to high-level motivational/affective evaluation (Yeung & Sanfey, 2004; Nieuwenhuis et al., 2005), it is possible that more attentional resources (Gray et al et al., 2004; Linden, 2005) are devoted to outcomes that benefit the decision-maker (Qu et al., 2013). As noted in the previous section, considerable research has linked the P3 amplitude with evaluative categorisation and peak P3 latency has been associated with stimulus evaluation time (Amodio et al., 2014).

In performance monitoring studies, the P3 amplitude has been found to be at its maximum at the Pz electrode sites, whereas in priming and preference choice studies it is more active at a midline electrode (Hruby & Marsalek, 2003; Polich 1999). In the priming and performance monitoring studies, the P3 component was found bilaterally symmetrical (Smith et al. 1990). In this thesis, amplitudes in the P3 will be examined in all three studies because it is a widely used component in the decision literature. In all studies (Study 2, Study 3 and Study 4) it is expected that higher P3 amplitudes will reflect motivational/affective evaluation of social stimuli.

Late processing and decision-related activity

The late processing and decision-related stage involves a final ERP component: the Late Positive Potential (LPP) which occurs typically around 450 - 650ms after stimulus onset. The LPP component typically occurs near the participants' response (i.e. decision) and is enlarged for choices, possibly indicating commitment to a choice with different decision thresholds or confidence in the impending response (Domenech & Dreher, 2010). The LPP has been associated with prolonged attentional focus and evaluative processing of the stimuli (Benning, et al., 2016; Weinberg, Hilgard, Bartholow et al., 2012). It has been argued that the LPP reflects increased attentional resources, stimuli evaluation processes, activation of motivational brain systems by emotional stimuli, and the initial memory storage during the processing of affective information (Bradley & Lang, 2007; Briggs & Martin, 2009; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2004). A number of studies have implicated LPP with evaluation of stimuli reflecting increased attention to evaluative judgements (Cacioppo, Crites, Berntson, & Coles, 1993; Crites & Cacioppo, 1996; Crites, Cacioppo, Gardner, & Berntson, 1995; Ito et al., 1998; Ito & Cacioppo, 2000). A recent study using perceptual tasks (Blank et al., 2013) revealed that the amplitude of the late component was significantly predictive of subjects' choices than the sensory or attentional allocation components. This suggests that the late component is more likely to reflect decision-related processing.

Larger LPP amplitudes are likely to reflect top-down influences of attention and decision-related processing. In affective priming studies, LPP amplitudes have been associated with attentional orienting towards the priming stimuli as a function of higher level of cognitive processing including stimuli evaluation and selection (Campanella, Quinet, Bruyer, Crommelink, & Guerit, 2002; Lu et al., 2011). In affective priming literature, words seem to have an effect on late ERP components with studies showing modulations in late temporal windows (Comesana et al., 2013; Gibbons, 2009). This is perhaps due to the fact that word stimuli dos not lead to fast, direct access to meaning representations (de Houwer & Hermans, 1994; Kouider & Dehaene, 2007) as face-primes do (Gibbons, 2009). So, in Study 2 discrimination differences between social and non-social stimuli in the sensory components are expected to be found, in Study 3 that uses a priming task with words, it is expected to find prolonged attentional focus and greater evaluative processing of the stimuli during the mid-range and later components especially in association to the most motivationally salient word-prime category which potentially is social than non-social as seen in the literature (Benning, et al., 2016; Weinberg, Hilgard, Bartholow et al., 2012).

In performance monitoring studies, no differences have been observed during the late processing stage, therefore in Study 4 social saliency of the context is not expected to influence the temporal dynamics of decision-making and performance monitoring. As shown in the Introduction (outlined in Chapter 1), Figure 3-7 outlines the stages of decision-making process from the initial registration of the stimuli till the final decision.

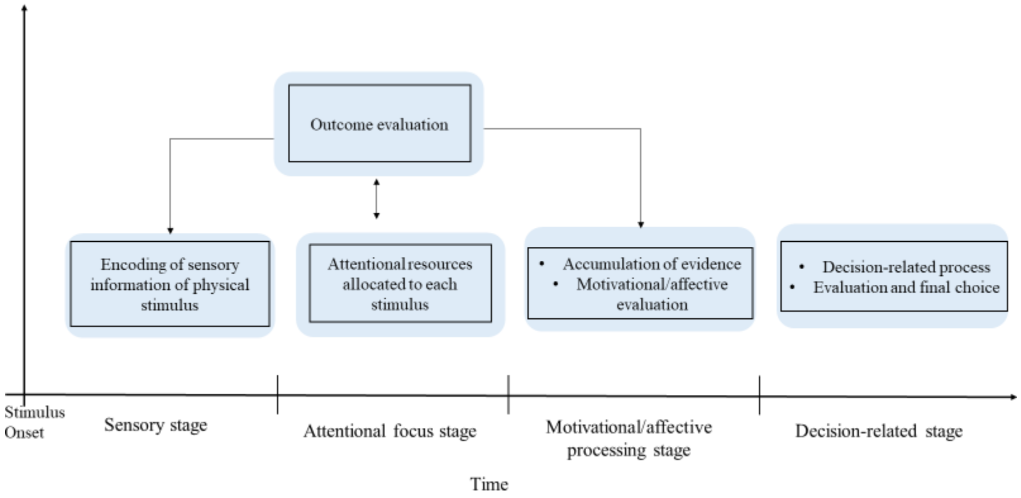


Figure 3-7. Schematic representation of stages of decision-making process from the initial registration of the stimuli till the final decision.

ERP Components in the current thesis

Therefore, for Study 2, the N1 component was measured between 120 – 200 ms following stimuli onset at the temporo–parietal (TP7/TP8) and parietal (P7/P8) electrode sites, the P2 component was measured between 210 – 270 ms following stimuli onset at the orbitofrontal (AF3/AF4), central (C3/C4), prefrontal lateral (FC3/FC4) and fronto–central (F3/F4) electrode sites, the P3 was measured between 400 - 600 ms following stimuli onset and the LPP was measured between 600 - 800 ms following stimuli onset at the mesial parietal (P3/P4) and lateral parietal (P7/P8) and central parietal (Pz, Cz, CP3/CP4) electrode locations (Foti & Hajcak, 2008; deFillipo & Grose-Fifer, 2016; Weinberg et al., 2012; Proverbio et al., 2009; 2008). The within subject factors in each ANOVA were: cerebral hemisphere (left and right), sociality (social and non-social), and electrode location (depending on the electrodes of interest). For Study 3, the P1 component was measured between 90 - 150 ms following prime onset at the occipital (O1/O2; OM), lateral-occipital (PO7/PO8; LO), occipito-parietal (P5/P6; OP) and parietal (P7/P8; OT) electrode locations, the N2 component was measured between 180 - 220 ms following prime onset at orbitofrontal (AF3/AF4; OBFL), central (C1/C2; CNT), and fronto–central (FC3/FC4; FC) electrode locations, the P3 component was measured between 350- 450 ms following prime onset at fronto-centro electrode locations (CPz, Pz, CP1/CP2, P3/P4, Fz, FCz, F1/F2, FC3/FC4) and the LPP component was measured between 500- 750 ms following prime onset at F1, F2, F3, F4, F5, F6, F7, F8, FC1, FC2, FC3, FC4, FCz, C1, C2, C3, C4, Cz, CP1, CP2, CP3, CP4, CP5, CP6, CP7, CP8, CPz electrode locations (Meconi et al., 2014; Nobre, Rao, & Chelazzi, 2006; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Foti & Hajcak, 2008). The within subject factors in the ANOVA for P1 and N2 were: cerebral hemisphere (left and right), sociality (social and non-social), valence category (negative and positive) and electrode location (depending on the electrodes of interest). The within subject factors in the ANOVA for P3 and LPP were: sociality (social and non-social) and valence category (negative and positive). For Study 4, P1 component was measured between 90 – 150 ms following feedback onset at the occipital (O1/O2; OM), lateral -occipital (PO7/PO8; LO), occipito-parietal (P5/P6; OP) and parietal (P7/P8; OT) electrode locations, the FRN was measured between 200 - 300 ms after feedback onset at Fz and Cz electrode locations, the P3 component was measured between 320 - 420 ms following feedback onset, at Pz electrode location and the LPP was measured between 500 - 750 ms following feedback onset at the mesial-parietal (P1/P2; MP) and lateral-parietal (P5/P6; LP) electrode locations (Cuthbert et al., 2000; Foti & Hajcak, 2008; Gehring & Willoughby, 2002; Goldstein, Cottone, Jia, et al., 2006; Hajcak et al., 2006; Hauser, Iannaccone, Stampfli, et al., 2014; Tian et al., 2015; Yeung, Holroyd, & Cohen, 2005). The within-subject factors in each ANOVA for all the components were: sociality (social and non-social), feedback valence (negative, positive and neutral) and electrode location (depending on the electrodes of interest). A potential confound of the analysis is that the mean amplitudes of the FRN component might be affected by the subsequent P3 signal. To account for this issue and to further illustrate the findings, difference waves were calcuated (ΔFRN component, well known in the literature as loss-minus-gain). A new variable was created by subtracting the positive feedback from the negative feedback signal for different social conditions and peak values of the difference waves in the 200-300 ms time window as measures of the FRN effect (Cohen & Ranganath, 2007; Hajcak, Moser, Yeung, & Simons et al., 2005; Hajcak, Moser, & Holroyd, 2007; Leng & Zhou, 2009). A repeated measures ANOVA with within subject factors: sociality (social and non-social) and electrode locations (Fz and Cz) was conducted on this measure.

Chapter 4. Study 1: The neural representation of social and non-social decision-making: A Systematic Review

4.1 Introduction

This chapter outlines a systematic review of existing literature that directly compares the neural underpinning of social and non-social decisions. In this thesis, social decision-making is given a broader term and is defined as both decisions made in a social context (i.e social presence, implied social presence, with another person – cooperation and competition) and those made under social influence (i.e. priming). Whereas, non-social decision-making is defined as those decisions not made in a social context or under social influence. The review aims to synthesise existing neurophysiological evidence that directly compares the neural basis of social and non-social decision-making involving all neuroimaging paradigms and task designs to examine patterns in brain correlates and temporal dynamics relating to social saliency and establish gaps in the literature to indicate directions for future research.

4.2 Background

As discussed in Chapter 2, there is an increasing number of studies examining the relationship between different types of decision-making in complex or interactive tasks, but only a few studies have explored the effect of social saliency on the temporal dynamics of simple perceptual decision-making tasks. There is a need for a systematic review of the literature that synthesises neurophysiological evidence from extant literature that directly compares the neural underpinnings of social and non-social decision-making because there is vast complexity and diversity in the tasks used (i.e. interactive, non-interactive) and in the experimental manipulations (i.e. rewards, social presence, affective processing, theory of mind, social cognition) employed in that literature.

As it is often the case with emerging literature, there is a lack of reviews that combine existing results and offer an interpretation based on current findings to map new avenues. There are currently a few meta-analyses that have contrasted social and non-social decision-making, but these have focused only on existing fMRI findings that provide evidence on how reward-related activity is influenced by the nature of rewards used (Levy & Glimcher, 2012; Sescouse, Caldu, Sergura & Dreher, 2013) or on the neurodevelopmental literature on reward processing specifically (Richards, Plate, Ernst, 2013). Therefore, there is a need for a systematic review that would synthesise findings across studies with diverse stimuli, task type and neuroscientific techniques.

It is important to include studies that have manipulated social saliency using reward, stimuli and social presence in order to outline differences between social and non-social decisions. Also, it is important to include studies that used tasks that involve both overt decisions and without overt decisions (i.e. passive viewing). This is crucial because a mapping of that literature will enable differences between social and non-social decision-making that are task-dependent to be highlighted. Finally, it is crucial that the systematic review synthesises findings across different methodologies (i.e. fMRI and EEG) to investigate the neural basis of social and non-social decision-making. This is important because studies that have employed fMRI provide information about the brain areas active during decision-making whereas EEG studies are informative about the temporal nature of the discrete decision processing stages. However, there has been no attempt in the literature to synthesise or collate these findings. This chapter aims to fill this gap in the literature by conducting a systematic literature review of existing empirical studies that have directly compared social and non-social decision-making and provide a synthesis of the extant findings and current knowledge in this area.

Although social decision-making is a complex process, in this review, it is argued that if decisions are broken down into different processes and constitutes, based on task, social saliency manipulation, one can identify different locations, and temporal stages of decision-making and establish some of the factors that may moderate the decision process. In this review, the extant empirical studies will be grouped based on the the task type used, the way that social saliency was manipulated (i.e stimuli type, reward-type and social presence) and the differences in the experimental designs, to examine potential differences and similarities between the findings of empirical studies.

4.3 The current study

This review systematically examines studies that have directly compared the neural mechanisms underlying social and non-social decision-making. Given the complexities and controversies in the literature, this review examines this literature systematically along five dimensions which might influence neural processing of decision-making: (1) task type, (2) social saliency manipulation a) stimuli type, b) reward-type (i.e. use of reward and if so, type of reward), c) the effect of social presence, (3) differences in experimental design (i.e. type of analysis) (4) evidence from ERP and fMRI neurophysiological techniques (i.e. brain areas active or temporal window), and (5) gender and age.

The review examines both fMRI and EEG/ERP studies to provide an overview of the human neuroimaging literature in this research area rather than focus on one specific methodology with an acknowledgement that they are equally informative: the former is more informative about the spatial aspects of decision-making and the latter is more informative about the temporal dynamics of decision-making. The systematic review provides insights in relation to the neural mechanisms involved in social and non-social decision-making, by synthesising neurophysiological findings from studies that manipulate social saliency in different ways involving all neuroimaging paradigms and task designs to explore differences/similarities in the brain correlates and temporal dynamics of social and non-social decision-making.

4.4 Method

The systematic review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, Altman, et al., 2009; Appendix 1).

Search Strategy

The literature search was conducted using PubMed and Scopus databases (from January 2000 to March 2016). Only studies published since

2000 were included, as an initial scoping search did not reveal any social and non-social decision-making research prior to this date.

Key words referring to the type of reward (i.e. (“money” OR “monetary” OR “financial”) AND stimuli (i.e. (“social” OR “non-social”) were used in order to identify neuroimaging and electrophysiology studies published in peer-reviewed journals which directly contrasted social and non-social decision-making. Hand searching was also conducted using existing narrative reviews and through the reference lists of retrieved articles.

Selection of Studies

Predetermined inclusion criteria for identified studies included: (1) peer-reviewed publications, (2) publications in English, (3) original research, and (4) research examining the association of the neural basis of social and non-social decision-making. Exclusion criteria included clinical populations as a sample and experimental designs that did not allow for direct comparison of social and non-social decision-making. Full inclusion and exclusion criteria are detailed in Table 4-1. For the purposes of this review, social decision-making is given a broader term and is defined as both decisions made in a social context (i.e social presence, implied social presence, with another person – cooperation and competition) and those made under social influence (i.e. priming). Whereas, non-social decision-making is defined as those decisions not made in a social context or under social influence. All studies that compared some sort of social and non-social decision were included independent of the task used. Studies that compared social to non-social stimuli using passive viewing tasks were also included in the review in order to explore potential contributions of task type in the decision process. There were no restrictions made regarding the methodological approaches of the studies.

Table 4-1. Screening/selection tool.

Criteria of Selection	**Include**	**Exclude**
Population	Humans Adults Healthy population	Animals Children Adolescents Clinical/Psychiatric Population Forensic Population
Tasks- Social	Social task	Only non-social decision-making tasks
Tasks -Non-social	Monetary tasks Gambling tasks	N/A
Design	Empirical studies	Literature Review Meta-analyses
Technique	fMRI EEG/ERP PET	Behavioural measures Computational Analysis
Source	Peer reviewed journal	Dissertations Conference reports Unpublished results Book Chapters
Language	Written in English	Any other language
Year	Jan 2000- Octo 2015	Before 2000 or after 2015

Following completion of the screening process, data were then extracted from selected articles by the author of the thesis using a predesigned data extraction form. To avoid any biases a reviewer (Director of Studies) also performed the screening and review process. Any discrepancies or disagreements were resolved through discussion between the two authors.

Data extracted from each of the studies included: brain imaging technique used, year of publication, demographic information (age and gender of participants), sample size, task type, social saliency manipulation (i.e. stimulus type, reward type, social presence), whether the data collection took place in the same day, fMRI contrast, type of analysis, whether the study examined individual differences, and key findings in relation to brain regions and temporal dynamics engaged during social and non-social decision-making.

Quality Assessment

A quality assessment tool for fMRI studies (Garrigan et al., 2016) was used which has a binary scale (1 = evidence reported, 0 = no evidence reported/unclear/not explicit; Appendix 2a). Papers with scores 0-10 were classed as low quality, 11-20 classed as medium quality and 21-30 classed as high quality. The assessment tool was adapted based on guidelines from previous studies (Poldrack et al., 2008) to assess and rank the quality of EEG studies (Appendix 2b). A binary scale (1 = evidence reported, 0 = no evidence reported/unclear/not explicit) was used to report the quality of each paper. Scores between 0-8 were classed as low quality, 9-16 classed as medium quality and 17-25 classed as high quality. Studies were reviewed by one person and then a sample was reviewed by a second person. The first reviewer (author of the thesis) performed quality assessment for all included studies and the second reviewer (Director of Studies) performed quality assessment on 20% of included papers independently.

4.5 Results

4.5.1 Data Extraction

The database searches identified 602 articles (Figure 4.1). Hand-searching (using existing narrative reviews and through the reference lists of retrieved articles) resulted in the inclusion of a further 15 articles. Of the 617 articles initially obtained, 57 were removed because of duplication. Following screening independently by the two authors on title and abstract 530 were excluded as not meeting the inclusion criteria. The full text of each article was then screened by each of the two authors independently to ensure that it fulfilled the specific selection criteria. After reviewing the full text of the remaining 30 studies, 4 studies were excluded because they did not directly compare the two types of decisions and due to limited analysis, that did not allow for comparison of the decision-making process. Figure 4-1 presents a flow chart with the reviewed studies.

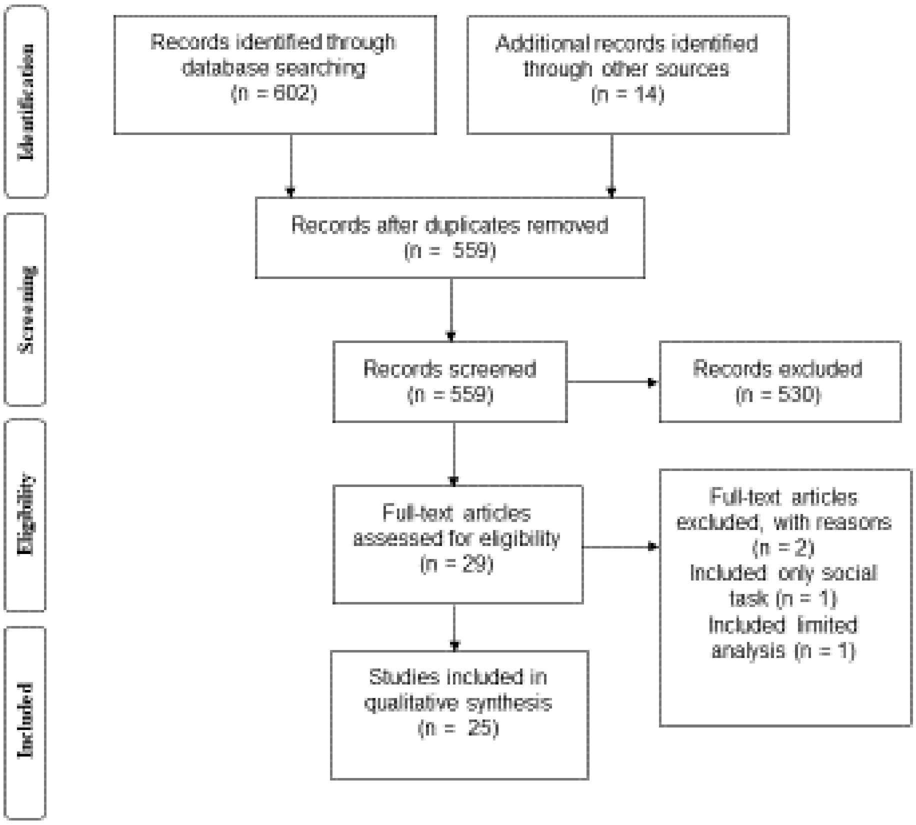


Figure 4-1. Flow chart of reviewed studies.

4.5.2 Description of Studies – Reasons for inclusion

Based on the selection criteria set at the beginning of the systematic review, 26 papers all reporting primary data (a list of papers can be found at Appendix 3) were selected to be included for review. A summary description of the studies is provided in Table 4-2.

Table 4-2. Description of the included studies.

Description of Studies		
Technique	fMRI (N = 20)	EEG/ERP (N = 5)
Data Collection	Same Day (N = 22)	2-days (N = 3)
Sample Size	Range 6 – 36 participants	
Design	Block	Event-related potential
fMRI Contrast	social > non-social (N = 9)	Other contrasts (N = 11)
Task Structure	Identical (N = 5)	Different (N = 15)
Individual Differences	Examined in 3 studies out of 25	

All the included studies explored directly, using fMRI or EEG, the neural basis or temporal dynamics of social and non-social decision-making in healthy adults. The included studies manipulated social saliency in a range of tasks involving decision-making (social vs. non-social decisions) including perceptual decisions (Heekeren et al., 2005; Philiastides et al., 2006; Proverbio et al., 2009; Pegors et al., 2013; Zeng et al., 2012), theory of mind (Janowski et al., 2013; Saxe et al., 2008; Mitchell, 2008), charity donations (Izuma et al., 2010; Moll et al., 2006; Harbaugh et al.,2007), decision-making in front of other people (Nawa et al., 2008; Zink et al., 2008), learning (Behrens et al., 2008; Lin et al., 2012), incentive delay (Flores et al., 2015; Hausler et al., 2013; Sescousse et al., 2010; Spreckelmeyer et al., 2009; Rademacher et al., 2010, 2014) and gambling (Rigoni et al., 2010; Izuma et al., 2008). A manipulation of social saliency using rewards was conducted in a total of 20 studies whereas only six studies did not use rewards. The majority of the studies used fMRI (n = 21) compared to only five studies that used EEG/ERP.

No studies using MEG, TMS or near-infrared spectroscopy (NIRS) were identified. In the majority of the studies, data collection for social and non-social decision-making took place in one session (n = 22), but there were a few studies where data for each decision type was collected on separate days (n = 3, i.e. Izuma et al., 2008; Janowski et al., 2013; Zink et al., 2008). The studies also varied between group size used (ranging from 6 participants to 36 participants). Only a limited number of studies used identical task structures for the social and non-social decisions (n = 8; Flores et al., 2015; Heekeren et al., 2004; Izuma et al., 2008; Pegors et al., 2015; Philiastides et al., 2006; Proverbio et al., 2006; Rigoni et al., 2010; Zeng et al., 2012). Therefore, all neuroimaging and electrophysiological studies, independent of the social saliency manipulation were included in this review as they are informative to the discussion of the neural differences between social and non-social decision-making. The findings from each paper are summarised in Table 4-3 and Table 4-4 in terms of the five dimensions [1] and selection criteria.

Table 4-3 presents a summary of the selected 20 fMRI studies. Table 4-4 illustrates the selected 5 EEG studies. The studies have used diverse tasks, manipulated social saliency in a variety of ways in the task used. Next sections of this review will outline differences in the included studies' patterns based on task structure, social saliency manipulation and experimental design.

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[1] (1) task type, (2) social saliency manipulation a) stimuli type, b) reward-type (i.e. use of reward and if so, type of reward), c) the effect of social presence, (3) differences in experimental design (i.e. type of analysis) (4) evidence from ERP and fMRI neurophysiological techniques (i.e. brain areas active or temporal window), and (5) gender and age.

Table 4-3. fMRI studies that directly compare social and non-social decision-making.

					Manipulation of social saliency						
Author	**Date**	**N (M:F)**	**Mage**	**Task Type**	**Stimuli**	**Reward** (NR = no reward)	**Social Presence**	**Contrast**	**Analysis** (ROI/WB)	**Common Activation**	**Effect of Social Saliency**
Rilling, et al.	2002	19(0:19)	28.8	Prisoner's dilemma Game	Game matrix	Money	✓ ***	Human > computer		vmOFC	avSTR, rACC
		17(0:17)	23.8								
Saxe et al.	2003	25(13:12)		Theory of Mind	Stories	NR	-	TofM>Non-TofM	ROI		TPJ-M, anterior superior temporal sulcus, precuneus, medial superior frontal gyrus
(two expts)		21(10:11)									
Heekeren et al.	2004	12(6:6)	31.1	Discrimination	Face	NR	-	-	ROI	dlPFC	Face-selective clusters in dlPFC
					House						
Moll et al.	2006	19(10:9)	28.2	Donation	Charity description	Altruism	-	Self> Other		-	VTA, vSTR, subgenual area, l_OFC
						Money					
Harbaugh	2007	19(0:19)		Dictator Game	Cells with values	Mandatory Voluntary giving Money	-	Mandatory payoff>charity		VS	Caudate, R nucleus accumbens, insula
Behrens, et al.	2008	24(14:10)	29	Reinforcement learning	Rectangles	Points	✓	Related to learning type	WB	vmPFC, VS	ACCs: experience based learning
											ACCg: social learning

Izuma, et al.	2008	19(9:10)	21.6	Gambling	Betting card Picture of self, desirability rating	Social Approval Money	-	Social > non-social	ROI	caudate nucleus striatum, putamen, cerebellum, thalamus	mPFC
Mitchell et al.	2008	20(9:11)	23	Theory of Mind Attention cueing	Stories	NR	-	valid > invalidBeliefs > photograph		TPJ	-
Nawa et al.	2008	19(10:9)	21.6	Gambling	Card	Money	✓ *	social vs non-social	ROI		Right, left AMY
Zink et al.	2008	24(12:12)	27.6	Visual discrimination task	Circle (colour changing) square (no. of dots)	Money	✓ *****	Superior ranking > inferior ranking	WB	Occipital/parietal, VS	dlPFC
Experiment 1										Parahippocampal cortex	
Experiment 2		24(12:12)	25.7								
Spreckelmeyer, et al.	2009	32(16:16)	29.0 (M) 28.8 (F)	Incentive Delay	White target square	Money Positive social feedback	-	reward magnitude	WB	Nacc, putamen, TH, precuneus	Gender difference – anticipation = more activation to social, males more activation to money

Hare et al.	2010	22 (0:22)	24.7	Donation	Charity image	Altruism		Social > non-social	ROI		vMPFC, anterior insular (increased activation)
Izuma, et al.	2010	23(11:12)	22.7	Donation	Charity description	Social Approval	✓	Presence > absence	ROI	v_STR	
						Money					
Rademacher, et al.	2010	28(13:15)	29.5 (M)	Incentive Delay	White target square	Money	-	Anticipation > consumption	WB/ROI	Anticipation: caudate, putamen, NAcc, v_STR	Social reward consumption: AMY
			27.2 (F)			Social feedback					
Sescousse, et al.	2010	18(18:0)	24	Incentive delay (visual discrimination)	Triangle or square	Money	-	Money> Erotic pics	WB	VS, ACC, aINS, midbrain	plOFC, AMY
						Erotic pictures					
Smith, et al.	2010	23(23:0)	21.8	Multimodal reward	Money, faces	Money	-	Monetary gain > loss	WB/ROI	a_vmPFC	fusiform face area and lateral occipital cortex
				(passive view)		Attractive faces				r_p_vmPFC	
Lin, et al.	2012	25(0:25)	22.4	Economic exchange Instrumental learning	Slot machines	Faces	-	-		vmPFC	-
						Money					
Janowski, et al.	2013	32(32:0)	22.8	Empathetic choice	Purchase decisions	Monetary	✓	self > other.		vmPFC	IPL, Stronger functional connectivity = IPL > vmPFC
						Altruism					
Hausler et al.	2015	33(33:0)	24.39	Monetary	Boxes	Money	-	Soccer>monetary		Reception:	-

				incentive				Monetary soccer		vmPFC, V_STR, PCC, dlPFC, vlPFC Prediction: VS	
Rademacher et al.	2014	14(12:12)	23.4	Incentive Delay	White target square	Money Social Feedback	-	Scenes>objects Social>monetary	WB	vSTR TH, anterior cingulate	Nacc
Pegors et al.	2015	28(14:14)	22.5	Preference choice	Face	NR	-	Faces > objects	ROI/WB	vmPFC	fusiform gyrus, rIPS
					Place			Scenes > objects			Face responsive clusters in vmPFC and rlatOFC

* Note: there was an outside of the fMRI subject. In the social trials, subjects initially made independent bets then cooperative bet. In the non-social trials, only the inside the fMRI scanner subject made a bet.

the protocol was manipulated so that the participant received advice from the confederate in all trials but could choose to follow advice (social learning) or learn from experience (non-social learning)

*** In experiment 1, two sessions were played with a human and one with a preprogrammed computer. In experiment 2, all 3 sessions were played with a preprogrammed computer without the knowledge of the subject.

***** Either with another player or with a photograph representation

~ People that relied on other person’s advice activated more the ACCg while people that relied more on their own personal experience activated more the ACCs. + In this study the empirical data for the social task was data from previous studies using non-social tasks (decisions about food items)

Table 4-4. EEG/ERP studies that compare social and non-social decision-making.

					Manipulation of social saliency						
Author	**Date**	**N (M:F)**	**Range/Mage (where reported)**	**Task type**	**Stimuli**	**Reward**	**Social presence**	**Early sensory processing**	**Attentional focus**	**Mid-range stage**	**Late processing**
Philiastides et al. **	2006	6(3:3)	21-37	Discrimination	Face Car	NR	-	Sensitive to social stimuli	-	Similar to both social and non-social stimuli	-
Proverbio et al.	2009	24(12:12)	19-38	Passive viewing	Face Urban scenes	NR	-	Sensitive to social stimuli	Sensitive to social stimuli	-	Sensitive to social stimuli
Rigoni et al.	2010	36(12:24)	18-26	Gambling	Images of balloons either neutral (non-social), comparison and competition (social)	Money	-	No difference	larger for gains than losses in the neutral (alone) condition than in the social context conditions	-	-
Zeng et al.	2012	18(0:18)	19-23/21.1	Visual Preference choice	Images of women Money	Money	-	-		-	Sensitive to social stimuli
Flores et al.	2015	23(10:13)	18-25/22	Incentive Delay	Faces Coins	Money Social feedback	-	Sensitive to social task	-	P3 main effect of task type = larger for non-reward vs reward – monetary, larger for reward vs non-reward – social	-

** Note: only single trial analysis was used. Results replicate current findings in ERP literature.

4.5.3 Quality Assessment

Table 4-5 and Table 4-6 provide the scores for the fMRI and EEG articles in terms of the quality measurement of the included studies. Quality assessment indicated that 24 articles were high quality, 2 was medium quality and none were low quality. The medium quality experiments did not report detailed information regarding the subjects and analysis procedures compared to the high-quality articles. It should be noted that the analysis was based on all articles independent of quality but issues regarding the quality of included articles are outlined in the discussion and should be taken into consideration when interpreting the findings. Cohen's K was run to determine the agreement between reviewers. Agreement between the two reviewers was substantial, k = .736, $p < .001$.

Table 4-5. Quality Score of included fMRI papers.

Author	**Year**	**Experimental design (/2)**	**Task specification (/2)**	**Subjects (/6)**	**Data acquisition (/5)**	**Data pre-processing (/5)**	**Analysis (/7)**	**Tables (/3)**	**Total (/30)**	**Descriptive category**
Rilling, et al.	2002	2	2	4	5	5	7	3	28	High Quality
Saxe et al.	2003	2	2	4	3	2	3	3	19	Medium Quality
Heekeren et al.	2004	2	2	4	5	4	6	6	29	High Quality
Moll et al.	2006	2	2	4	5	5	7	3	28	High Quality
Harbaugh et al.	2007	2	2	4	5	5	7	3	28	High Quality
Behrens, et al.	2008	2	2	4	5	5	6	3	27	High Quality
Izuma, et al.	2008	2	2	5	5	5	5	3	27	High Quality
Mitchell et al.	2008	2	2	5	5	5	7	3	29	High Quality
Nawa et al.	2008	2	2	4	5	5	7	3	28	High Quality
Zink et al.	2008	2	2	5	5	5	7	3	29	High Quality
Spreckelmeyer, et al.	2009	2	2	5	5	5	7	3	29	High Quality
Hare et al.	2010	2	2	5	5	5	4	0	23	High Quality
Izuma, et al.	2010	2	2	4	5	5	6	3	27	High Quality
Rademacher, et al.	2010	2	2	5	5	5	7	3	29	High Quality
Sescousse, et al.	2010	2	2	5	4	4	6	3	27	High Quality
Smith, et al.	2010	2	2	4	5	5	6	0	24	High Quality
Lin, et al.	2012	2	2	5	5	5	6	3	28	High Quality
Janowski, et al.	2013	2	2	5	5	5	6	3	28	High Quality
Rademacher, et al.	2014	2	2	6	5	5	7	3	30	High Quality
Hausler et al.	2015	2	2	5	5	4	6	3	27	High Quality
Pegors et al.	2015	2	2	4	5	5	7	3	28	High Quality

Table 4-6. Quality Score of included EEG papers.

Author	**Year**	**Experimental design (/2)**	**Task specification (/2)**	**Subjects (/6)**	**Data acquisition (/5)**	**Data pre-processing (/4)**	**Analysis (/5)**	**Total (/24)**	**Descriptive category**
Philiastides et al.	2006	2	2	3	3	3	4	17	High Quality
Proverbio et al.	2009	2	2	6	3	4	5	22	High Quality
Rigoni et al.	2010	2	2	2	2	2	4	14	Medium Quality
Zeng et al.	2012	2	2	6	4	4	5	23	High Quality
Flores et al.	2015	2	2	4	5	4	5	22	High Quality

Task type

The tasks used in the included studies varied significantly in the decision type and included, incentive delay, donation, gambling and discrimination tasks. Studies that used cooperation/competition tasks included the presence of another individual. The influence of social saliency on the task type is explored below.

Studies that employed the *incentive delay task* required participants to react to a target stimulus presented after an incentive cue to win or to avoid losing the indicated reward. These studies find brain activity in amygdala, insula and prefrontal cortex (Rademacher et al., 2010; Sescousse et al., 2010; Spreckelmeyer et al., 2009) for social stimuli, whereas, activation in the ACC and ventral striatum for both social and non-social stimuli. Studies that employ *the donation task* found that the prefrontal cortex, insula, VTA and subgenual brain area were more sensitive to social stimuli and whereas ventral striatum area was active for both types of stimuli (Izuma et al., 2010; Hare et al., 2010; Moll et al., 2006).

Studies that used *gambling tasks* participants are given a set of different options and an endowment of fake money and are instructed to try to lose the least amount of money and win the most. These studies find that bilateral amygdala and prefrontal cortex were more sensitive to social stimuli and caudate nucleus, striatum, putamen, cerebellum and thalamus brain areas were active for both types of stimuli (Nawa et al., 2008; Izuma et al., 2008). Whereas studies that used *discrimination task* required participants to select a target stimuli amongst non-targets. These studies find that face-selective clusters in dlPFC encoded social stimuli whereas a set of brain areas including, prefrontal cortex, occipital/parietal, parahippocampal cortex and ventral striatum were sensitive to both social and non-social stimuli (Heekeren et al., 2004; Zink et al., 2008).

Across all studies, despite the task differences, the ventral striatum is activated for both social and non-social stimuli indicating that it is active regardless of the task type whereas, activity in brain regions of the prefrontal cortex and the insula is higher for social stimuli activation indicating that are sensitive towards socially-related tasks only.

Manipulation of Social Saliency

Social saliency was manipulated in included studies in diverse ways using a range of stimuli, rewards and by exploring the effect of social presence (i.e. familiarity and social engagement) in order to explore differences/similarities between social and non-social decisions.

Stimuli type

Studies varied the type of stimuli used; some studies compared social to non-social rewards (e.g. money vs. social approval, money vs. positive social feedback, money vs. erotic pictures, money vs. altruistic giving) while others compared social to non-social stimuli (cars vs. faces, urban scenes vs faces). In some studies, social presence was manipulated (n= 5). The effect of stimuli type will be explored below by contrasting findings from studies that explored the contribution of reward to studies that did not involve rewards, but instead manipulated the social saliency of stimuli or by outlining the effects of social presence.

Reward type- Comparison between studies with rewards and non-rewards tasks

A total of ten studies compared social to monetary rewards. Rewards used in the selected studies in this review span from social interactions with specific “others”, vicarious decision-making and learning to influences of abstract social principles on valuation and behavior. In studies using monetary rewards, the amount of money given is based on player’s performance or divided amongst players. In studies using social rewards, such as positive feedback (Rademacher et al., 2010; 2014; Spreckelmeyer et al., 2009), smiley faces or social approval comments (Izuma et al., 2008; 2010), the rewards are either given in full as a positive reaction/feedback or not given at all.

Results of these studies show common activation for both social and monetary rewards in the ACC, putamen, thalamus, precuneus, anterior insula, vmPFC, and striatum (Izuma et al., 2008; 2010; Janowski et al., 2013; Lin et al., 2012; Moll et al., 2006; Rademacher et al., 2010; 2014; Sescousse et al. 2010; Smith et al, 2010; Spreckelmeyer et al., 2009), areas which are typically associated with reward processing. But a different set of brain areas was found active only for social rewards, including the VTA, IPL, amygdala and face-selective clusters in the frontal lobe.

In contrast, studies that did not involve reward compared social to non-social task stimuli (i.e. faces vs. houses) and reported activation for both stimuli in dlPFC, vmPFC and TPJ brain areas (Saxe et al., 2003; Heekeren et al., 2004; Mitchell et al., 2008; Pegors et al., 2015). Activation for social stimuli only, when tasks did not involve rewards, was found in fusiform area, precuneus, STS, lateral occipital cortex and face clusters of PFC (Saxe et al., 2003; Heekeren et al., 2004; Mitchell et al., 2014; Pegors et al., 2015; Smith et al., 2010).

Across studies that used rewards and those that did not use reward to examine neural differences in decisions made in social and non-social domains, the vmPFC region was found active regardless of whether a reward was present, indicating that this brain area may play an important role in decision-making for all types of decisions, regardless of whether a reward is expected or not. The brain areas reported for social decisions in tasks with rewards differ from the ones active for social decision in tasks without rewards which indicates that reward processing takes place in a set of specific brain areas. This finding supports previous literature that had shown that vmPFC is implicated in the brain's reward system (Kohls et al., 2013; O'Doherty et al., 2006; Barta et al., 2013)

Social Presence: familiarity, inferring mental states and social engagement

Seven studies examined the effect of social presence either in the form of an unfamiliar observer or the use of tasks involving cooperation and competition with another person.

Familiarity

Studies (N = 6) that examined neural differences in the presence of an unfamiliar observer (social condition) compared to completing the task independently (non-social condition) have found greater activation in vmPFC vmOFC, ACC, ventral striatum and parahippocampal cortex for both social and non-social conditions, while greater activation in the IPL, dlPFC, bilateral amygdala, TPJ, anterior STS, medial superior frontal gyrus for the social condition only (Behrens et al., 2008; Janowski et al., 2013; Nawa et al., 2008; Rilling et al., 2002; Saxe et al., 2003; Zink et al., 2008).

Specifically, studies that manipulated the familiarity of social presence have either used passive viewing tasks or purchase decisions. The studies that used passive viewing tasks contrasted brain activation while participants were observed by an unfamiliar person and while playing alone and found dlPFC and bilateral amygdala activation for the social condition (Nawa et al., 2008; Zink et al., 2008). Studies that used purchase decisions found activation at IPL region in response to social processes such as empathy in contrast to self-oriented decisions (Janowski et al., 2013). Studies that used tasks that manipulated the influence of inferring another person’s mental states in response to stories describing or implying a character’s goals and beliefs (social condition) and stories about non-human objects (non-social condition) found greater TPJ-M activity in the social condition (Saxe et al., 2003). This finding confirms that the TPJ-M brain area is specfically involved in theory of mind (Deen, Kildewyn, Kanwisher & Saxe, 2015; Izard, 2009; Saxe & Baron-Cohen, 2006).

Across the studies that manipulated familiarity of social presence, certain regions at the prefrontal cortext were found active for both social and non-social conditions including, vmPFC and dlPFC.

Social engagement: observation, competition, collaboration

Four studies examined social exchange by manipulating social observation, competition and collaboration. The fMRI studies that explored brain activation when participants played in cooperation with another player (social condition) and when playing independently (non-social condition) show increased activation in the ventral striatum and OFC for the social condition only (Rilling et al., 2002). When participants performed simple tasks in collaboration with participants that were not physically present, dlPFC, amygdala, thalamus and mPFC were found active only in the social condition (Zink et al., 2008), whereas activity in the occipital/parietal cortex, ventral striatum and parahippocampal areas was reported in both conditions.

Studies that examined differences between associative learning from a human (social condition) and from a non-human source (non-social condition) found that ACCg is active in social condition whereas ACCs is active in non-social condition and ventral striatum was found active for both types of learning (Behrens et al., 2008). The vmPFC was shown to be active in response to the decision-making process. Across all studies that manipulated social presence, the ventral striatum the vmPFC and the dlPFC were found active independent of the manipulation.

Experimental Design: Evidence from neurophysiological techniques

ERP

Five studies examined the temporal dynamics of decision-making in social and non-social domains. The temporal dynamics of social and non-social stimuli were explored in the included studies using tasks that varied significantly including, discrimination, perception, gambling, visual preference choice and incentive delay tasks and differences were found in the ERP amplitudes.

Studies that used discrimination task between social (faces) and non-social (car) images found that N1/P1 components are more sensitive to social compared to non-social stimuli whereas P3 amplitudes were larger for both types of stimuli (Philiastides et al., 2006). When participants completed a passive perception task of social (faces) and non-social stimuli (urban scenes) P1, N2/P2 and LPP components were found active for faces (social) rather than urban scenes (non-social stimuli) (Proverbio et al., 2009). In a study that used a gambling task in which participants receiving outcomes in neutral, comparison and competition conditions the P1/N2 component was sensitive to non-social condition (i.e. alone condition) compared to social condition, whereas no differences were found in the P3 stage (Rigoni et al., 2010).

When participants were asked to make visual preference choices between images of attractive females (social) and money (non-social), social images elicited larger amplitudes during the attentional focus (P2) and the late processing stage (LPP) compared to non-social images (Zheng et al., 2012). In a study that used incentive delay task, participants completed the task in the social condition (social approval) and non-social condition (monetary feedback conditions) and found that N1/P1 is sensitive to social condition whereas P2/N2, FRN and P3 components were enlarged for the non-social compared to social condition (Flores et al., 2015). Taken together, task variability influences the decision process with sensory components being more sensitive to social stimuli whereas attentional focus and mid-range components being more sensitive to non-social stimuli.

A total of 3 out of the 5 ERP studies used rewards (Rigoni et al., 2010; Zeng et al., 2012; Flores et al., 2015) and revealed that images of sexy or beautiful females (social reward) elicit larger P2/N2 amplitudes and LPP amplitudes compared to receiving monetary rewards (Zheng et al., 2012). Whereas in another study, P2 and P3 amplitudes were found larger in response to monetary rewards than social rewards (social feedback) (Flores et al., 2015). Similar to this, other ERP study found larger P2 amplitudes when participants received monetary rewards in the alone condition compared to competition or collaboration (Rigoni et al., 2010). Overall, sensory components have been shown to be more sensitive towards social rewards than attentional focus and mid-range components which were found enlarged in response to non-social rewards.

Gender and Age influence neural processing

There were only a few studies that examined whether gender and age influence the neural processing of social and non-social decisions.

Gender

Two studies examined gender differences in relation to the neural basis of social and non-social decision-making. Studies showed that male participants respond faster to monetary rather than social rewards and had an increased activation in the putamen for monetary rewards compared to women. In contrast, women showed stronger activation in response to social rewards in the caudate nucleus compared to men (Spreckelmeyer et al., 2009). Gender-related differences were also found in the early ERP components, with males and females processing social rewards differently. Female participants had greater N2 amplitude when viewing social than non-social stimuli (Proverbio et al., 2009).

Age

Only one study examined age-related brain responsiveness to social and non-social decisions. The Nacc was found more responsive to monetary than social rewards in young participants, while in older participants the Nacc was more responsive to social vs. monetary rewards (Rademacher et al., 2014).

4.6 Discussion

This is the first review to synthesise existing neurophysiological evidence that directly compares the neural basis of social and non-social decision-making in studies that manipulated social saliency involving all neuroimaging paradigms and task designs to examine patterns in brain correlates and temporal dynamics relating to social saliency and establish gaps in the literature to indicate directions for future research. Therefore, neurophysiological evidence across a range of task types, social saliency manipulation (i.e. stimuli, reward and social presence) and methodologies were included in this review. This is important in order to provide an overview of the human neuroimaging/electrophysiological literature in this research area acknowledging that they are equally informative: fMRI is more informative about the spatial aspects of decision-making and EEG is more informative about the temporal dynamics of decision-making. The review of the literature revealed that the manipulation of social saliency in the literature is diverse and it is achieved by varying the type of stimuli and reward used and by examining the effect of social presence on the decision process. The findings of the review highlight the scarce electrophysiological literature examining differences between social and non-social decision-making and the limited use of simple perceptual decision-making tasks in that literature.

The synthesis of the neurophysiological evidence from the extant literature indicated that a set of brain regions are active in response to social decisions only including anterior insula, amygdala, TPJ, OFC, vmPFC, dlPFC, fusiform area and extrastriate body. Those areas have been previously reported in studies examining processing of social information (Amodio & Frith, 2006) and appear to be responsible for processing social stimuli. Whereas specific regions were found active for both social and non-social decisions including the ventral striatum, vmPFC, extending into ACC and the mOFC. Activity in these brain areas was moderated by several factors such as task type and social saliency manipulation. Those brain areas have been consistently associated in the literature with the processing of both social and non-social information.

The contribution of the manipulation of social saliency in a range of tasks involving decision-making was evident in the neural correlates of social and non-social decision-making. Across studies involving an incentive delay task, the amygdala, insula and prefrontal cortex were found sensitive to social stimuli, whereas, ACC and ventral striatum were active in response to both social and non-social stimuli. Evidence from studies that employ the donation task shows that the prefrontal cortex, insula, VTA and subgenual brain areas were more sensitive to social stimuli and whereas ventral striatum was active for both types of stimuli. However, these activation patterns differ in studies that use gambling tasks. These studies report activations in bilateral amygdala and prefrontal cortex were in response to social stimuli and activation in caudate nucleus, striatum, putamen, cerebellum and thalamus brain areas for both types of stimuli. Findings across studies that use discrimination task indicate that dlPFC encodes social stimuli whereas a set of brain areas including, prefrontal cortex, occipital/parietal, parahippocampal cortex and ventral striatum are sensitive to both social and non-social stimuli. Overall, the ventral striatum was active across all tasks independent of the social saliency of the stimuli or the tasks used, indicating that it may be a specific mechanism in the brain involved in decision-making in general. This finding aligns with current literature that supports that ventral striatum is part of the decision-making network in the brain (Rilling & Sanfey, 2012).

The contribution of the manipulation of social saliency in tasks that involve rewards was quantified by contrasting findings from studies that use a reward paradigm to those that do not use a reward paradigm and apparent brain activation differences were demonstrated. Studies without rewards find enhanced activation at vmPFC, TPJ and dlPFC and PFC, fusiform area, IPS and TPJ-M whereas studies that used rewards find enhanced activation at ventral striatum, insula, ACC, caudate nucleus, putamen, vmPFC and thalamus (Heekeren et al., 2004; Mitchell et al., 2008; Pegors et al., 2015; Rademacher et al., 2010; 2014; Saxe et al., 2003). Across all studies, either using rewards or not, the vmPFC was consistently activated representing the decision value (i.e. Behrens et al., 2009; Pegors et al., 2012; Janowski et al., 2013).

One important factor that can be identified from the extant literature is the contributions of the manipulation of social saliency through social presence on the neural networks associated with decision-making. Typically, across the studies involving social presence, the ventral striatum and amygdala are implicated depending on the type of task. For example, social presence has been found to alter activation in the ventral striatum during charitable decisions (Izuma et al., 2010), simple tasks (Zink et al., 2008), learning tasks (Behrens et al., 2008) and interactive games (Nawa et al., 2008; Rilling et al., 2002). Literature argues that ventral striatum activation reflects a function of approachable behaviour whereas amygdala activation reflects threat and hostile behaviour towards the co-player (Ernst et al., 2006). Therefore, findings indicate that both striatum and amygdala are associated with encoding not only emotional valence but also the sociality of the stimuli/context. Interestingly, findings across studies that manipulate the reward type and social presence show that ventral striatum is active for both social and non-social conditions indicating that presence of another person could be rewarding for humans. These findings are consistent with the literature implicating ventral striatum in the brain's reward system (Kohls et al., 2013; O'Doherty et al., 2006; Barta et al., 2013).

Evidence from the few ERP studies in the review showed differences in temporal dynamics for social and non-social decisions. Findings from the ERP studies reviewed highlight the effect of task and stimuli type as well as the manipulation of reward. Evidence from the included electrophysiological studies suggests that processing of decisions occurs in stages spanning from sensory processing to decision formation. A number of electrophysiological markers of these processes have been identified in this review. Differences between social and non-social stimuli were evident in the early stages (around 90-300ms), where sensory processing is taking place: ERP amplitudes were found enlarged in response to social stimuli compared to non-social stimuli (Flores et al., 2015; Proverbio et al., 2009). In the attentional focus stage (around 180-300ms): social stimuli continued to capture the attention and elicited larger ERP amplitudes than non-social stimuli (Proverbio et al., 2009; Zheng et al., 2012), but showed higher amplitudes for the non-social condition when participants played a competitive game for money (Rigoni et al., 2010). In the mid-range stage (around 300-450ms): higher amplitudes were observed for social stimuli when a passive viewing task was used (Proverbio et al., 2009) but when monetary rewards were implicated higher amplitudes for non-social condition were observed (Flores et al., 2015). Whereas no differences were found at this stage when simple perceptual decision-making task was used (Philiastides et al., 2006). In the later decision-related stage (around 400-800ms) higher amplitudes were observed for social stimuli in studies that used images of sexy females (Zheng et al., 2012) and when a passive viewing task was used (Proverbio et al., 2009). Overall, social saliency manipulation influenced differently each of the underlying temporal stages of processing that lead to decision-making based on the type of reward and stimuli used.

Taken together, the findings across the included studies in the systematic review highlight the heterogeneity of task used and the influence of the manipulation of social saliency in terms of the stimuli, reward used and social presence. The synthesised neurophysiological evidence highlights the scarcity of ERP studies in the literature that explore the impact of social saliency in the temporal dynamics of simple perceptual decision-making tasks. For example, across the 26 included studies in this review, only five of them had used EEG/ERP methodology. The majority of the EEG studies used either a gambling or a passive viewing task and only two of them had looked at simple perceptual decision-making tasks. Therefore, there is a gap in the literature of studies that explore the temporal dynamics of social and non-social decision-making using simple perceptual decision-making tasks.

Factors that influence decision-making

Another important finding in the current review is that age and gender modulate neural processing of social decisions. Findings suggest that males and females process some types of social rewards differently, which indicates gender differences in the perception and encoding of social rewards, including a greater sensitivity of females when viewing pain in others (Proverbio et al., 2009) and gender-specific reward activation in the brain relating to social and non-social rewards (Spreckelmeyer et al., 2009). It is also possible that the female brain prioritises images of humans as compared to money especially when these images carry affective information. This is because, women have been found to be more sensitive to prosocial rewards (i.e. altruism, social context) than men who were found sensitive towards selfish rewards such as money (Borland, Rilling, Frantz, & Albers, 2018).

Secondly, age-related brain responsiveness to social and non-social decisions has been found. The results of one study included in this systematic review, show that the Nacc was found more responsive to monetary than social rewards in young participants, while older participants were more responsive to social vs monetary rewards (Rademacher et al., 2014). Therefore, it is possible that differences in brain activation reported in these studies may be due to age difference which might contribute to discrepancies in the results or in differentiated brain activation. Therefore, these gender and age differences might play an essential role in the neural underpinning of decision-making. Future research is needed that explores age and gender contributions because variations might lead to differences in magnitude of activation relating to social saliency.

Strengths & limitations

This review is the first to synthesise evidence from neurophysiological literature that directly contrasted neural mechanisms underlying social and non-social decisions. The synthesis of existing neurophysiological evidence revealed that specific brain regions are active in decision-making based on the social saliency manipulation including ACC, putamen, thalamus, precuneus, anterior insula, vmPFC, and striatum for both social and monetary rewards compared to dlPFC, vmPFC and TPJ brain areas that were active for both social to non-social task stimuli in studies that did not involve reward. The current review indicated that the neural basis of decision-making is modulated by task type, social saliency manipulation (i.e. stimuli type, use of rewards, social presence) and age and gender variability.

However, there are some limitations with the systematic review that should be considered in the interpretation of the findings. In terms of the included fMRI studies, one significant issue was that social condition is not always contrasted in the analysis to the non-social, rather other but related contrasts are made, for example, superior vs inferior ranking, anticipation vs consumption of rewards, or valid vs invalid beliefs. Therefore, it is not clear in the included studies whether the final results indicate differences between social and non-social decisions or differences identified based on the contrast used.

In addition, there was a difficulty in separating whether the brain activation was due to the anticipation, prediction or consumption of the reward in the different task trials. Only one study attempted to break down the analysis by processes of decision-making (anticipation, prediction, reward) and this study reported that during reward probability stage dlPFC, TPJ, right postcentral gyrus brain areas are active for both types of rewards, during reward prediction stage the vmPFC, ventral striatum, PCC, dlPFC, vlPFC brain areas were active for both types of rewards and finally during prediction error stage the brain areas active for both social and monetary rewards was bilateral ventral striatum (Hausler et al., 2015). Careful task design is crucial to dissociate different stages of decision-making process, but often comes at the expense of longer trial durations, and subsequent restriction in the number of repeats of a given condition.

Future Directions

Given the scarce literature around perceptual decision-making, future research should focus on exploring the underlying neural and temporal processing of perceptual decision-making using diverse tasks. An interesting avenue for future exploration of perceptual decisions is the influence of social and affective manipulation on the decision process. Evidence from the included studies indicate that both social saliency and affect influence the processing of decisions in the brain (Gutnik et al., 2006). However, evidence remains scance. Therefore, future work should explore the influence of social saliency and affect on the temporal dynamics of decision-making.

Also, as illustrated in the current systematic review the synthesis of the neurophysiological evidence showed that only a few ERP studies have explored the impact of social saliency on simple perceptual decision-making tasks. The majority of the ERP studies have used passive viewing or gambling tasks. Therefore, future avenues for research are to use ERP to explore the underlying temporal processing of simple perceptual decision-making tasks under the influence of social manipulation.

Another important contribution that future studies could make is to investigate how age and gender variations might account for differences in the neural basis of social and non-social decision-making. This is important as gender variability might impact the perception of social information. As previous ERP studies have shown females are more sensitive towards orienting their attention to social compared to non-social information (Proverbio et al., 2008). Gender is often not able to be examined in studies due to the small sample sizes, future studies should ensure large enough sample sizes to examine gender as studies reveal gender differences in magnitude of activation relating to social stimuli and location of brain activation relating to whether a reward is social or monetary.

4.7 Conclusion

The current review synthesised existing neurophysiological evidence that directly compares the neural basis of social and non-social decision-making in studies that manipulated social saliency involving all neuroimaging paradigms and task designs. The findings of the systematic review established patterns in brain correlates and temporal dynamics relating to social saliency and highlighted gaps in the literature to indicate directions for future research. This study identified three major findings: 1) social saliency influences the decision-process at different temporal stages and brain areas, 2) there is a vast literature that has used fMRI to contrast the different types of decision-making but there is a lack of ERP studies examining the influence of social saliency on the temporal dynamics of social and non-social decision-making thus, most of existing findings relate to spatial dynamics rather than temporal properties of decision-making, and 3) social decision-making is influenced by task type, social saliency manipulation and age and gender variability.

Evidence from the current systematic review highlights that social decisions could be influenced by reward type and social presence in the ventral striatum, vmPFC, amygdala and insula which are associated with non-social decision-making as well. The studies reviewed included a wide range of aims, focuses, measurement tools and indicators of both social and non-social decision-making.

The next chapter outlines Study 2 (Chapter 5) which addresses the gap illustrated in this review and examines the influence of social saliency on the temporal dynamics of decision-making in social and non-social domains using EEG.

Chapter 5. Study 2: Towards the temporal characterization of social decision-making.

5.1 Introduction

Study 1 (outlined in Chapter 4) synthesised existing neurophysiological evidence about the neural basis and temporal dynamics of social and non-social decision-making. The systematic review highlighted the scarce literature examining the influence of social saliency on temporal dynamics of decision-making and the scarcity of perceptual decision-making tasks in that literature. Thus, this chapter outlines the second study in the thesis that provides electrophysiological insights into the neural basis of decision-making by manipulating the sociality of the stimuli (social vs. non-social) in a preference choice task.

5.1.1 Judgement formation

Judgement formation is often made rather quickly and precedes other diverse cognitive processes, ranging from recognition to categorisation, and has been considered a major evaluative mechanism (Kim, Adolphs, O’Doherty, Shimojo, 2007; Zajonc, 1980). Preference judgements of faces could have a major impact on various social decisions, ranging from selecting friends and mates (Johnston, 2006) to political votes (Antonakis & Dalgas, 2009; Lindsen, Jones, Shimojo, Bhattacharya, 2010; Todorov, Mandisodza, Goren, et al., 2005). Given the pervasiveness of preference judgements in daily life, it is surprising that little is still known about their underlying neural substrates and the time course of activation. As discussed in Study 1 (Chapter 4), only a few studies have used ERPs to examine the influence of social saliency on the temporal dynamics of perceptual decision-making, and these have mainly used passive viewing of images rather than having participants make an actual decision/choice. The systematic review in Chapter 4 highlighted that, a recent fMRI study which manipulated the social saliency of images using a preference (i.e. attractiveness) judgement task (Pegors et al., 2015) found an effect of social saliency in the posterior and ventral portions in the right hemisphere of the frontal cortex when multivoxel pattern analysis (MVPA) was used and that both stimuli activated the vmPFC when mean neural responses were examined. The current study builds on Pegor's et al. work by providing electrophysiological insights into the neural basis of decision-making by manipulating the sociality of the stimuli (social vs. non-social) using a preference judgement task.

Following the discussion of literature in Chapter 2, studies that have manipulated social saliency (social vs. non-social stimuli) in decision-making tasks (Izuma, et al., 2008; Lin, Adolphs, & Rangel, 2012; Rademacher et al., 2010, 2014; Smith, et al., 2010; Spreckelmeyer, et al., 2009; Zink, et al., 2008) report inconsistent findings: some studies have identified distinct neural mechanisms, whereas other studies show overlapping activity in vmPFC (Lin et al., 2012; Sescousse, et al., 2010; Izuma et al., 2008; Smith et al., 2010). These findings further reinforce the need to better understand the exact effect that social saliency has on the underlying temporal processing of perceptual decision-making.

As discussed in Chapter 3, ERPs provide high temporal resolution (in milliseconds) and is a useful technique to examine temporal dynamics of decisions especially when comparing early, relatively automatic activity to later more controlled cognitive processes (deFillipo & Grose-Fifer, 2016; Luck, 2005). Studies in aesthetics judgements indicate that there might be a two-stage process for evaluative judgements; first the impression formation takes place followed by evaluative categorisation at approximately 600 ms upon stimuli onset (Jacobsen & Hofel, 2003; Hofel & Jacobsen, 2007). Findings from ERP studies using visual categorisation tasks and passive viewing indicate that there may be differences in the time course of neural activation relating to the social and non-social decisions. Previous ERP studies discussed and analysed in the systematic review outlined in Chapter 4, that have directly examined the temporal dynamics of social versus non-social stimuli by using passive viewing of social (visual scenes involving people) and non-social scenes (Proverbio, Zani, & Adorni, 2008; Proverbio, Adorni, Zani et al., 2009) showed that sensory processing and attentional focus processing stages are sensitive to social stimuli than non-social stimuli (P1, N2) (Proverbio et al., 2008; 2009). Only one of these studies (Proverbio et al., 2009) examined the decision-related stage during the LPP (500-700ms) and found that social stimuli elicited larger amplitudes compared to non-social stimuli. These studies examined solely passive viewing of images rather than asking participants to make an overt judgement (i.e. choice or rating). Therefore, the exact effect that social saliency has on the temporal dynamics of simple perceptual decision-making tasks remains unclear because mainly only passive viewing has been examined in that literature. The current study addresses this gap in the literature by examining the influence of social saliency on the temporal dynamics of simple perceptual decision-making tasks using a preference choice task.

5.2 The current study

To advance our understanding of the neural processing underlying preference judgements and the highlighted gaps in the systematic review outlined in Chapter 4 of this thesis, the current study employed ERPs to examine preference judgements of faces (happy vs. sad) and landscapes (happy vs. sad). As discussed in Chapter 3, in order to directly measure changes in brain activity at the whole-time window of decision-making, four different interacting stages of information processing will be examined, as reflected in ERP components including the N1, P2, P3 and LPP. By exploring the influence of social saliency across different timepoints in the decision process it would be possible to provide more accurate temporal insights that would contribute to the temporal mapping of social and non-social decision-making. Also, these components have been previously associated with the neural responses to social and non-social stimuli (Hofel & Jacobsen, 2007; Jacobsen & Hofel, 2003; Proverbio et al., 2008; 2009). Previous studies have shown that social saliency influences sensory and attentional focus ERP components (N1 and P2) which were found sensitive to social elements such as faces (deFillipo & Grose-Fifer, 2016; Griffin, Miniussi, &

Nobre, 2002; Weinberg et al., 2012). Therefore, in the current study it is predicted that N1 and P2 components will show an enhanced amplitude to social stimuli than non-social stimuli, reflecting greater sensory processing and attentional focus (Luck, 2005; deFillipo & Grose-Fifer, 2016; Griffin, Miniussi, & Nobre, 2002). Previous studies have suggested that in passive viewing tasks social stimuli might be lateralised on the right hemisphere during early processing stages whereas during the mid-range and late processing stages there is evidence for left hemisphere activation (Groen, Wijers, Tuch et al., 2013; Proverbio et al., 2009) and right-hemisphere activation (Hofel & Jacobsen, 2007). Therefore, lateralisation will also be explored in the present study.

The P3 is thought to reflect the capture of attention while the LPP is related to evaluative processing of the stimuli and final decision (Benning, et al., 2016; Weinberg, Hilgard, Bartholow et al., 2012). Given previous studies (Proverbio et al., 2009), it is expected that stimuli type will modulate P3 component, reflecting the capture of attention from stimuli presentation (Weinberg et al., 2012) and the motivational/affective evaluation. A number of studies (Cacioppo, Crites, Berntson, & Coles, 1993; Crites & Cacioppo, 1996; Crites, Cacioppo, Gardner, & Berntson, 1995; Cunningham, Espinet, De young, & Zelazo, 2005; Hofel & Jacobsen, 2007; Ito et al., 1998; Ito & Cacioppo, 2000; Jacobsen & Hofel, 2003) have implicated LPP with evaluation of stimuli reflecting increased attention to evaluative judgements and monitoring aspects of response selection. Also, the LPP has been found to show stronger right hemispheric asymmetry for evaluative judgements (e.g., Schupp et al., 2000). A recent ERP study that looked at differences between viewing a face and a car reported no differences at the LPP amplitude for social and non-social stimuli (Philiastides et al., 2009). Hence, no differences between the social and non-social choices are expected to be found during the LPP reflecting the decision-related neural processes for both choices independent of the social saliency.

5.3 Materials and Methods

5.3.1 Participants

Twenty-four participants were recruited. Data for 3 participants were excluded from the analysis due to excessive artefacts that did not allow for a sufficient number of trials to be extracted and another 3 for technical errors during the recording session. Thus, the reported analysis is based on 18 participants (14 females; mean age = 25.47, SD = 4.19). All participants were right-handed, fluent speakers of English, had normal or corrected-to-normal vision and did not report any history of neurological or psychiatric disorder. All participants gave written consent prior to participation. The study was approved by the University of Bolton Local Ethics Committee.

5.3.2 Stimuli

The stimuli were of two types; social and non-social and were presented in two separate blocks. The social stimuli consisted of 64 images depicting facial stimuli: 32 happy and 32 sad facial expressions obtained from the Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998). The pictures had been previously rated for emotional content, intensity and arousal

(Goeleven, DeRaedt, Leyman, & Verschuere, 2008) and are considered to have high ecological validity when compared to computer-developed faces (Sucksmith, Allison, Baron-Cohen, Chakrabarti, & Hoekstra, 2013). Thirty-two faces were chosen from the KDEF dataset that had the highest emotional intensity ratings for both happy and sad emotional expression (happy ratings- range = 3.97 – 7.42, mean = 5.95, SD = 0.81 and sad ranges - range = 3.59 – 6.81, mean = 5.22, SD = 0.87) using a 9-point Likert scale, ranging from ‘‘1’’ (not at all) to ‘‘9’’ (completely). Equal numbers of faces of men and women were used in the current study from the data set and all faces used were upright and forward-facing with either a happy or sad emotional expression. The faces were presented in a randomised order, with no face appearing more than once in a row.

The non-social stimuli consisted of pictures of landscapes (N = 64) depicting natural environments with no manmade elements. The landscapes were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) and from the public domain available on the Internet chosen to cover a large variety of styles, such that different aesthetic tastes could be expressed, for example, sea, flowers, sun, and beach. Prior to the ERP experiment, an independent sample of participants (N = 104; 76 females, age range = 19-60 years old, mean age = 28.42, SD = 10.02) provided 7-point Likert ratings of each landscapes emotional intensity (1 representing “not intense” and 7 representing “very intense”). Participants were presented with a total of 124 front-facing landscape pictures and were instructed to rate the intensity of the happy and the sad emotion in each picture presented one at a time (Izuma & Adolphs, 2013). From the larger pool of 124 pictures, 64 landscape stimuli with the highest intensity ratings were selected: 32 happy pictures (range = 4.83 - 5.98, mean = 5.33, SD = 0.29) and 32 sad pictures (range = 4.02 - 5.32, mean = 4.40, SD = 0.37). A direct contrast between the emotional ratings of the social and non-social stimuli cannot be made as two different ratings scales were used. In both conditions stimuli was presented in pairs (with one picture happy and one sad).

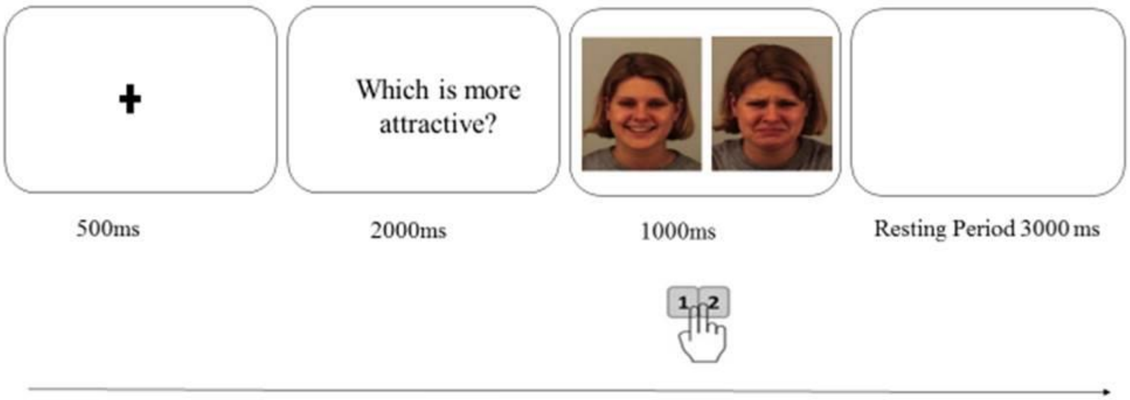
5.3.3 Procedure

Participants were seated in a semi-dark laboratory room. Stimuli were presented sequentially in the centre of a CRT monitor (size = 16in; refresh rate = 60 Hz; resolution: 1024 × 768 × 32 pixel) 100 cm away from the participants. Stimulus presentation and behavioural data collection were implemented using Stim2 4.0 Presentation Software (Compumedics Neuroscan, NC, USA). Participants were asked to avoid eye blinking, any body movements and to keep their eyes fixated on the centre of the screen while performing the task.

Participants performed two structurally identical versions (social and non-social) of the preference choice task. During the task, participants were asked to make a choice between a pair of pictures (one happy and one sad). A block design was used to avoid any carry over effects. Block order was counterbalanced across participants. For all trials, the two pictures presented belonged to the same category (either face or landscape). In the social condition, all pairs were of the same identity to limit the number of confounding variables (i.e. gender, age). Each trial began with a fixation cross at the centre of the computer screen (500 ms). A question appeared on the screen, “Which is more attractive”, (2000 ms) followed by a pair of pictures. Participants were instructed to observe the pairs and make a preference choice (1000 ms) by pressing one of the left key for the left image and the right for the right one using the mouse pad. As typical with previous literature (Liu, Mu, He et al., 2016) participants were told to respond within a set timeframe (1000ms) in order to avoid overthinking and ensure that all participants will respond at a similar pace to allow for comparison of reaction times. Each trial always ended with a blank screen (3000 ms). To lessen any possible carry over effects, each experimental block contained 18 distractor pictures of musical instruments, transportation modes or flowers which were randomly presented in blocks of 3. The paradigm was kept simple in order to avoid overthinking and allow participants to focus on the preference choice. Happy and sad faces were used in the task because people are better at detecting and discriminating between happy and sad facial emotions than other facial emotions.

Participants completed a total of 128 trials (64 social: faces and 64 non-social: landscapes). Between each block, there was a 15-minute break. During these breaks, participants were told to relax and move if they felt restless. Trial sequence is displayed in Figure 5-1 below.

A) Social Condition



B) Non-social Condition

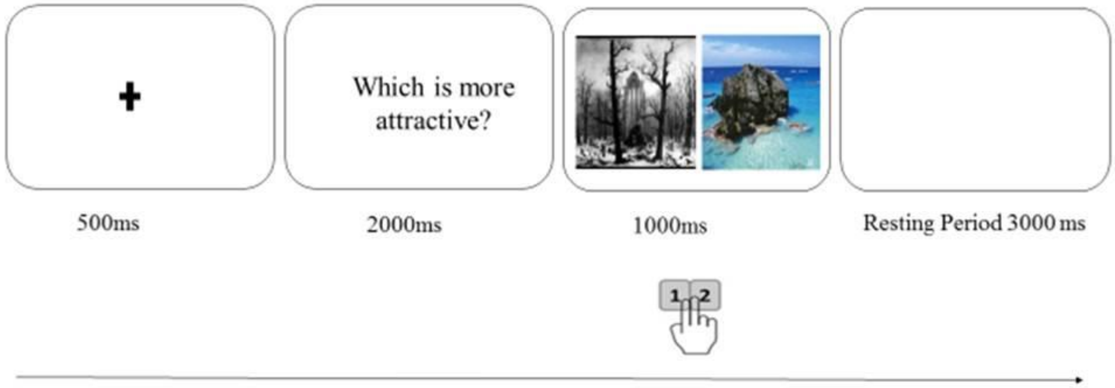


Figure 5-1. Schematic display of trial sequence. A) Social Decision-making task, B) Non-social Decision-making task. At the beginning of each trial, a fixation cross at the centre of the screen was displayed. Following this, a question appeared in the screen asking which picture is more attractive. Pair of pictures were then presented (one happy and one sad). Participants are instructed to look at the pictures and make preference choices.

5.3.4 EEG recording

The EEG data were recorded with NuAmps amplifier (El Paso, TX, USA) and CURRY 7 Acquisition Software. The ERPs were recorded at 34 scalp locations (FP1, FP2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC3, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) using silver/silver chloride (Ag/AgCl) electrodes mounted in a Quick-cap (Compumedics, Texas, USA) according to the International 10–20 system. One reference electrode was placed on the left earlobe and the other on the right earlobe and re-referenced offline to the common averaged activity. The ground electrode was placed on the medial fontal aspect (AFz electrode). Electrooculogram (EOG) was recorded binary from electrodes placed lateral to the outer canthi of both eyes. Throughout the whole recording, impedances of all electrodes were kept below 5 kΩ. The amplified band-pass of EEG and EOG data was 0.05-20 Hz, and the sampling rate was 1000 Hz.

5.3.5 Data Analysis Plan

The Neuroscan 7.0.6 edit program (Compumedics, Texas, USA) was used for off-line analysis of EEG evoked by stimuli. Single trial data were stored off-line for averaging and analysis. First, EEG data were re-referenced to the common average. Following this, ocular artefacts were automatically corrected using the Gratton method (Gratton, 1998) implemented in Neuroscan software. Trials with any EEG artefacts (exceeding ±30 μV and ± 70 μV respectively) were discarded. A 30 Hz low-pass filter and a 1 Hz high-pass filter were also re-applied in off-line analysis (Luck, 2014). After filtering, the EEG epochs were segmented from 200 ms pre-stimulus (serving as baseline) to 1000 ms post-stimulus and separate average waveforms were created for each condition time-locked to the target stimuli (faces and landscapes) as a function of preference judgement. Artefact rejection was performed for all EEG channels with rejection criteria ± 70 µV. An average of 62 trials in the social condition and 61 in the non-social condition were retained for ERP analysis after artefact artefact rejection. There was no significant difference in the included the number of trials between conditions (t(17) = 1.740, p = .100).

Based on previous studies (Foti & Hajcak, 2008; deFillipo & Grose-Fifer, 2016; Weinberg et al., 2012; Proverbio et al., 2009; 2008) the N1, P2 and LPP ERP components were measured and quantified. N1 mean area amplitudes were measured as the mean amplitude between 120 – 200 ms following stimuli onset at the temporo–parietal (TP7/TP8) and parietal (P7/P8) electrode locations. P2 was measured as the mean amplitude at electrode locations orbitofrontal (AF3/AF4), central (C3/C4), prefrontal lateral (FC3/FC4) and fronto–central (F3/F4) between 210 – 270 ms following stimuli onset. The P3 was measured for each participant as the mean amplitude between 400 - 600 ms and the LPP was measured between 600 - 800 ms following stimuli onset at the mesial parietal (P3/P4) and lateral parietal (P7/P8) and central parietal (Pz, Cz, CP3/CP4) electrode locations.

ERP amplitudes for each component were exported to IBM SPSS Statistics for Windows (Version 20.0) for analysis. Differences in the ERP amplitude values were analysed using 3-way repeated-measures analysis of variance (ANOVA) separately for each ERP component. The within subject factors in each ANOVA were: cerebral hemisphere (left and right), sociality (social and non-social), and electrode location (depending on the electrodes of interest).

Behavioural data (reaction times, RTs) were analysed using t-tests and an examination of the frequency of a happy preference choice between social and non-social conditions was conducted using a chi-squared analysis.

For all ANOVA analyses, results are reported with Greenhouse-Geisser corrected p values when the assumption of sphericity was violated. Bonferroni-corrected post-hoc t-tests were performed to analyse the significant main effects and interactions. All tests were one-tailed. For all analyses, the statistical significance level was set at $\alpha < .05$. Effect size estimates for analyses of variance were calculated with partial eta-squared (η^2 p; η^2 =0.01 is a small effect size, 0.06 is a medium effect size, and 0.14 is large effect size; (Kittler, Menard, & Phillips, 2007) for ANOVAs.

5.4 Results

5.4.1 Behavioural Performance

Reaction time

There was no significant difference in RTs between social (mean = 859 ms, SD = 47) and non-social stimuli (mean = 866 ms, SD = 60; t(16) = - .197, p = .846), indicating that the speed to make a decision was the same in both social and non-social conditions.

Preference choice

A chi-square test was performed to examine differences when choosing between happy and sad stimuli across the two conditions. The relation between these variables was significant, (χ^2 (1) = 322.18, $p< .001$) and results showed that participants chose the happy stimuli 8 times more than the sad stimuli in both conditions.

5.4.2 Electrophysiological scalp data

The grand average waveforms and topographical maps evoked by the two conditions: social and non-social choices for frontal, central and parietal brains areas are displayed in Figure 5-2. Differences between trial types were visually evident in the N1, P2, P3 and LPP components of the ERP waveforms. Repeated-measures ANOVAs were thus computed in four-time windows in order to explore these differences. The ANOVA results and post-hocs for each ERP component are displayed in Table 5-1.

N1(120 – 200 ms)

A 2(Cerebral Hemisphere: right, left) × 2(Sociality type: social, non-social) × 2 (Electrode Locations: (temporo-parietal vs. parietal)) repeated-measures ANOVA was conducted. There was a significant main effect of stimuli type: the N1 amplitude was larger for social stimuli than non-social stimuli. Also, there was a significant main effect of electrode location: the N1 amplitude was larger at temporo-parietal electrode locations than parietal. There was no significant main effect of cerebral hemisphere or a significant interaction for hemisphere × sociality type, and hemisphere × electrode location, and sociality type × electrode location.

P2 (210 – 270 ms)

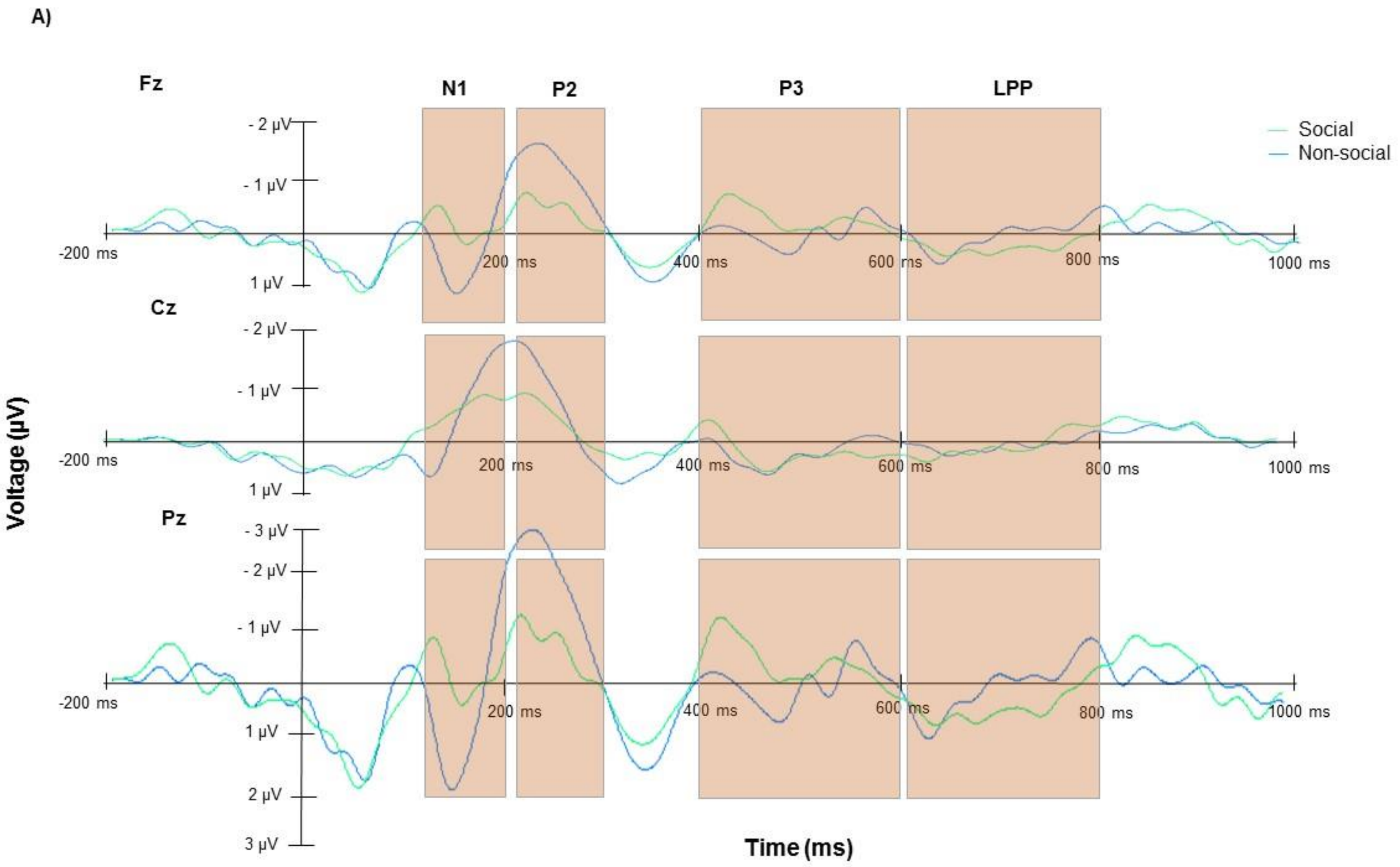
A 2(Cerebral Hemisphere: right, left) × 2(Sociality type: social, non-social) × 4(Electrode Locations: (orbitofrontal, central, prefrontal lateral, and fronto–central)) repeated-measures ANOVA was conducted. There was a significant main effect of stimuli type: the P2 amplitude was larger for social stimuli compared to non-social stimuli. There was no significant main effect of cerebral hemisphere. There was a significant main effect of electrode location with greater P2 amplitudes over central and prefrontal lateral electrode locations. There was also a significant interaction between sociality type and electrode location with stronger P2 amplitudes over central and prefrontal lateral electrode locations for social compared to non-social stimuli.

P3 (400-600 ms)

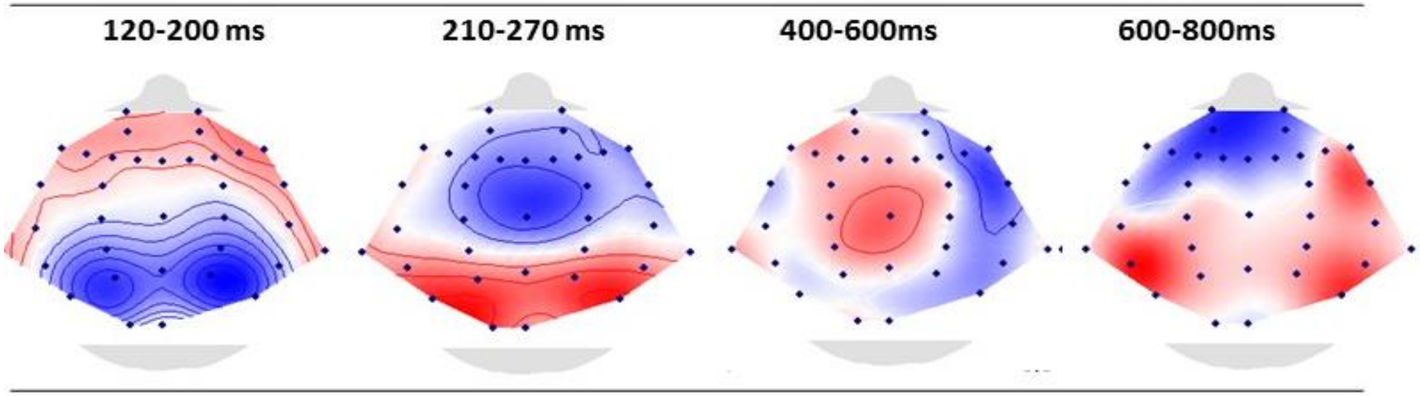
A 2(Cerebral Hemisphere: right, left) × 2(Sociality type: social, non-social) × 4(Electrode Locations: (mesial parietal, lateral parietal and central parietal)) repeated-measures ANOVA was conducted. There was significant main effect of stimuli type with larger P3 amplitudes in response to non-social stimuli than the social stimuli. There was also a significant main effect of electrode locations with larger P3 values observed over mesial-parietal areas than lateral parietal or central-parietal. There was not a significant main effect of cerebral hemisphere. There was a significant interaction between sociality type and electrode location with larger P3 amplitudes in response to non-social stimuli over the lateral parietal than the social stimuli. There was a significant interaction between sociality type and cerebral hemisphere with ambilateral activation for non-social stimuli.

LPP (600-800 ms)

A 2(Cerebral Hemisphere: right, left) × 2(Sociality type: social, non-social) × 4(Electrode Locations: (mesial parietal, lateral parietal and central parietal)) repeated-measures ANOVA was conducted. For the time-window of 600-800ms the ANOVA did not show any significant main effect main effects or interactions ($p > .05$).


A)
Fz
N1
P2
P3
LPP
Social
Non-social
- 2 μV
- 1 μV
1 μV
-200 ms
200 ms
400 ms
600 ms
800 ms
1000 ms
Cz
- 2 μV
- 1 μV
1 μV
-200 ms
200 ms
400 ms
600 ms
800 ms
1000 ms
Pz
- 3 μV
- 2 μV
- 1 μV
1 μV
2 μV
3 μV
-200 ms
200 ms
400 ms
600 ms
800 ms
1000 ms
Voltage (μV)
Time (ms)

B) Topographical Maps for N1, P2, P3 and LPP components in social condition.



C) Topographical Maps for N1, P2, P3 and LPP components in non-social condition.

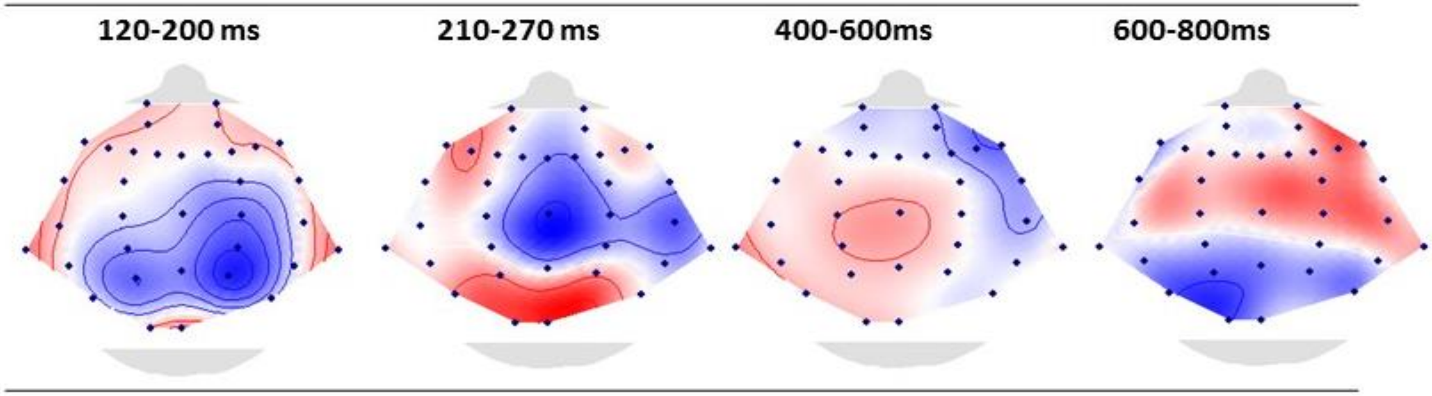


Figure 5-2. A) The grand-average ERPs over frontal, central and parietal electrodes as a function of social and non-social choices. The boxes reflect the window selected to calculate mean amplitude for each component: N1, P2, P3 and LPP. Time 0 reflects the onset of the stimuli presentation, B) topographical maps of the ERP components in social condition, C) topographical maps of the ERP components in non-social condition.

Table 5-1. ANOVA and post-hoc comparison results for all ERP components.

ERP component	Electrode location	Mean µV (SE) Sociality type		Main effect/Interactions	Post Hoc comparisons
		Social	Non-social		
N1	OP: 1.44 (.09) OT: 1.89 (.14)	1.90µV (.13)	1.43 µV(.11)	S = F(1,17) = 15.01, p = .001, ηp^2 = 46** E = F(1, 17) = 22.84, p < .001, ηp^2 = 57** H = F(1, 17) = 2.46, p = .135, ηp^2 = .135 H × S = F(1, 17) = .062, p = .806, ηp^2 = .004 H × E = F(1, 17) = .745, p = .400 ηp^2 = .042 S × E = F(1, 17) = .500, p = .489, ηp^2 = .029	
P2	OBFL: .94 (.07) PFL: 1.28 (.12) CNT: 1.31 (.14) FC: .74 (.04)	1.22 µV (.09)	.91 µV (.05)	S = F(1, 17) = 19.41, p < .001**, ηp^2 =.53 E = F(3,51) = 9.24, p = .001, ηp^2 =.35 * H = F(1, 17) = 1.23, p = .281, ηp^2 = .068 S x E = F(3,51) = 7.85, p = .003, ηp^2 = .31 S × H = F(1, 17) = .871, p = .364, ηp^2 = .049 H × E = F(1, 17) = .125, p = .945, ηp^2 = .007	**E:** OBFL vs. PFL t(17) = - 2.75, p = .014, OBFL vs. CNT t(17) = - 2.18, p = .043, CNT vs. FC t(17) = 3.94, p = .001, PFL vs. FC t(17) = 4.48, p < .001 **S × E**: Social OBFL vs. Social CNT t(17) = - 3.04, p = .007, Social OBFL vs. Social PFL t(17) = - 3.66, p = .002, Social CNT vs. Social FC t(17) = 3.88, p = .001, Social PFL vs Social FC t(17) = 4.24, p = .001, Non-social CNT vs. Non-social FC t(17) = 2.26, p = .037, Social vs. Non-social CNT t(17) = 4.24, p = .001 Social vs. Non-social PFL t(17) = 3.49, p = .003

P3	MP: 1.6 (.16) LP: 1.24 (.10) CP: 1.17 (.08)	1.18µV (.07)	1.49µV (.14)	S = F(1,17) = 7.66, p = .013, ηp^2 = .31* E = F(2, 34) = 7.36, p = .002, ηp^2 = .30* H = F(1, 17) = .063, p = .806, ηp^2 = .004 S x E = F(2,34) = 3.424, p = .044, ηp^2 = .168* S × H = F(1,17) = 5.11, p = .037, ηp^2 = .23* H × E = F(2, 34) = .513, p = .604, ηp^2 = .029	E: MP vs. LP t(17) = - 2.54, p =.021, MP vs. CP t(17) = 4.29, p < .001 S × E: Social MP vs. Social LP t(17) = 3.41, p = .003, Social CP vs. Social MP t(17) = 3.64), p = .002, Non-social CP vs. Non-social MP t(17) = 3.53, p = .003, Social LP vs. Non-social LP t(17) = - 4.23, p = .001 S × H: Social vs. Non-social RH t(17) = - 2.17, p = .044, Social vs. Non-social LH t(17) = - 3.01, p = .008, Social RH vs. Social LH t(17) = 1.38, p = .184, Non-social RH vs. Non-social LH t(17) = .765, p = .455

Note: **significant at p < .01 level, *significant at p < .05 level, S = Stimuli type, E = Electrode, H = Hemisphere, OT: occipito-temporal, CNT: central, PF: prefrontal, MP: mesial-parietal, LP: lateral-parietal, CP: centro-parietal, RH: right hemisphere, LH: left hemisphere. For post-hoc comparisons only the significant comparisons are displayed.

5.5 Discussion

The current study investigated the influence of social saliency on the behavioural and temporal dynamics of simple perceptual decision-making by manipulating the social content of the task stimuli in a preference choice task. Based on previous studies (deFillipo & Grose-Fifer, 2016; Griffin, Miniussi, & Nobre, 2002; Weinberg et al., 2012), it was predicted that the sensory component (N1), the attentional focus component (P2) and the P3 component would be sensitive to the social saliency of the stimuli with greater amplitudes for social stimuli compared to non-social stimuli whereas no differences in processing during the late processing stages (LPP) were predicted. The current findings revealed an effect of social saliency during the sensory processing which sustained until mid-range processing stages between 100 and 300 ms post-stimulus onset. Although the task in the current study involved an actual decision to be made, the results are consistent with the literature discussed in Chapter 2 and in the Systematic Review outlined in Chapter 4 and the initial predictions. Greater amplitude during 300-500ms for non-social stimuli was evident which is different to previous studies. This effect did not sustain during the late processing stages (> 600ms) which resulted in a similar decision-related mechanism for both types of stimuli.

In terms of the behavioural performance in the current study, reaction times did not differ between social and non-social preference judgements. The lack of a difference in behavioural task performance in the current study between the social and non-social stimuli suggests that the neural differences in processing are not reflected at the behavioural level. Previous studies that have examined reaction times relating to evaluative judgements have found contradictory evidence. A few studies have reported faster reaction times when choosing monetary compared to social cues (Flores, Münte, Doñamayor, 2015; Rademacher et al., 2010), while others have not found any differences (Cartmell, et al., 2014; Nawa, Nelson, Pine, et al., 2008; Sescousse et al., 2010; Saxe & Kanwisher, 2003).

The finding of modulation of sensory and attentional focus ERP components (N1 and P2) by social stimuli is in support with previous studies discussed in the systematic review (Study 1) that have examined passive viewing of social and non-social images showing an effect of social saliency during sensory components (Proverbio et al., 2008; 2009). The results are also in line with the literature discussed in Chapter 2 and with the findings in Study 1 on face-processing suggesting that facial expressions elicit larger sensory and attentional focus component (Philiastides et al., 2006; Rossion, Joice, Cottrell & Tarr, 2003). Specifically, the findings suggest that social images, due to the early timing of N1 (120 to 200 ms), draw initial attention more effectively than non-social stimuli which may reflect an early modulation to biologically relevant stimuli (Proverbio et al., 2009). In addition to that, the larger N1 amplitude found for social stimuli indicates that the properties of relatively unanimated scenes were extracted about 50ms after those of human scenarios.

Another important finding in the current study was that social stimuli elicited greater P2 amplitude than non-social stimuli at central and prefrontal areas. This finding suggests an enhanced processing of social relative to non-social information, which could be translated to greater decoding of facial expressions (Campanella, Rossignol, Mejias et al., 2004). These findings are consistent with previous studies indicating that N2 reflects cortical activity in response to viewing conspecifics (Bartles & Zeki, 2004; Proverbio et al., 2008) and its origin is thought to derive from the orbitofrontal area (Proverbio et al., 2009). At the same time, the results might indicate that participants responded preferentially to biologically relevant stimuli (i.e. human faces) by shifting the attentional focus to the faces, and thus, eliciting larger earlier ERP components.

Further, the results show that P3 is more sensitive to the non-social stimuli compared to social which is inconsistent to previous findings. This indicates that non-social stimuli continued to capture the attention of participants as an automatic response to emotionally-salient pictures. The increased amplitude in P3 for non-social stimuli might be explained by the fact that the landscapes had more components and contrasts (i.e. colour and light) so may have continued to be encoded, requiring sustained attention which led to a different process in the allocation of attention. In this study, processing of non-social stimuli elicited bilateral activation during the P3 amplitudes. This finding contributes to the literature, as extant findings are inconsistent, with some studies suggesting left hemisphere activation (Groen, Wijers, Tuch et al., 2013; Proverbio et al., 2009) and other right-hemisphere activation (Hofel & Jacobsen, 2007).

Importantly, there were no differences in the stage of late processing reflected during the LPP amplitude (600 – 800 ms) and therefore no effect of social saliency. Only one study (Proverbio et al., 2009) has examined the decision-related stage during the LPP (500-700ms) and found that social stimuli elicited larger amplitudes compared to non-social stimuli. This difference in the results might be due to the different tasks used as Proverbio et al. employed a passive viewing task compared to the preference judgement task used in the current study. The LPP activity has been previously associated with in-depth processing (Choi & Watanuki, 2014; Olofsson, et al., 2008; Weinberg, et al., 2012) and the current findings may indicate that both types of stimuli continued to capture participants' attention equally after 400ms, which may reflect more sustained and elaborative processes related to top – down influences from the task (Foti & Hajcak, 2008; Olofsson, Nordin, Sequeita, & Polich, 2008; Weinberg & Hajcak, 2011).

Strengths and Weaknesses

The current study is the first to examine temporal dynamics of preference judgements comparing social and non-social domains and extends findings in this field regarding the timeframe of activation demonstrating the effect of social saliency in the early and mid-range than late processing stages. Previous studies have examined the temporal dynamics of social saliency on decision-making using only passive viewing tasks, so the findings of the current study add to the literature by demonstrating that there is no effect of stimuli's social saliency when a preference choice is made. Previous studies that reported a social saliency effect during the LPP amplitudes have either used passive viewing tasks that did not involve an actual decision to be made (Proverbio et al., 2009) or have compared decisions between erotic/beautiful females to money in the same trial (Zheng et al., 2012) thus reflecting the choice of either viewing a social or a non-social stimulus not the preference choice made.

The current study did not come without shortcomings. The stimuli were not matched in terms of physical characteristics such as colour and brightness and emotional intensity ratings, therefore, the results in the current study may reflect differences in the emotional intensity and/or physical characteristics of the social stimuli and non-social stimuli. It is important that future studies match stimuli in terms of their emotional intensity to assure that data reflect processing differences rather than differences in visual characteristics.

5.6 Conclusion and links to other chapters

The current study compared the temporal properties of preference judgements for faces and landscapes. The findings of the study provide further electrophysiological evidence about the effect of social saliency on decision-making during the sensory, attentional focus and mid-range processing stages of preference judgements with no differences observed for the two stimuli during the decision-related evaluative judgement stage.

Study 1 (Chapter 4) reviewed the literature and identified the scarce literature examining the influence of social saliency on temporal dynamics of decision-making and the scarcity of perceptual decision-making tasks in the extant literature. The current study addressed those gaps by providing electrophysiological evidence about the influence of social saliency on the temporal dynamics of simple perceptual decision-making. Building on findings in the current study and on evidence provided in the systematic review (Chapter 4), the next studies (outlined in Chapter 6 and 7 respectively) extended knowledge about the neural basis of decision-making by providing electrophysiological evidence on the impact of social saliency and affect on other simple perceptual decision-making tasks. In Study 3 a priming task is used to examine the influence of social saliency on unconscious processing and in Study 4 social presence is manipulated to examine the influence of performing a simple perceptual task in the presence of another person in contrast to completing the task alone.

Chapter 6. Study 3: Can I trust you? The effect of Unconscious influences on social judgements.

6.1 Introduction

In Study 2 (outlined in Chapter 5) the influence of social saliency on the temporal dynamics of simple perceptual decision-making task was examined by manipulating the sociality of the stimuli presented to participants. The findings of Study 2 demonstrate the effect of social saliency on decision-making during the sensory, attentional focus and mid-range processing stages of preference judgements. In the late processing stages, there was no evident influence of social saliency during the decision-related evaluative judgement stage. This chapter outlines the third study of this thesis, which builds on the previous empirical studies in the thesis (Study 2) by exploring the impact of social saliency on unconscious influences using a simple perceptual decision task involving trustworthiness ratings about neutral faces. In Study 3, instead of manipulating the task stimuli as in Study 2, the social saliency of prime words was manipulated so the focus for examination is on unconscious influences on decision-making. Also, in this study an examination of the affect of prime words is included (positive and negative) to examine the contributions of affect on decision-making. This study builds on the understanding of the temporal dynamics of perceptual decision-making by offering insights into the effect of both social saliency and affect of word primes on the decision process.

6.1.1 Social Judgements

The ability to accurately decode and react to social cues depicted on another person's face is important in human social interaction. Accurate trustworthiness judgements are essential for assessing social threats in order to decide on appropriate action to follow. A critical feature of trustworthiness judgements is that they are often based on very little information (Sessa & Meconi, 2015), such as a person's facial characteristics, and these judgements significantly influence our willingness for a social exchange with others (Willis, Dodd, & Palermo, 2013). Trustworthiness evaluations of strangers happen instantly upon seeing a person's face (Sessa & Meconi, 2015; Todorov, Said, Oosterhof, & Engell, 2011) and these initial impressions of other people guide our interactions with them.

Previous research using EEG has shown that people evaluate the trustworthiness of a face quickly and unconsciously even if the information provided is irrelevant to the task the person is completing (Meconi & Sessa, 2014). In particular, only minimal exposure to a face (of as little as 100 ms) allows individuals to discriminate between different categories for faces (Bar, Neta, & Linz, 2006) and make trustworthiness judgements (Willis & Todorov, 2006). Given the fast processing of facial characteristics it is important to explore whether unconscious emotional messages influence trustworthiness judgements of a person and examine how affect impacts on subsequent behavioural performance.

Affective priming studies have used both faces and words as primes. Studies that have used face-primes, with varying affect (positive vs. negative), have found differences in affect in the sensory and attentional focus processing stages (P1, N1, P2) reflecting the processing of the physical characteristics of the face-prime (Key, Dove & Maguire, 2005; Lu, Zhang, Hu & Luo, 2011) especially in relation to perceptual processing of negative stimuli (Li, Zinbarg, Boehm, & Paller, 2008). This is supported by evidence revealing sensitivity of P1, N1 and P2 amplitudes towards fearful face-primes compared to happy face-primes (Hsu, et al., 2008; Li, et al., 2008; Lu et al., 2011) which could be the result of perceptual analysis of threat stimuli. The sensory and attentional focus orientation towards fearful face-primes could also explain why fearful face-primes have been consistently reported in the literature to elicit larger priming effects (Comesana, et al., 2013; Dijksterhuis & Aarts, 2003; Marcos & Redondo, 2005). Results from studies using face-primes indicate that ERP components such as the N1 are influenced by face processing and are associated with early, fast processing of the stimuli before thorough attentional focus occurs (Compton, 2003).

In contrast to results found when faces are used as primes, studies that have used word primes have found activation during mid-range and late ERP components (N400, P3, LPP) in response to positive words, rather than negative words (Gibbons, 2009). The sensitivity of sensory and attentional focus ERP components in response to face-primes and mid-range and late ERP components towards word-primes was further illustrated in a recent study comparing affective priming using words and emoticons (Comesana, et al., 2013). Results showed enhanced P1 component after the presentation of emoticons rather than emotional words (Comesana et al., 2013) and affective priming effects in N2 component for negative target words and LPP component for positive target words.

Despite the literature discussed outlining the impact of affective prime information on a number of tasks, the impact of social saliency of word primes on simple perceptual decision-making tasks is completely unexplored. It is important to examine the impact of social saliency on perceptual decision-making as a number of psychology studies have demonstrated differences between social and non-social information processing using other paradigms/task (i.e passive viewing, visual discrimination). For example, existing studies have already established the subtle effects of social cues on a person's performance (Higgins, 1996), often without them being aware, using implicit priming of trait associations (Bengtsson, Dolan, & Passingham, 2011). Other studies have used social primes to activate mental or perceptual representations of a social group (e.g., older people, professors, dumb blondes) leading to behavioural differences (Bry et al., 2008; Dijksterhuis & Van Knippenberg, 1998; Hull et al., 2002). Findings indicate improved performance following the presentation of social primes. Also, a number of studies that have examined the effect of social primes on intellectual tasks have found that social primes influence positively performance in these tasks (Levy, 1996; McIntyre, Paulson, & Lord, 2003; McIntyre, Lord, Gresky, Ten Eyck, Frye, & Bond, 2005). Another study has shown that social primes influence the likelihood of selecting a beer/wine voucher over a tea/coffee voucher, but only for people who regularly drink (Sheeran et al., 2005). However, no study to date has examined the influence of social and non-social affective primes on the temporal dynamics of a perceptual decision-making task, especially trust decisions.

A number of ERP studies that have explored the effect of social saliency on neural processing and decision-making have shown that social information leads to increased neural activation compared to non-social information (diFilipo & Groser-Fifer, 2016), and specifically, studies have found enhanced sensitivity to pictures with humans compared to pictures with visual scenes, such as landscapes (Groen, Wijers, Tucha et al., 2013; Proverbio et al., 2009). This finding indicats a prioritised processing of socially relevant information which is in line with a previous ERP study making the same distinction between social stimuli and non-social scenes (Proverbio, Zani, & Adorni, 2008). Also, studies discussed in the literature review chapter of this thesis (Chapter 2) and in the systematic review (Chapter 4) as well as findings of Study 2 in this thesis (Chapter 5) on the effect of social saliency on decision-making show differentiated neural processing based on social saliency. Taken together, this evidence shows that the underlying differences between social and non-social information processing have been studied in a variety of diverse research fields and highlight the effect of sociality in information processing. The current research has yet to examine the effect of the social saliency on affective priming. There is one study that has examined the influence of affect and arousal of word primes on preference judgements about paintings of faces (social condition) and landscapes (non-social condition) (Gibbons, 2009). This study did not report an effect of social saliency on priming. However, there was an impact of affect:

greater LPP amplitude for positive word primes than negative mainly in the right-hemisphere, for both types of stimuli. Therefore, there is scarce literature on the impact of social saliency on priming and the current study will address this gap by looking at the effects of social primes and non-social primes on trustworthiness ratings. In the current study, instead of manipulating the target stimuli (which is the same across conditions) the social saliency of prime words is manipulated to explore whether the sociality of prime words influence differently the trustworthiness judgements of neutral faces.

6.2 The current study

The current study addresses the gap in the literature by examining the impact of social saliency on the temporal dynamics of affective priming using primes that vary in sociality and affect to examine the impact of both sociality and affect on the neural processing underlying trustworthiness judgements about neutral faces. The current study combines two facets of research; affective priming by presenting subliminal words and social saliency by presenting words that vary in sociality.

The task involved the presentation of subliminal affective words followed by presentation of a face with a neutral expression and participants were asked to make a trustworthiness judgement about the person presented. Neutral faces were used as target stimuli because the valence rating of neutral expressions lie in the middle of the valence scale and have been argued to be more prone to the influence of subliminal affective primes since they cover both pleasant and unpleasant experiences (Lu, et al., 2011). Similar to Study 2, in order to examine the whole-time window of decision-making, four different interacting stages of information processing will be examined, as reflected in ERP components including the P1, N2, P3 and LPP. These components have been previously associated with the neural responses to social and non-social stimuli (Hofel & Jacobsen, 2007; Jacobsen & Hofel, 2003; Proverbio et al., 2008; 2009) and would allow to provide insights across different timepoints in the decision process in order to establish the temporal dynamics of social and non-social decision-making. As discussed in Chapter 2, extant literature on affective priming has shown that the affective nature of word-primes mainly elicits electrophysiological activation in the P3 and LPP amplitudes (Comesana et al., 2013; Gibbons, 2009). Therefore, in the current study it is predicted that an effect of priming would be evident during the mid-range and late processing stages reflecting further evaluation of information related to the affective nature of word-primes. Previous studies have suggested that in passive viewing tasks social stimuli might be lateralised on the right hemisphere during sensory processing stages whereas during the mid-range and late processing stages midline electrodes are examined (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Foti & Hajcak, 2008; Meconi et al., 2014; Nobre, Rao, & Chelazzi, 2006). In terms of behavioural performance, it is expected that reaction time to make a trustworthiness judgement could also be influenced by the sociality of the decision-making process (Hinojosa, et al., 2009; Zhang, Lawson, Guo, & Jiang, 2006). It is also expected that the affective nature of primes would impact on reaction times because previous studies have reported faster reaction times for trials preceded by positive primes (Comesana et al., 2013). Also, given that this is the first study, to our knowledge, that examines the interaction between social saliency and affect in a priming context, the analysis has an explorative nature in terms of this.

6.3 Materials and Methods

6.3.1 Participants

Twenty right-handed female undergraduate students ranging in age from 19 to 39 years (mean = 27.90, SD = 5.20) volunteered to take part in the current study. Previous research has shown gender differences in relation to decoding facial expressions. Women identify facial expressions (McClure, 2000) and recall others' physical appearances more accurately than males (Horgan et al., 2009) and women are quicker to extract social information from scenes than men (Vanmarcke & Wagemans, 2015) and show preferential activation for social than non-social pictures (Proverbio et al., 2009; Proverbio et al., 2008). So, in the current study only female participants were recruited to avoid any task-irrelevant gender-stereotypical behaviour influencing the results.

The behavioural analysis was restricted to 18 participants due to technical difficulties related to task output, but neural analysis was conducted for all participants (N = 20). All participants reported normal or corrected-to-normal vision and no history of psychiatric or neurobiological disease and were all naïve to the purposes of the study and had no prior knowledge of the research topic. All participants gave written consent prior to participation. The study was approved by the University of Bolton Local Ethics Committee.

6.3.2 Stimuli

Target pictures consisted of 128 forward facing neutral faces selected from the Karolinska Directed Emotional Faces (Lundqvist et al., 1998). The average width and height of the targets were 10.63 cm and 14.61 cm. Faces from a variety of races were included to provide a more representative set of pictures.

Word-primes varied in sociality (social and non-social) and valence (positive and negative) and were grouped into four categories; 24 social positive prime words (e.g. funny, polite and loyal), 24 social negative prime words (e.g. shy, jealous, guilty), and 24 non-social positive words (e.g., holiday, relax and free), and 24 non-social negative words (e.g., vomit, pain, coffin). All word-primes were selected from Bradley and Lang (1999). Social words were defined as those that relate to humans and describe attitudes, human traits for example, shy, jealous, guilty, funny, polite and loyal. Non-social words were defined as words that do not describe attitudes, human traits rather imply an action, for example, vomit, pain, coffin, holiday, relax and free. The words were matched across categories for valence (Meansocial prime words = 5.27, SE = .49, Meannon-social word primes = 4.93, SE = .51, t(23) = 1.87, p = .74). There were no significant differences in the word length between the conditions (length range: 3-9): the mean word length for social positive words was 6.31 (1.42), for social negative words was 6.34 (1.42), for non-social positive words was 6.34 (1.47) and for non-social negative words was 6.34 (1.51), with no significant differences $p > .05$. The word list is included in the appendices.

Word primes were presented in white-on-black text in 12-point Times New Roman font. Masks consisted of rows of X's to ensure that primes were not visible.

6.3.3 Procedure

Participants were seated in a semi-dark laboratory room. Stimuli were presented sequentially in the centre of a CRT monitor (size = 16in; refresh rate = 60 Hz; resolution: 1024 × 768 × 32 pixel) 100 cm away from the participants. Participants used a four-button response box (Neuroscan) with both hands with their thumbs positioned on the outermost response buttons. Stimulus presentation and behavioural data collection were implemented using Stim2 4.0 Presentation Software (Compumedics Neuroscan, NC, USA). Participants were asked to avoid eye blinking, any body movements and to keep their eyes fixated on the centre of the screen while performing the task.

Participants completed a trustworthiness judgement task (adapted from Adolphs, Tranel, & Damasio, 1998), for 96 trials (4 blocks of 24 trials each). Primes were assigned to faces, with no face presented twice in the same block. The experiment started by presenting an imaginary scenario to participants describing a situation before rating each face; "imagine trusting the person in a very serious situation, for instance, with all your money or with your life" (adapted from Adolphs et al. 1998). Participants were informed that the study was designed to explore how individuals form first impressions of other people and that their decisions should be made as quickly and accurately as possible.

The trial structure is shown in Figure 6-1. Each trial started with a blank screen (505.88 ms), followed by a prime word (23.53 ms). Then the noise mask appeared (400 ms) and immediately followed by the target face (neutral unfamiliar face). Above each face, a question “How trustworthy is this person?” appeared for 6000 ms. Participants were instructed to rate each face on a 4-point scale according to how trustworthy they felt the face appeared to them (1 = highly untrustworthy to 4 = highly trustworthy) using the Neuroscan keypad. Due to the scaling used, each response could be either positive or negative, with no option for a neutral response, in order to enhance sensitivity for detecting affective priming. Participants were instructed to maintain fixation at the centre of the target face and were encouraged to discriminate any facial differences that would help them make the trustworthiness judgements.

The different types of trials (social negative, social positive, non-social negative and non-social positive) were presented in blocks which were counterbalanced across participants.

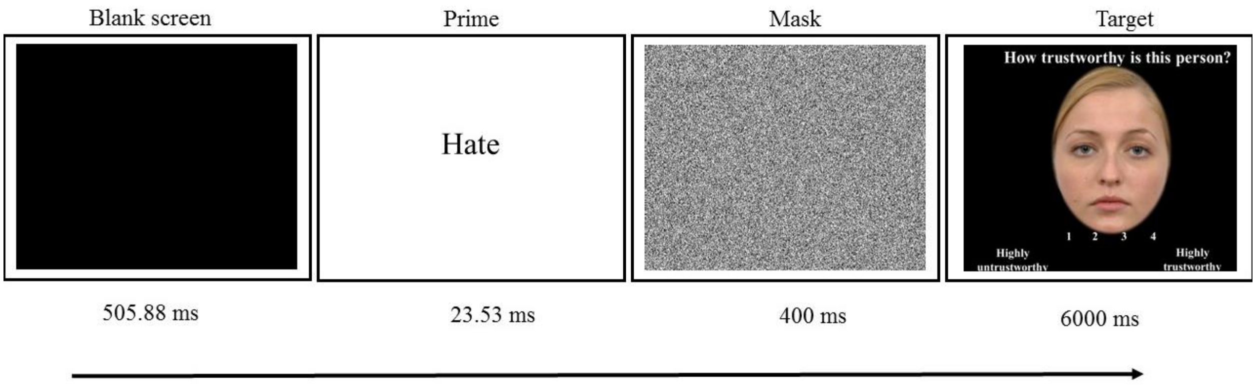


Figure 6-1. Schematic display of the trial sequence. Trial starts with a blank screen. Following this, a word-prime appeared briefly in the screen, immediately followed by a mask. Then participants were asked to make a trustworthiness judgement of a neutral face.

Awareness Check

Upon completion of the trustworthiness judgement task, an emotion manipulation check adapted from Li et al (2008) was used. Participants were interviewed following the end of the study. The questions included: 1) “Did you see anything on the screen other than the target faces?” 2) “Did you see anything before the target faces?” 3) “There was a flicker before the target faces. Have you noticed?” 4) “Did you see any words on the screen?” The interview was designed to explore participants’ subjective awareness of primes and included questions that gradually provided information about the study design. None of the participants reported to seeing some words before the trustworthiness judgement. Based on the subjective information provided by the participants, it was concluded that participants were not aware of the existence of word-primes.

6.3.4 EEG recording

The EEG data were recorded with SynAmps amplifier (El Paso, TX, USA) and CURRY 7 Acquisition Software. The ERPs were recorded from 64 Ag/AgCl electrodes (FP1, FPz, FP2, AF7, AF5, AF3, AFz, AF4, AF6, AF8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCz, FC4, FC6, FT8, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO5, PO3, POz, PO4, PO6, PO8, O1, Oz, O2) embedded in a Quick-cap (Compumedics, Texas, USA) according to the International 10–20 system. The reference electrode was placed on the left earlobe and then re-referenced offline to the common average reference, and a ground electrode on the medial fontal aspect (AFz electrode). Horizontal electrooculograms (HEOG) were recorded binary from electrodes placed lateral to the outer canthi of both eyes. Vertical electrooculograms (VEOG) were recorded from a pair of electrodes (bipolarly), one above and one below the left eye. Throughout the whole recording, impedances of all electrodes were kept below 5 kΩ. The amplified band-pass of EEG and EOG data was 0.05-20 Hz, and the sampling rate was 1000 Hz.

6.3.5 Data Analysis Plan

The Neuroscan 7.0.6 edit program (Compumedics, Texas, USA) was used for off-line analysis of EEG. Single trial data were stored off-line for averaging and analysis. First, EEG data were re-referenced to the common average. Following this, ocular artefacts were automatically corrected using the Gratton method (Gratton, 1998) implemented in Neuroscan software. Trials with any EEG artefacts (exceeding ± 70 μV, drifts) were discarded. A 30 Hz low-pass filter and a 2 Hz high-pass filter were also re-applied in off-line analysis (Luck, 2014). After filtering, the EEG epochs were segmented from 200 ms pre-stimulus (serving as baseline) to 1000 ms post-stimulus and separate average waveforms were created for each condition time-locked to the prime stimuli. Artefact rejection was performed for all EEG channels with rejection criteria ± 70 μV. An average of 24 trials remained in each condition after artefact rejection. Following artefact rejection, separate average waveforms for each condition were generated time-locked to the word-prime as a function of trustworthiness judgement.

Based on previous literature (Comesana et al., 2013; Gibbons, 2009) and on the basis of findings in Study 2 (Chapter 5), sensory (P1), attentional focus (N2), mid-range (P3) and late (LPP) processing ERP components were chosen for analysis. P1 component was measured for each participant as the mean amplitude between 90 - 150 ms following prime onset at the occipital (O1/O2; OM), lateral - occipital (PO7/PO8; LO), occipito-parietal (P5/P6; OP) and parietal (P7/P8; OT) electrode locations (Proverbio et al., 2009). The N2 was measured between 180 - 220 ms at orbitofrontal (AF3/AF4; OBFL), central (C1/C2; CNT), and fronto–central (FC3/FC4; FC) electrode locations (Nobre et al., 2006; Proverbio et al., 2009). The mean amplitude of P3 was measured and analysed between 350 - 450 ms at fronto-centro electrode locations (CPz, Pz, CP1/CP2, P3/P4, Fz, FCz, F1/F2, FC3/FC4) as suggested by previous studies (Meconi et al., 2014; Nobre, Rao, & Chelazzi, 2006). The LPP was measured between 500 - 750 ms at F1, F2, F3, F4, F5, F6, F7, F8, FC1, FC2, FC3, FC4, FCz, C1, C2, C3, C4, Cz, CP1, CP2, CP3, CP4, CP5, CP6, CP7, CP8, CPz electrode locations (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Foti & Hajcak, 2008).

ERP amplitudes for each component were exported to IBM SPSS Statistics for Windows (Version 20.0) for analysis. Differences in the ERP amplitude values were analysed using repeated-measures analysis of variance (ANOVAs) separately for each of the ERP component. For P1 and N2 a repeated measures ANOVA with four within-group factors: cerebral hemisphere (left and right), sociality (social and non-social), affect type (negative and positive) and electrode location (depending on the electrodes of interest) was manipulated. Therefore, cerebral hemisphere will not be a factor in the ANOVA for P3 and LPP amplitudes. For P3 and LPP a repeated measures ANOVA with two within-group factors: sociality (social and non-social) and affect type (negative and positive) was computed. For all analyses, results are reported with Greenhouse-Geisser corrected p values when the assumption of sphericity was violated. Bonferroni-corrected post-hoc t-tests were performed to analyse the significant interactions. All tests were two-tailed.

Regarding behavioural performance, reaction times (RTs) and trustworthiness ratings were calculated for each subject and analysed using 2 (Sociality Type: social and non-social) × 2 (Affect type: negative and positive) repeated measures ANOVAs.

For all ANOVA analyses, results are reported with Greenhouse-Geisser corrected p values when the assumption of sphericity was violated. Bonferroni-corrected post-hoc t-tests were performed to analyse the significant main effects and interactions. All tests were one-tailed. For all analyses, the statistical significance level was set at $\alpha < .05$. Effect size estimates for analyses of variance were calculated with partial eta-squared (η^2 p; η^2 =0.01 is a small effect size, 0.06 is a medium effect size, and 0.14 is large effect size; (Kittler, et al., 2007) for ANOVAs.

6.4 Results

6.4.1 Behavioural Performance

Trustworthiness Ratings

Trustworthiness ratings are displayed by sociality and affect type in Figure 6-2. A significant main effect of sociality type (F(1, 194) = 17.13, p < .001, ηp^2 = .08) was evident. Participants rated targets that were preceded by social word primes (M = 2.06, SE = .05) as more trustworthy than targets that were preceded by non-social word primes (M = 1.81, SE =.04). There was no main effect of affect type (F(1, 194) = 1.23, p = 2.68, ηp^2 = .006) and no significant interaction effect between sociality and affect (F(1, 194) = .18, p = .66, ηp^2 = .001).

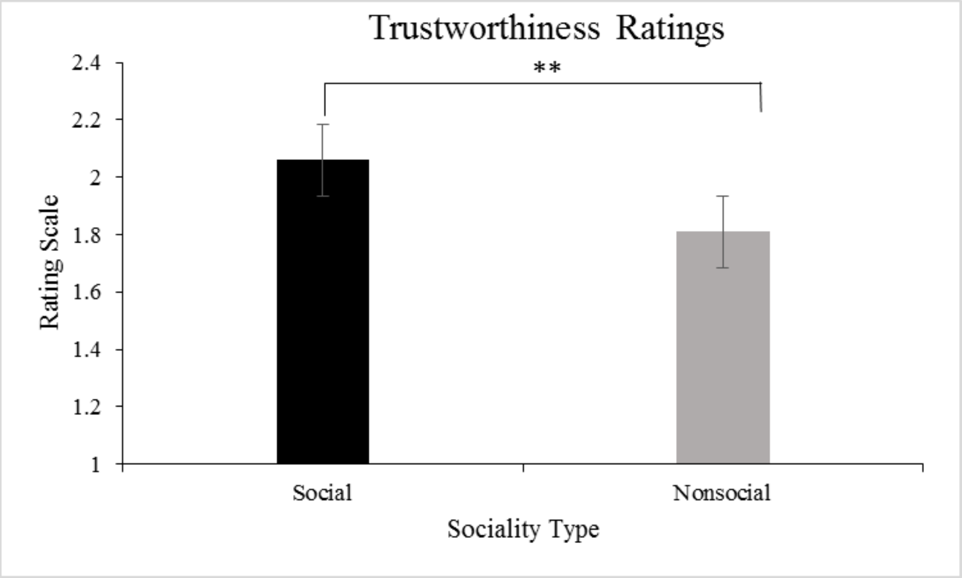


Figure 6-2. Mean trustworthiness ratings of neutral face-targets by sociality type. Participants made trustworthiness ratings of neutral face-targets in a 4-point scale using a keypad during EEG session. Trustworthiness ratings for social and non-social trials. Error bars represent the standard error of the mean (SEM). **$p < .001$, *$p < .05$ (paired t test, two-tailed).

Reaction Time

Reaction times are displayed by sociality type and affect in Figure 6-3 and Figure 6-4. There was a significant main effect for sociality type ($F(1, 194) = 19.02$, $p < .001$, $\eta p^2 = .08$). The RTs were significantly faster for targets preceded by a non-social prime (M = 2.19, SE = .04) than by a social prime (M = 2.46, SE = .06). There was a significant main effect for the affect type ($F(1, 194) = 9.48$, $p = .002$, $\eta p^2 = .047$). The RT was faster in trials preceded by positive primes (M = 2.19, SE = .04) than by negative primes (M = 2.43, SE = .63). The interaction between sociality and affect type was not found to be significant ($F(1, 194) = 1.50$, $p = .22$, $\eta p^2 = .008$).

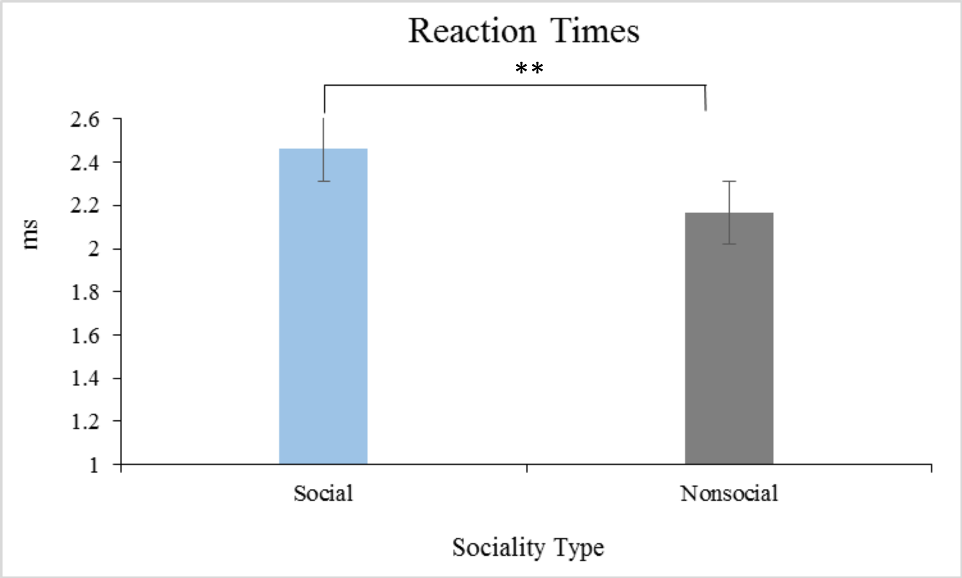


Figure 6-3. Mean reaction times by sociality type. Note: Error bars represent the standard error of the mean (SEM). **p < .001 (paired t test, two-tailed).

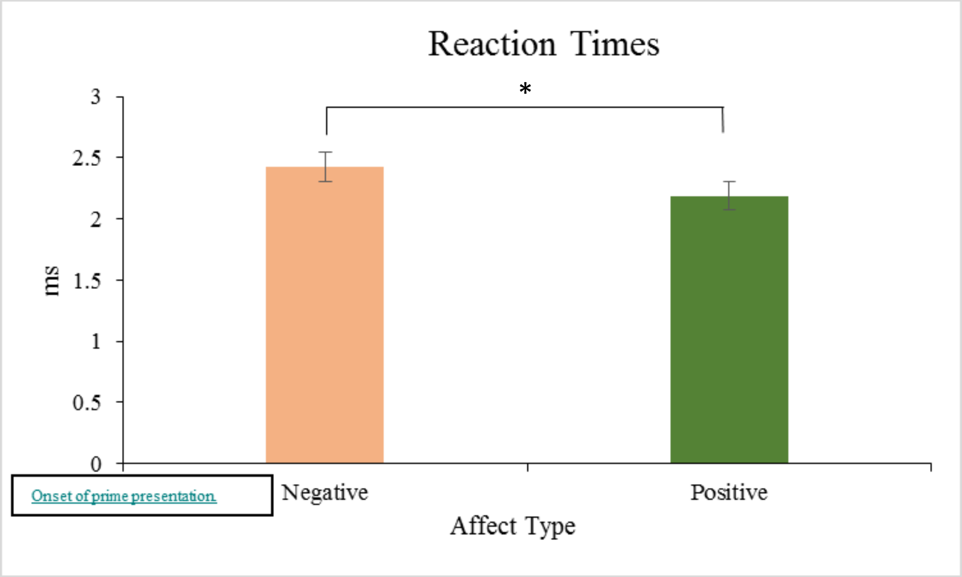


Figure 6-4. Mean reaction times by affect type. Note: Error bars represent the standard error of the mean (SEM). *p < .005 (paired t test, two-tailed).

6.4.2 Electrophysiological Scalp data

The grand average waveforms and topographical maps evoked by the two conditions: social and non-social, for frontal, central and parietal brains areas are displayed in Figure 6-5.

P1 (90 – 150 ms)

At P1 there was no significant main effect of sociality type (F(1,18) = .176, p = .679, η^2_p = .010) or affect type (F(1, 18) = .013, p = .909, η^2_p = .001) or cerebral hemisphere (F(1,18) = .220, p = .645, η^2_p = .012) or electrode location (F(3, 54) = 1.91, p = .138, η^2_p = .096). There was also no significant interaction effect for sociality type x affect (F (1, 18) = .043, p = .838, η^2_p = .012), sociality type x electrode (F(3, 54) = 1.38, p = .257, η^2_p = .071), affect x electrode (F(3, 54) = .283, p = .838, η^2_p = .015), cerebral hemisphere x sociality type (F(1, 18) = .659, p = .427, η^2_p = .035), cerebral hemisphere x affect type (F(1, 18) = .931, p = .348, η^2_p = .049), cerebral hemisphere x electrode locations (F(3, 54) = .644, p = .590, η^2_p = .035).

N2 (180 – 220 ms)

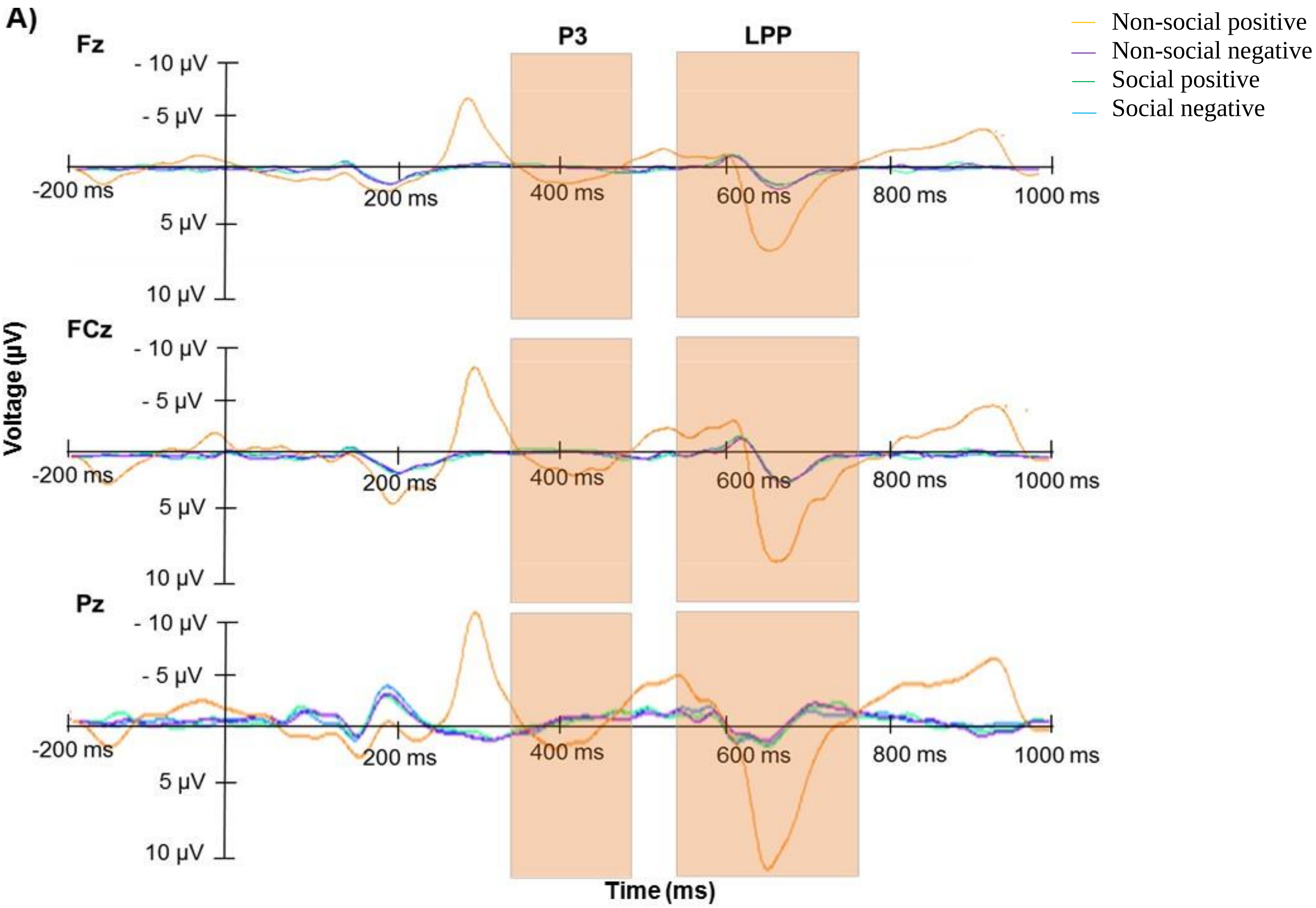
At N2, there was no significant main effect of sociality type (F(1,17) = 1.07, p = .315, η^2_p = .059) or affect type (F(1, 17) = 4.40, p = .051, η^2_p = .206) or cerebral hemisphere (F(1,17) = 2.10, p = .165, η^2_p = .110). There was a significant main effect of electrode location (F(2, 34) = 29.15, p < .001 , η^2_p = .632). Post-hoc comparisons revealed significant differences between orbitofrontal and central electrode locations ($t(17) = -5.96$, $p < .001$) with higher voltages at central ($M = 2.15$, $SD = .95$) than orbitofrontal electrode locations ($M = .906$, $SD = .46$), between orbitofrontal and frontocentral electrode locations ($t(17) = -6.17$, $p < .001$) with higher voltages at frontocentral ($M = 1.77$, $SD = .76$) than orbitofrontal electrode locations ($M = .906$, $SD = .46$), between central and frontocentral electrode locations ($t(17) = 2.62$, $p = .018$) with higher voltages at central ($M = 2.15$, $SD = .95$) than frontocentral electrode locations ($M = 1.77$, $SD = .76$). There was no significant interaction effect for sociality x cerebral hemisphere ($F(1, 17) = .052$, $p = .823$, $\eta^2_p = .003$) or sociality type x affect type ($F(1, 17) = .980$, $p = .336$, $\eta^2_p = .005$) or sociality type x electrode locations ($F(2, 34) = .498$, $p = .612$, $\eta^2_p = .028$), cerebral hemisphere x affect type ($F(1, 17) = 1.65$, $p = .215$, $\eta^2_p = 089$), cerebral hemisphere x electrode location ($F(2, 34) = .116$, $p = .891$, $\eta^2_p = .075$), affect type x electrode locations ($F(2, 34) = 1.59$, $p = .291$, $\eta^2_p = .086$).

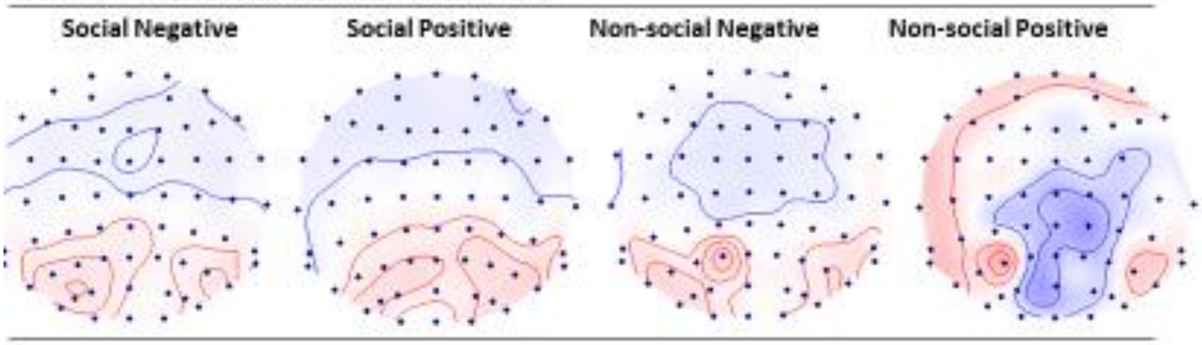
P3 (350 – 430 ms)

At P3, there was no main effect of sociality type ($F(1, 18) = .199$, $p = .661$, $\eta^2_p = .011$). There was a significant main effect of affect type ($F(1, 18) = 5.36$, $p = .033$, $\eta^2_p = .230$), with greater P3 amplitude preceeding negative primes ($M = 2.49$, $SE = .21$) than positive primes ($M = 1.95$, $SE = .15$). The interaction effect for sociality x affect type ($F(1, 18) = .602$, $p = .448$, $\eta^2_p = .032$) was not significant.

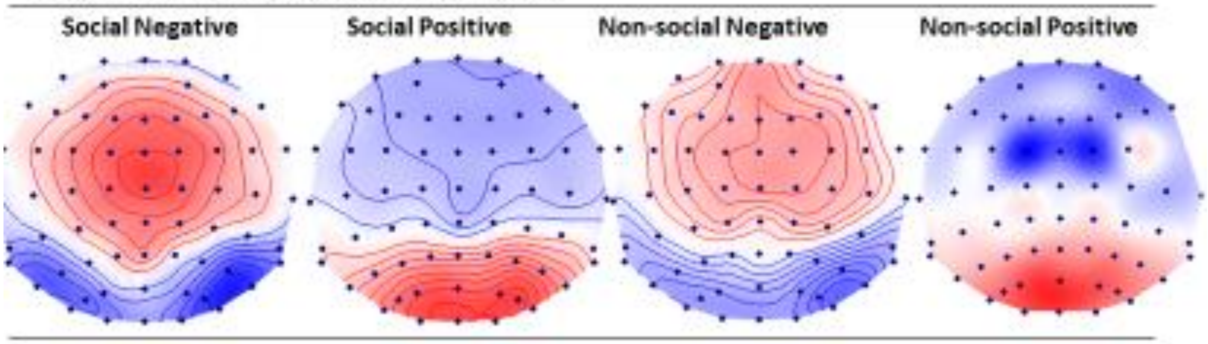
LPP (500 – 750 ms)

For LPP, there was a trend towards significance for sociality (F(1, 18) = 3.67, p = .071, η^2_p = .169) with a greater LPP amplitude for social stimuli (M = 2.10, SE = .265) than non-social stimuli (M = 1.65, SE = .116). There was a significant main effect of affect type (F(1,18) = 4.75, p = .043, η^2_p = .209), with greater LPP amplitude for negative primes (M = 2.14, SE = .264) than positive primes (M = 1.62, SE = .125). The interaction effect for sociality x affect type (F(1, 18) = .304, p = .588, η^2_p = .017) was not significant.


A)
Non-social positive
Non-social negative
Social positive
Social negative
Fz
FCz
Pz
P3
LPP
- 10 µV
- 5 µV
5 µV
10 µV
-200 ms
200 ms
400 ms
600 ms
800 ms
1000 ms
Voltage (µV)
Time (ms)



B) Topographical Maps for the P3 component



C) Topographical Maps for the LPP component

Figure 6-5. A) The grand-average ERPs over frontal, central and parietal electrodes as a function of sociality and valence for P3 and LPP components. Time 0 reflects the onset of prime presentationB) topographical maps of the P3 component for the different conditions, C) topographical maps of the LPP component for the different conditions.

6.5 Discussion

The current study addressed the gap in the existing literature that is the lack of ERP studies examining the impact of social saliency and affect on the temporal dynamics of affective priming. Therefore, the current study explored the temporal dynamics of affective priming using primes that varied in sociality (social vs. non-social) and in affect (positive vs. negative) to examine the underlying temporal processing of trustworthiness judgements about neutral faces. The current study combines two facets of research, affective priming and social saliency of primes.

Consistent with previous studies (Comesana et al., 2014; Gibbons, 2009) positive primes evoked faster RTs compared to negative primes demonstrating a successful manipulation of affective priming (Andrews, Lipp, Mallan, & Konig, 2011). The influence of social saliency was evident in the behavioural results; reaction times were faster in trials preceded by non-social primes than social word primes and faces preceded by social word primes were rated as more trustworthy compared to non-social word primes. It would be expected that responses following social word primes would be faster, because they are more task relevant and would aid the decision-making process, but in the current study, judgements about the faces were slower following social word-primes. A reason for this is maybe that social information is more complex than non-social information (Proverbio 2008; Proverbio et al., 2009) and research has shown that the complexity of the information related to the task or the complexity of the task itself influences the speed at which participants respond (Loring-Meier & Halpern, 1999; Snodgrass, 1972).

There was no impact of affect of word primes on the sensory processing and attentional focus stages in the current study. This finding might be explained by literature suggesting that pictures may lead to a more direct access to meaning representations than word stimuli (de Houwer & Hermans, 1994; Kouider & Dehaene, 2007) which is potentially the reason that word-primes do not affect the sensory processing and attentional focus components in priming paradigms.

Findings from recent studies suggest that the affective nature of word-primes is not that efficient compared to face-primes in eliciting emotional effects during sensory processing and attentional focus stages on as they do not possess physical characteristics that could influence perceptual processing (Gibbons, 2009; Li et al., 2008). In contrast, studies that have used face-primes have shown differences in these processing stages (P1, N1, P2) which might reflect face processing (Key, et al., 2005; Lu, et al., 2011). However, in the affective priming literature when word-primes are used, no effects of evaluative priming on the sensory processing components P1 and N1 have been observed. Thus, it is not surprising that face-primes influence amplitudes during sensory components relative to word-primes, as literature suggests a differential processing of pictures and words (Herbert et al., 2006; Liu et al., 2010; Zhang, Lawson, Guo, & Jiang, 2006). This finding is supported by a recent study that compared priming effects from words and emoticons (Comesana et al., 2013).

However, affective nature of word-primes influenced the P3 and LPP amplitudes. This finding is consistent with the prediction made in the introduction of this chapter that affective priming would influence mid-range and late rather than early stages of processing. Specifically, both P3 and LPP components were found larger for negatively-valenced word primes than positive word primes which might reflect motivational/affective evaluation of negative words and stronger encoding of the negatively-valenced sensory information rather than positive. This finding is similar to previous studies that have used word primes (Li et al., 2008; Comesana et al., 2013).

There was no effect of social saliency during the sensory processing and attentional focus stages. There was a trend for an influence of social saliency of the primes on the LPP amplitude, with greater ERP amplitudes for social word primes compared to non-social word primes, but this trend did not reach statistical significance in the analysis. This finding could be the result of small sample size and small number of trials and might indicate that with a larger sample size it might reach significance. Although the results potentially indicate that social saliency of primes does not impact on temporal dynamics of decision-making, the identified trend during the LPP amplitudes highlights that future research is necessary. These results are in contrast to findings from Study 2 that social saliency of target stimuli was manipulated. The results of Study 2 showed differences in the temporal dynamics of preference choices specifically, in the sensory processing, attentional focus and the mid-range ERP components but not in the late decision-related components.

Strengths and Weaknesses

The current study makes an important contribution to the field because it is the first study in the literature to manipulate both the social saliency and the affect of word-primes to explore the temporal dynamics of affective priming when making trustworthiness judgements of neutral faces. The findings showed an effect of social saliency in trustworthiness judgements with neutral faces being judged more trustworthy following social word-primes. In terms of the temporal dynamics, the impact of the affective nature of word-primes was evident at the P3 and LPP amplitudes with greater activity for negative primes.

However, there are some limitations with the current study. The small number of included trials per condition (approximately 24 trials per condition) and the small sample size might have led to the observed insignificant sociality effects. An effect of social saliency was observed on the behavioural results, indicating a priming effect, but there were no differences in temporal dynamics. This finding indicates that social saliency of the primes impacts on decision-making but not at the sensory or encoding stages. The findings in this study might be the result of using word-primes that had matched affective properties; a difficult endeavour because social words tend to have a higher valence and emotional significance to humans than non-social. So, this may have led to less emotionally arousing social words in this study which in turn impacted on the lack of differences at the temporal dynamics of affective priming based on social saliency. The results of this study indicate (due to the reported trend at the LPP amplitude) that future studies may demonstrate that temporal differences lie in the later stages of processing (i.e. decision-making and evaluation stage).

6.6 Conclusion and links to other chapters

The current study examined the temporal dynamics of affective priming when making trustworthiness judgements of neutral faces by manipulating both the social saliency and the affective nature of prime words. This is the first study that examined the influence of social saliency on the temporal dynamics of affective priming. The current study provides evidence about the effect of social saliency at behavioural level but not in the temporal dynamics; trustworthiness judgements with neutral faces were judged more trustworthy following social word primes. Also, the affective nature of word primes influenced the mid-range and the late processing stages of trustworthiness judgements with no differences observed for the two stimuli during the sensory processing and attentional focus stages. These findings are in contrast to the results in Study 2 (outlined in Chapter 5) which revealed the effect of social saliency during the sensory and attentional focus stages.

The next study (Chapter 7) examines the effect of the social presence on perceptual decision-making and feedback monitoring. The last study extends findings from Study 1, 2 and 3 and moves from manipulating the social saliency and affect of the task stimuli or word-primes to manipulating the social saliency of context (social presence vs alone) in a simple perceptual decision-making task when participants were given performance feedback that varied in affect (positive, neutral, negative).

Chapter 7. Study 4: Neurocognitive networks of performance monitoring and perception of feedback in social and non-social settings.

7.1. Introduction

The aim of this thesis is to examine the influence of social saliency on the temporal dynamics of decision-making. To address this, social saliency was manipulated in each of the studies in different ways. In Study 2 (outlined in Chapter 5) the effect of social saliency on the temporal dynamics of simple perceptual decision-making task was examined by manipulating the social content of the task stimuli. In Study 3 (outlined in Chapter 6) instead of manipulating the target stimuli, the social saliency of word-primes was manipulated. Findings of Study 2 indicate that the effect of social saliency is evident in the sensory processing and attentional focus stages during which the encoding of physical characteristics of facial stimuli takes place. This effect sustained until the mid-range processing stages whereas no differences were observed during the late processing stages (> 600 ms). In constrast, in Study 3, there was no effect of social saliency during the sensory processing and attentional focus stages. However, social word primes elicited a trend towards higher ERP amplitudes during the late processing stages. This chapter outlines the final study of the thesis which builds on the evidence in previous chapters by moving from manipulating the social saliency and affect of the task stimuli to manipulating social presence (i.e. social saliency) and also examines the impact of giving participants performance feedback (i.e. affect).

7.1.1. Social decision-making in the presence of others

The presence of other people has been found to influence a person's task performance. The influence of social presence on individual's task performance is defined as Social Facilitation or Social Inhibition (Allport, 1924). Social presence can either improve an individual's performance if a task is simple or well-learned or diminish performance if the task is complex and new (Zajonc, 1965). Social facilitation refers to improved task performance whereas social inhibition refers to reduced task performance in the presence of others (Crisp & Turner, 2010; Fiske, 2010; Hogg & Cooper, 2007; Klehe, Anderson, & Hoefnagels, 2007; Wagstaff et al., 2008). Social facilitation and inhibition have been documented in insects (Baumeister & Finkel, 2010), children (Arteberry, Cain, & Chopko, 2007), and adults (male and female).

The mere presence of others is an ubiquitous form of social influence (Guerin, 2010), observable in both humans and animals, affecting a range of behaviours from basic ones, such as food consumption, to more sophisticated behaviour, such as visual categorisation (Monfardini, et al., 2016). According to Cottrell (1968), it is not the presence of other people that is important for social facilitation/inhibition to occur, but the apprehension about being evaluated by them. Effects of social facilitation/inhibition have mainly been found with behavioural tasks (Bond & Titus, 1983), including: turning reels (Triplett, 1898), playing sports (Forgas, Brennan, Howe, Kane, & Sweet, 1980), and driving (Baxter et al., 1990). But there is also evidence of a social facilitation/inhibition effect when cognitive activities are used in research, such as Stroop tasks (Huguet, Galvaing, Monteil, & Dumas, 1999) and card-sorting (Griffin, 2001).

However, findings from behavioural tasks alone are not sufficient to delineate the underlying neural networks and cognitive processing of decision-making in the presence of others compared to being alone. Hence, neuroscience studies have recently began to explore how the presence of another person influences the neural basis of social decision-making. ERP studies have mainly focused on self-relevant gain (Knuston et al., 2001), social interaction (Izuma et al., 2008; Young, Dodell-Feder, & Saxe, 2010), closeness and friendship in relation to reward processing (Mobbs et al., 2009; Fareri, Niznikiewicz, Lee, & Delgado, 2012; Nicolle et al., 2012) and the role of social relationships while making decisions (Braams et al., 2014). Other studies have explored the neural basis of decision-making in more interactive environments including two-player tasks during which one’s performance could influence the other’s (Koban, Pourtois, Bediou, Vuilleumier, 2012; de Bruijn, Miedl, & Bekkering, 2011). But there are limited studies that have examined the impact of mere presence of another person on decision-making using neurophysiological measures. To bridge that gap in the literature, the current study examines the temporal dynamics of decision-making and feedback monitoring when social presence is manipulated. In addition, the current study extends the literature by using self-reported measures to examine the association of participants’ interest, motivation and feelings during the task with the magnitude of the ERP components.

7.1.2. The impact of others on neural response to decision-making

In this thesis so far, different aspects of social decision-making have been examined by manipulating the social saliency (social vs non-social) and affective properties of the stimuli or word-primes (i.e. positive vs. negative) on the temporal dynamics of simple perceptual decision-making tasks. So, building on knowledge from Studies 2 and 3, the current study manipulates the social context (mere presence- social condition, alone- nonsocial condition) and takes research one step further by examining its effect on the temporal dynamics of decision-making and feedback monitoring. As discussed in the Introduction Chapter of this thesis (Chapter 1), processes such as preferences, judgements and performance monitoring are essential to the decision-making (van den Boss et al., 2013). Taking a gradual approach into looking at the temporal dynamics of decision-making and having established in previous chapters the effect of social saliency on preference judgements and priming, the last study extends this knowledge to performance monitoring. This is important because feedback processing is part of all humans' decisions either explicitly or implicitly and positive and negative outcomes (i.e., reward and punishment) differentially influence our future behaviour. Research examining the neural basis of decision-making and feedback monitoring is of paramount importance and has attracted great interest in the last years (Gehring & Willoughby, 2002; Holroyd & Coles, 2002; Yeung & Sanfey, 2004; Yeung, Holroyd, & Cohen, 2005). Hence, in the current study, the effect of social presence on decision-making and feedback monitoring will be examined.

Currently, there are only a few studies in the literature that have examined the effect of mere presence on the temporal dynamics of decision-making and feedback monitoring because previous literature in this area has typically used co-action paradigms. A recent fMRI study examined the effect of implied mere presence (through video-camera) on decision-making and neural processing of feedback monitoring using three types of feedback (positive, neutral, negative) and found activation at the ventral striatum during the implied social presence condition compared to playing alone (Simon et al., 2014). A recent EEG study contrasted the effect of mere presence of an unfamiliar person and a familiar person to the participant in the temporal dynamics of feedback monitoring. This study found increased FRN amplitude during the mere observation of the familiar person to the participant (Hobson & Inzlicht, 2016) highlighting the effect of familiarity on the ERP amplitudes. Only one EEG study has explored the effect of social presence to the temporal dynamics of feedback monitoring when playing a gambling game whilst being observed by an unfamiliar peer than when playing alone (Tian, Feng, Gu, et al., 2015). The findings of this study showed an effect of social presence at both FRN and P3 amplitudes with larger amplitudes in the social condition. However, these ERP studies contrasted only positive and negative feedback which is limited as the full range of a feedback scale was not considered. This gap in the literature will be covered in the current study by exploring three different types of feedback outcome, positive, negative and neutral.

Also, another gap in the literature is that existing studies that have looked at mere presence effects in performance monitoring have not explored participants self-reported states during the task. Self-reported states have been previously associated with ERPs' magnitude as studies that have examined participants' perception of self-performance during competitive gambling games have shown that participants' involvement in the task is associated with ERPs' magnitude between 200-300ms (Fukushima et al., 2006; Yeung et al., 2005). Hence, it is essential to understand their contribution in the decision process. Given the scarce literature on the effect of social presence on the temporal dynamics of decision-making and feedback monitoring our understanding of ERPs and social facilitation theory is very limited.

Therefore, the current study addresses the gap in the electrophysiological literature by building on Tian's et al. study and examining the impact of social presence on decision-making using three types of feedback (positive, neutral, negative) to allow for an investigation of the effects of feedback outcome across the full range of a feedback scale (Simon et al., 2014). The current study also extends existing knowledge by measuring associations between FRN and participants' self-reported states.

7.2. The current Study

The current study examines the impact of social presence on decision-making and feedback monitoring using an illusory conjunction task in which participants have to indicate whether a target-symbol is present. Previous studies have demonstrated that illusory conjunctions can be reliably reduced in this task by having a co-actor present (Muller et al., 2004). Participants received positive, negative or neutral feedback. Also, self-reported states of motivation, interest and feelings towards winning were gathered to increase understanding about the neurocognitive mechanisms underlying performance outcome monitoring. Similar to other studies that have examined the effect of social presence on the temporal dynamics of feedback monitoring (Tian et al., 2015; Yeung et al., 2005) pre-determined feedback was used to match feedback across conditions.

As in previous studies of this thesis (Chapter 5 and 6), in order to measure changes in brain activity at the whole-time window of decision-making, four different interacting stages of information processing will be examined; the P1, FRN, P3 and LPP, ERP components. The FRN component will be measured specifically in this study as it is associated with performance monitoring and reflects feedback related processing (Hobson & Inzlicht, 2016; Tian et al., 2015). The ERP analysis across these four-time windows would provide more accurate temporal insights on the influence of social saliency in the decision process that would contribute to the temporal mapping of social and non-social decision-making. Also, these components have been previously associated with the neural reponses to social and non-social stimuli (Hofel & Jacobsen, 2007; Jacobsen & Hofel, 2003; Proverbio et al., 2008; 2009).

On the basis of prior findings in Chapter 5 and 6 (Study 2 and 3), an effect of social saliency during the sensory processing stage reflected at P1 component, will not be evident as this component was found sensitive to facial stimuli (Study

2). Based on the extant literature (Leng & Zhou, 2009; Tian et al., 2015; Hobson & Inzlicht, 2016), given that the task involves feedback monitoring, it is expected that both FRN and P3 would be influenced by the affective nature of feedback: with negative and neutral feedback (loss) eliciting more negative FRN compared to positive feedback (win) as seen in previous studies (Leng & Zhou, 2009). It was also expected that the amplitudes of FRN difference wave (amplitudes of negative feedback minus positive feedback) will be augmented in the social condition, due to higher motivation in the presence condition (social condition) than the alone condition (non-social condition). As the P3 is sensitive to the arousal level of ongoing events (Olofsson et al., 2008) and to the amount of attentional resources devoted to information about wins and losses (Wu & Zhou, 2009), it was also expected that social presence would influence P3 amplitudes and would be specifically higher in the social condition than in the non-social condition.

In terms of behavioural performance, theories suggest that another person’s presence enhances motivation (enhanced cortisol levels; Zajonc, 1965) and/or increases performance (Harkins, 2006). Given the predictions from the distraction-conflict theory (Baron, 1986) and findings of a study that used the same task (Muller et al., 2004), social presence is expected to be a distraction for the player in the illusory conjunction task which will lead to a social inhibition phenomenon. So, reaction times are expected to be faster in the non-social condition indicating a social inhibition effect. In terms of the self-reported measures, literature suggests that participants allocate more attentional resources on their own performance compared to their opponent (Villuendas-Gonzalez & Gonzalez-Garrido, 2016).

7.3. Materials and Methods

7.3.1. Participants

Twenty undergraduate and postgraduate students (7 males) participated in the current study. All participants were between 19 to 34 years old (M = 25.6, SD = 4.2), had normal or corrected-to-normal vision and were reported to be right-handed (assessed by asking participants which hand they normally use). All of the participants self-reported that they did not have any neurological or psychiatric disorders. Participants received a fixed monetary compensation for their participation of £5. Two postgraduate students (1 male and 1 female) who were unknown to the participant played the role of the confederate in the task. The confederate was selected to match the gender of the participant. All participants gave written consent prior to participation. The study was approved by the University of Bolton Local Ethics Committee.

7.3.2. Stimuli

The stimuli was taken from Treisman and Paterson (1984) and consisted of black shapes, letters and/or characters on a white display as described in Treisman (1984; Figure 7-1). Ninety-two conjunctive and ninety-two non-conjunctive items were created. Conjunctive items contained 10 items which included, tilted “S”, right angles, diagonal lines, arrows and triangles (Figure 7-1A). Non-conjunctive items -the target displays- contained a tilted “$” (a tilted dollar sign) which replaced the “S” (Figure 7-1B). The frequency of appearance of the target sign was one display in every four resulting in 46 target displays in each condition. In order to account for familiarity effects, a number of “control” displays were also included. These displays consisted of either 10 shapes of ‘‘S’’s or 10 right angles or 10 diagonal lines or 10 arrows or 10 triangles (Figure 7-1C).

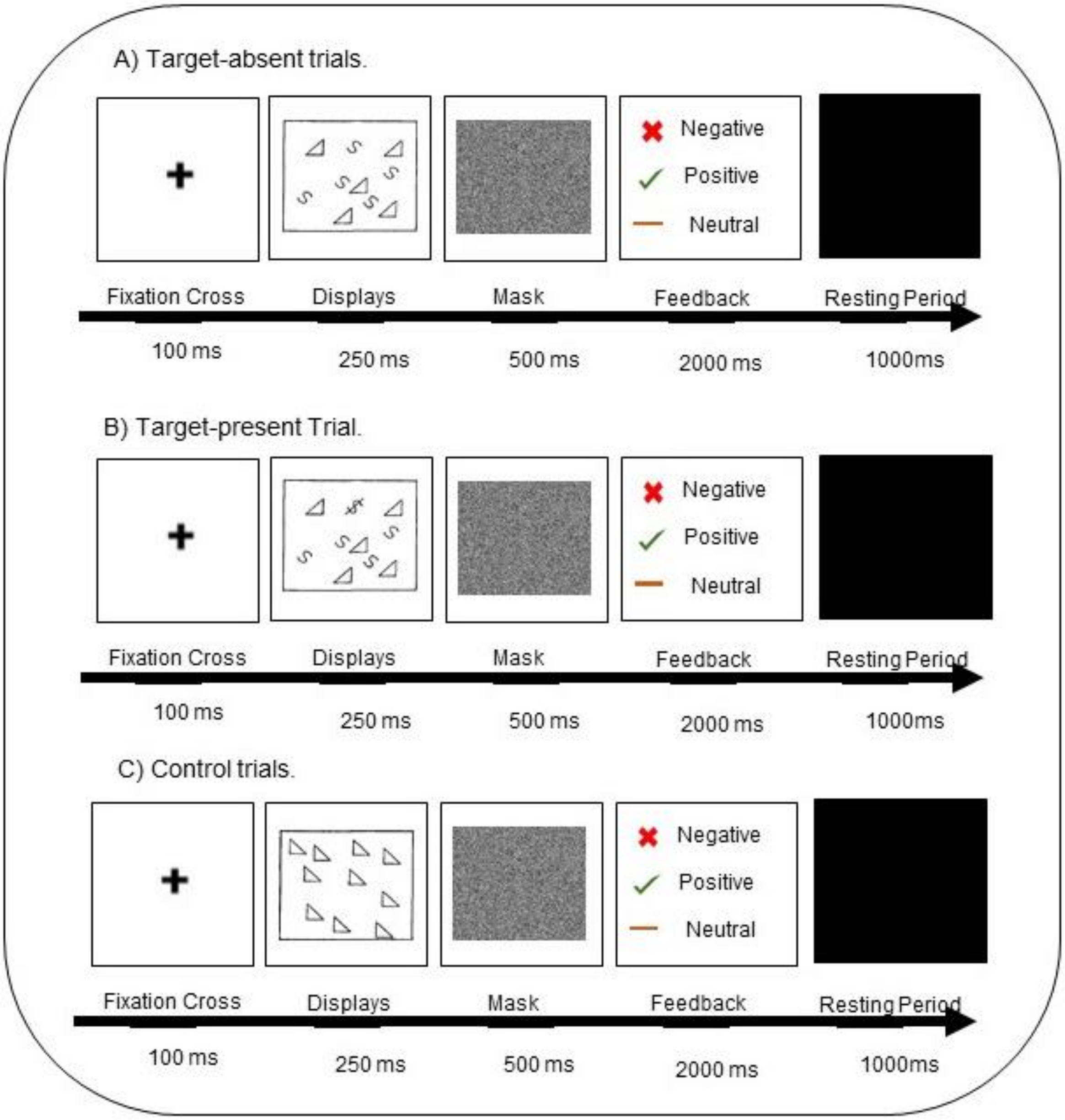


Figure 7-1 Schematic display of trial sequence. A) Target-absent trials, B) target-present trials, C) control trials. At the beginning of each trial, a central cross was displays. Following this, displays with different shapes were presented and immediately afterwards a mask was displayed. During the mask participants were instructed to indicate whether the target was present or absent. Feedback is provided after each response. The trial finishes with a resting period (task adapted from Treisman, 1984).

7.3.3. Procedure

Participants were seated in a semi-dark laboratory room. Stimuli were presented sequentially in the centre of a CRT monitor (size = 16in; refresh rate = 60 Hz; resolution: 1024 × 768 × 32 pixel) 100 cm away from the participants. Stimulus presentation and behavioural data collection were implemented using Stim2 4.0 Presentation Software (Compumedics Neuroscan, NC, USA). Participants were asked to avoid eye blinking, any body movements and to keep their eyes fixated on the centre of the screen while performing the task.

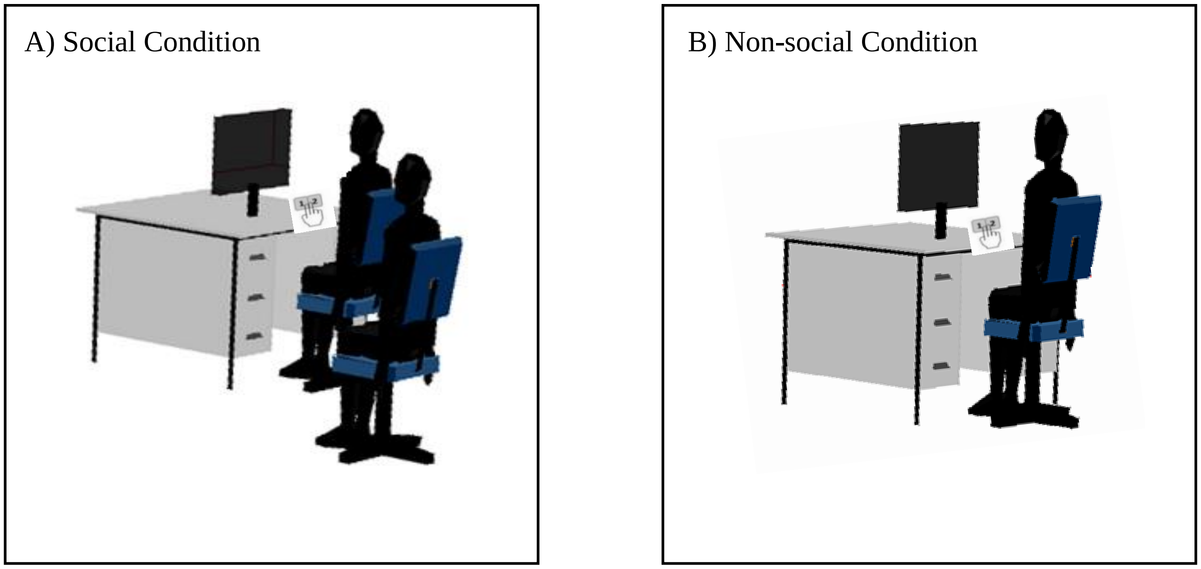
Participants completed a modified version of the Target Discrimination Task (Treisman & Paterson, 1984) (Figure 7-1). Longer trial duration and additional trials were added to ensure that a sufficient number of trials would remain after the EEG pre-processing. This task examines illusory conjunctions and previous studies have demonstrated that illusory conjunctions can be reliably reduced in this task by having a co-actor present (Treisman & Paterson, 1984; Muller et al., 2004). Each trial started with a fixation cross presented for 100 ms, followed by an image with different shapes presented for 200 ms, followed by a mask for 2000 ms which signified the response phase. The duration of stimuli presentation was increased to allow sufficient time for participants to view the shapes and record electrical activity. Responses were recorded using the Neuroscan keypad. Participants were asked to indicate if the target -symbol ‘‘$’’- was present in the image displayed by pressing 1, if it was present, or by pressing 2, if it was absent. Participants were instructed to be as fast and as accurate as possible. Illusory conjunctions occur in this task when a participant indicates that a dollar sign was present in a trial when it was not present.

In this modified version of the task, upon confirmation of their response, performance feedback was provided for all trials. Feedback remained on the screen for 1000 ms. Feedback was given in the form of a green arrow (for winning trials), a red X (for losing trials) and an orange dash (which signified neutral feedback). Positive and negative outcomes were presented in a fixed order and were not determined by the participants' actual responses. Neutral feedback was used to create an appropriate control condition that visually stimulated participants but provided no information about the subjects' performance (Nieuwenhuis et al., 2005; Simon et al., 2014). Adapting Tian's et al experimental paradigm, will be used in order to match the number of trials across three feedback conditions as previously (Chen et al., 2012; Li, Yuan, Jia et al., 2009; Rigoni et al., 2010; Tian et al., 2015; Qu et al., 2013; Zhang et al., 2012; Yeung & Sanfey, 2014). Following presentation of the feedback there was a resting period in which a blank screen was presented for 1000 ms.

Social and non-social condition

Participants performed the task under two conditions (225 trials each): a social condition (when another person was present) and independent condition (when the participant was alone in the laboratory room). In the social presence condition (Figure 7-2A), before the task was due to begin, the confederate entered the laboratory and reported that he/she was scheduled to take part in the study but had arrived too early. Then the researcher asked the EEG participant and the confederate whether it was okay for the confederate to watch the participant playing for a block to get familiar with the task. Although participants were able to refuse this request, all participants in the study agreed for the confederate to remain in the room whilst completing the task. The confederate sat behind participants to watch them playing the target discrimination task (Figure 7-2A). The participant and the confederate were told to remain quiet during the task and not to talk to each other. All participant-confederate pairs were gender matched to avoid any biases relating to gender. In the alone condition (Figure 7-2B) participants completed the task without the researcher or confederate present in the laboratory room.

In both conditions participants were informed prior to starting the task that the researcher would sit in an adjacent room during the task and would return when the block of trials was finished to set up the next block (experimental programming was automatically terminated after each block). The order of the conditions was counterbalanced across participants; half of the participants completed the social presence condition first and half of the participants completed that condition second.



A) Social Condition

B) Non-social Condition

Figure 7-2. Example of testing room configuration. Participants performed the task in two conditions. Conditions were counterbalanced across participants. In the social condition (A) a gender-matched confederate sat behind the EEG participant and observed him/her play. In the non-social condition (B) the EEG participants played independently the task.

Post-recording questionnaires

At the end of the EEG session (and the completion of both conditions), participants completed a series of questions to examine their subjective reactions to their involvement in the task (questionnaire adapted from Fukushima et al., 2006). Questions and rating scales for each of the self-report measures can be found in the appendices (Appendix 6). These questions were included to provide additional measures regarding participants’ interest and motivation. The measures were correlated with the FRN to examine whether these were associated the magnitude of the FRN.

Awareness of feedback manipulation

Following the self-report questions, an awareness manipulation check for the target discrimination task was conducted to investigate: 1) whether participants were aware during the experimental procedure that the feedback did not relate to their actual performance and 2) whether participants were aware that the confederate was not the next EEG player but was part of the task.

Upon completion of the awareness check, participants were fully debriefed on the deception about the pre-determined feedback and the identity of the confederate. The use of deception in this task was necessary to maximise equivalence in the experience across participants with regard to the feedback received and the confederate’s presence. During debriefing, participants were informed of the reasons behind these two critical design aspects. One risk of the use of deception is that participants may not be as susceptible to the manipulation, particularly if they are suspicious of deception in experimental studies. However, this awareness of deception was not evident in post-experimental debriefing sessions.

7.3.4. EEG Recording

The EEG data was recorded with SynAmps amplifier (El Paso, TX, USA) and CURRY 7 Acquisition Software. The ERPs were recorded from 64 Ag/AgCl electrodes (is similar configuration as in Chapter 6) embedded in a Quick-cap (Compumedics, Texas, USA) according to the International 10–20 system. Detailed characteristics and images of the equipment can be found in Chapter 3.

The neurophysiological data acquisition, filtering, averaging and data analysis is the same as in Study 3 and is explained in Chapter 6.

7.3.5. Data Analysis Plan

An average of 185 trials (SE = 13) in social condition and 188 trials (SE = 8) in non-social condition were retained for ERP analysis after artefact rejection. There was no significant difference in the included trials between conditions (t(19) = .35, p = .724). Following artefact rejection, separate average waveforms for each condition were generated time-locked to the feedback type as a function of performance monitoring.

On the basis of findings in previous chapters (Study 3- Chapter 6), P1 was measured between 90 – 150 ms following feedback onset at the occipital (O1/O2; OM), lateral -occipital (PO7/PO8; LO), occipito-parietal (P5/P6; OP) and parietal (P7/P8; OT) electrode locations (Proverbio et al., 2009). The LPP was measured between 500 - 750 ms following feedback onset at the mesial-parietal (P1/P2; MP) and lateral-parietal (P5/P6; LP) electrode locations (Cuthbert et al., 2000; Foti & Hajcak, 2008).

On the basis of previous findings (Gehring & Willoughby, 2002; Goldstein, Cottone, Jia, et al., 2006; Hajcak et al., 2006; Hauser, Iannaccone, Stampfli, et al., 2014), both early (FRN) and late (P3) ERP components were chosen for analysis. The FRN was measured as the mean amplitude between 200 - 300 ms after feedback onset at Fz and Cz electrode locations (Yeung, Holroyd, &

Cohen, 2005). The P3 was quantified as the average voltage in the 320 - 420 ms window following feedback onset, at Pz electrode location (Tian et al., 2015).

ERP amplitudes for each component were exported to IBM SPSS Statistics for Windows (Version 20.0) for analysis. Differences in the ERP amplitudes were analysed using repeated-measures ANOVAs, separately for each of the components. The within-subject factors in each ANOVA were: sociality (social and non-social), feedback valence (negative, positive and neutral) and electrode location (depending on the electrodes of interest). A potential confound of the analysis is that the mean amplitudes of the FRN component might be affected by the subsequent P3 signal. To account for this issue and to further illustrate the findings, difference waves were calcuated (ΔFRN component, well known in the literature as loss-minus-gain). A new variable was created by subtacting the positive feedback from the negative feedback for different social conditions and peak values of the difference waves in the 200-300 ms time window as measures of the FRN effect (Cohen & Ranganath, 2007; Hajcak, Moser, Yeung, & Simons et al., 2005; Hajcak, Moser, & Holroyd, 2007; Leng & Zhou, 2009). A 2 × 2 repeated measures ANOVA with within subject factors: sociality (social and non-social) and electrode locations (Fz and Cz) was conducted on this measure.

To examine the association between the self-reported ratings by participants of interest, affect and motivation and FRN Pearson's correlations were conducted.

Reaction times were calculated for each participant, grouped by condition and analysed using paired t-test to examine the effect of social presence on the behavioural data (RTs).

For the illusion conjunction task used, to demonstrate that illusory conjunction effect is present, error rates will be examined, using a paired-samples t-test to examine differences between conjunctive and non-conjunctive items in the social and non-social condition (Muller et al, 2004). To check for the trade off between speed and accuracy, an examination of reaction times and accuracy performance was made by looking at the mean reaction time and percentage of correct responses.

For all ANOVA analyses, results are reported with Greenhouse-Geisser corrected p values when the assumption of sphericity was violated. All tests were one-tailed. For all analyses, the statistical significance level was set at $\alpha < .05$. Effect size estimates for analyses of variance were calculated with partial eta-squared (η^2 p; η^2 =0.01 is a small effect size, 0.06 is a medium effect size, and 0.14 is large effect size; (Kittler, et al., 2007) for ANOVAs.

7.4. Results

7.4.1 Behavioural Performance

Figure 7-3 displays RT by sociality condition. A paired t-test was conducted to examine whether social presence had an effect on RT. Results reveal that there were significant differences between the social and non-social condition (t(3750) = -2478, p = .013), with faster reaction times in the non-social condition

(M= .676 sec, SD = 9.74) compared to the social condition (M = 1.66 sec, SD = 22.4).

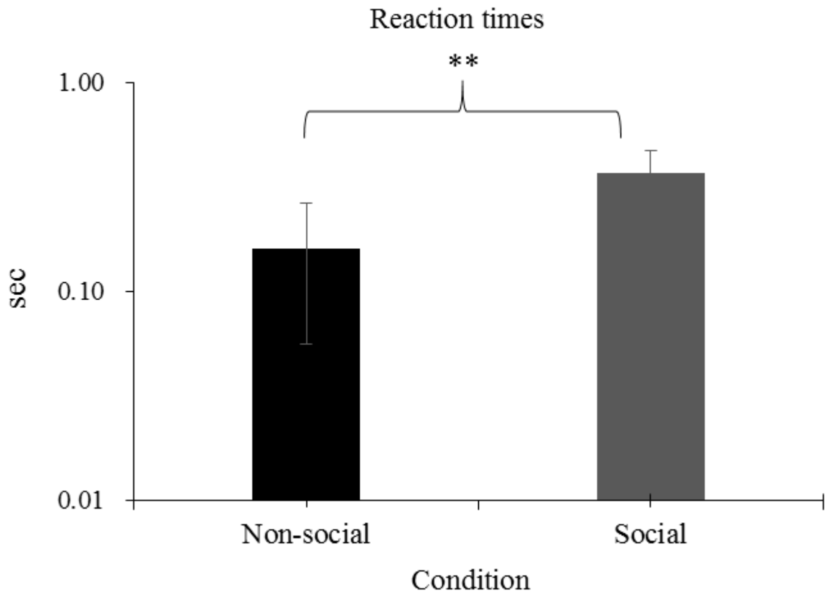


Figure 7-3. Mean reaction times for social and non-social condition.
Note: Error bars represent the standard error of the mean (SEM).
**p < .001, (paired t test).

7.4.2 Illusory conjunction effect

Table 7-1 displays the mean error rates by sociality condition. A paired-samples t-test was conducted to examine differences between conjunction and non-conjunction error rates in the social presence and alone condition in order to determine whether an illusory conjunction effect occurred. The paired samples t-tests revealed a significant difference between the error rates in conjunction and non-conjunction items in the non-social condition (t(19) = 5.13, p < .001) with higher error rates for the conjunction items (M = 27.65, SD = 5.7) than non-conjunction items (M = 19.20, SD = 6.1). There was also no significant difference between error rates in the conjunction and non-conjunction items in the social condition (t(19) = 1.15, p = .264), in the error rates in the conjunction items between social and non-social condition (t(19) = 1.77, p = .092), and in the error rates in the non-conjunction items between social and non-social condition (t(19) = - 1.25, p = .227).

Table 7-1. Mean error rates for the social and non-social conjunction and non-conjuction items.

	Condition	
	Social	**Nonsocial**
Conjunction	24.60 (SE = 1.94)	27.65 (SE = 1.28)
Non-conjunction	21.80 (SE = 1.61)	19.20 (SE = 1.38)

7.4.3 Accuracy Performance

The mean number of accurate trials in social condition was 60 out of 180 (33.3%; SE = 2.7) and in non-social condition 62 out of 185 (33.3%; SE = 3.5). There was no significant difference between the number of correct trials in the two conditions (t(19) = .660, p = .517). The mean RT in the two conditions and the accuracy percentage are shown in Table 7-2.

Table 7-2. Values for the mean response time and accuracy.

Condition	**Mean RT (ms)**	**Accuracy (%)**
Social	1.66	33.33%
Non-social	.676	33.33%

7.4.4 Electrophysiological Scalp Data

The grand average waveforms and topographical maps evoked by the two conditions: social and non-social, for frontal, central and parietal brains areas are displayed in Figure 7-4. Differences between trial types were explored in the time-windows P1, FRN, P3 and LPP using repeated-measures ANOVA. Details of the analysis can be found in Chapter 3.

P1 (90 - 150ms)

At P1 there was no significant main effect of social presence (F(1,19) = .35, p = .556, $\eta^2_{p =}$ .019) or feedback valence (F(2, 38) = 2.62, p = .116, η^2_p = .121) or electrode location (F(3, 57) = .1.35, p = .260, η^2_p = .067). There was also no significant interaction effect for sociality x feedback valence (F(2, 38) = .325, p = .725, η^2_p = .017), sociality x electrode location (F(3, 57) = 1.29, p = .285, η^2_p = .064) and feedback valence x electrode locations (F(6, 114) = .712, p = .640, η^2_p = .036).

Feedback-related negativity (200 – 300ms)

FRN at the frontal and central locations is displayed in Figure 7-4 as a function of sociality and affect. There was no a significant main effect of sociality

(F(1, 19) = .091, p = .766, η^2_p = .005). There was a significant main effect of feedback valence (F(2, 38) = 7.69, p = .002, η^2_p = .288). Post-hoc comparisons revealed a significant difference between the positive and negative feedback outcome (t(19) = 3.60, p = .002) with more negative FRN signals for the negative feedback (M= 1.50, SD = .93) compared to positive feedback (M= 2.15, SD = 1.06). Also, there was a significant difference between positive and neutral feedback (t(19) = 3.10, p = .006) with more negative FRN signal during the neutral feedback (M = 1.4, SD = .83) compared to positive feedback (M= 2.15, SD = 1.06). No significant difference was found between neutral and negative feedback (t(19)= .272, p = .788).

There was a significant interaction between feedback valence and electrode location (F(2, 38) = 4.28, p = 0.21, η^2_p = .184). Post-hoc comparisons showed a more negative FRN activation at Fz electrode location for neutral feedback (M = 1.33, SE = .22) compared to positive feedback (M = 1.93 µV, SE = .20, (t(19) = - 3.00, p = .007). Also, there was a significant difference between negative and positive feedback at Fz electrode location (t(19)= 2.83, p = .011), with a more negative FRN signal following negative feedback (M = 1.48, SE = .21) than positive feedback (M = 1.93, SE = .20). But there was no significant difference between negative and neutral feedback at the frontal locations (t(19) = -.77 p = .449). At the Cz location post-hoc tests revealed a more negative FRN activation for neutral feedback outcome (M = 1.57 µV, SE = .17) than positive feedback at Cz (M = 2.36 µV, SE = .30, (t(19) = - 2.94, p = .008) and more negative FRN amplitude for negative feedback at Cz (M = 1.32 µV, SE = .23) than positive feedback (M = 2.36 μV, SE = .30, (t(19) = 3.88, p = .001). But there were no significant differences between FRN for negative feedback than neutral feedback for Cz location (t(19) = .24, p = .811). Post-hoc tests did not reveal any significant difference between the FRN for positive feedback at Fz and Cz (t(19) = -2.01, p = .059), negative feedback at Fz and Cz (t(19) = -.26, p = .791) or neutral feedback at Fz and Cz (t(19) = - 1.62, p = .121). Results indicate that at frontal and central locations of the brain FRN signal is more sensitive to negative and neutral feedback than positive feedback. The main effect of electrode location was not significant (F(1, 19) = 2.16, p = .158, η^2_p = .102), the interaction between sociality and electrode (F(1, 19) = .089, p = .768, η^2_p = .005) and the interaction between sociality and valence were not significant (F(2, 38) = 1.05, p = .358, η^2_p = .053).

For the analysis of the ΔFRN (loss-win) there was not main effect of sociality (F(1, 19) = .1.81, p = .194, η^2_p = .087). But there was a significant main effect of electrode location (F(1, 19) = 9.36, p = .006, η^2_p = .330) with a larger ΔFRN over the Cz electrode (M = - .45 μV, SE = .16) than the Fz electrode location (M = - .83 μV, SD = .21) indicating that ΔFRN (i.e. the difference between FRN amplitudes for negative and positive feedback) is greater over central electrode locations than frontal locations. The interaction between sociality and electrode location was not significant (F(1, 19) = .22, p = .639, η^2_p = .012).

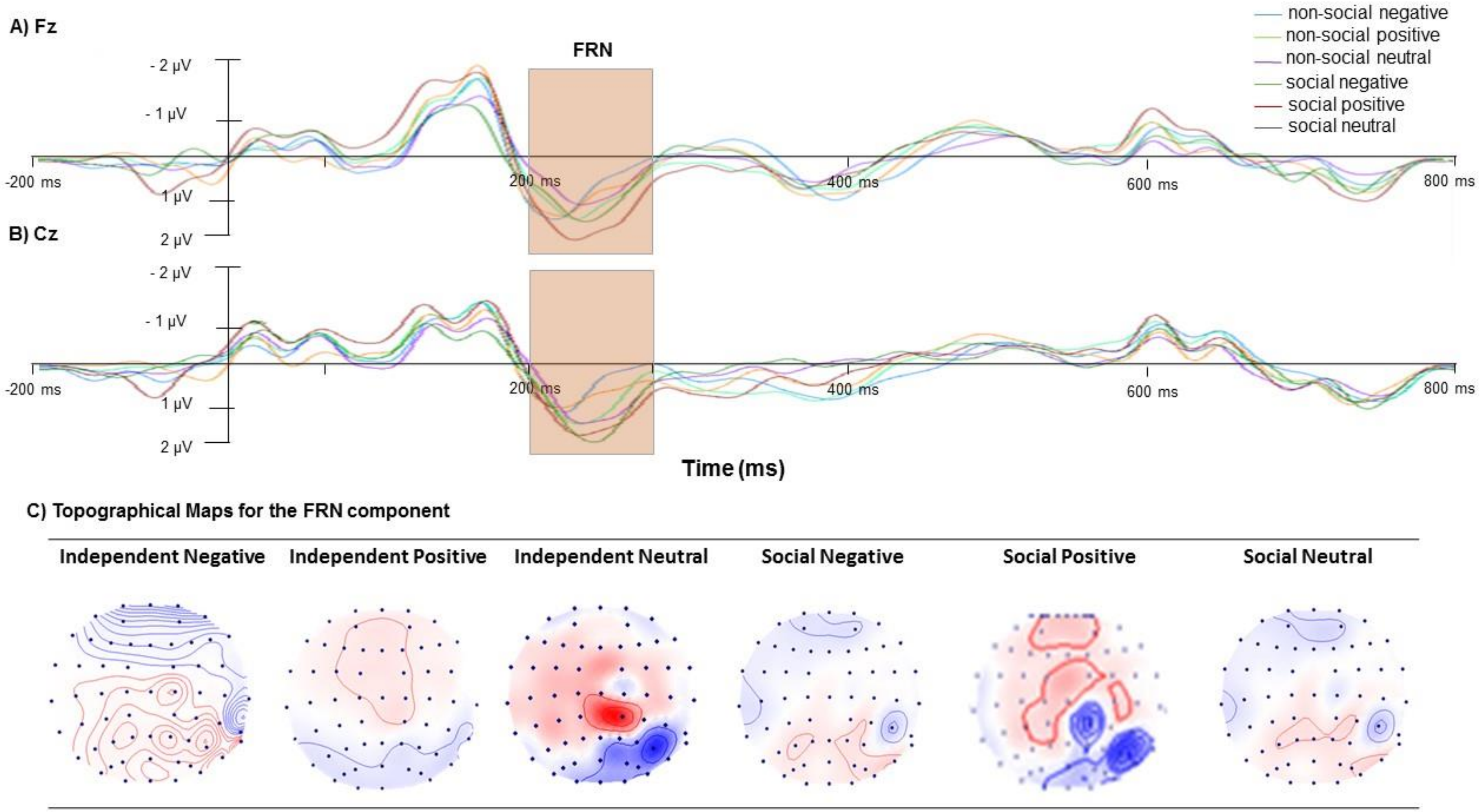


Figure 7-4. The grand-average ERPs over fronto-central electrodes as a function of sociality and affect. FRN was measured at 200-300ms A) frontal electrode and B) central location, time 0 represents the onset of feedback. C) topographical maps of the FRN for the different conditions.

P3 (320 – 420ms)

P3 at the parietal location is displayed in Figure 7-5 as a function of sociality and valence. There was not a significant main effect of sociality (F(1, 19) = 2.48, p = .131, η^2_p = .116) but there was a significant main effect of feedback valence (F(2, 38) = 8.94, p = .001, η^2_p = .32). Post-hoc comparisons revealed greater P3 amplitudes for positive feedback (M = 1.77, SE = .31) than neutral feedback (M = .95, SE = .13, t(19) = 3.61, p = .002) and greater P3 amplitudes for negative feedback (M = 1.39, SE = .20) compared to neutral feedback (M = .95, SE = .13, t(19)= 2.72, p = .013). But there were no differences for positive and negative feedback (t(19) = 2.02, p = .057) in the P3 amplitudes. This finding indicates that neutral feedback produced more positive voltages at P3 amplitudes compared to positive and negative feedback. This result demonstrates that neutral feedback was more arousing compared to positive and negative outcomes.

There was a significant interaction between feedback valence and sociality (F(2, 38) = 3.76, p = .032, η^2_p = .165). There was a trend for higher P3 for non-social negative feedback (M = 1.61, SE = .27) than social negative feedback (M = 1.17, SE = .17) (t(19) = 1.97, p = .064). This finding indicates there was more attention given to negative feedback in the alone condition than in the presence of another person, hence, P3 for negative feedback was moderated by the sociality of the condition.

Other post hoc comparisons conducted were not significant (social and non-social positive feedback: t(19) = 1.73, p = .100, and social and non-social neutral feedback: t(19) = - .91, p = .373).

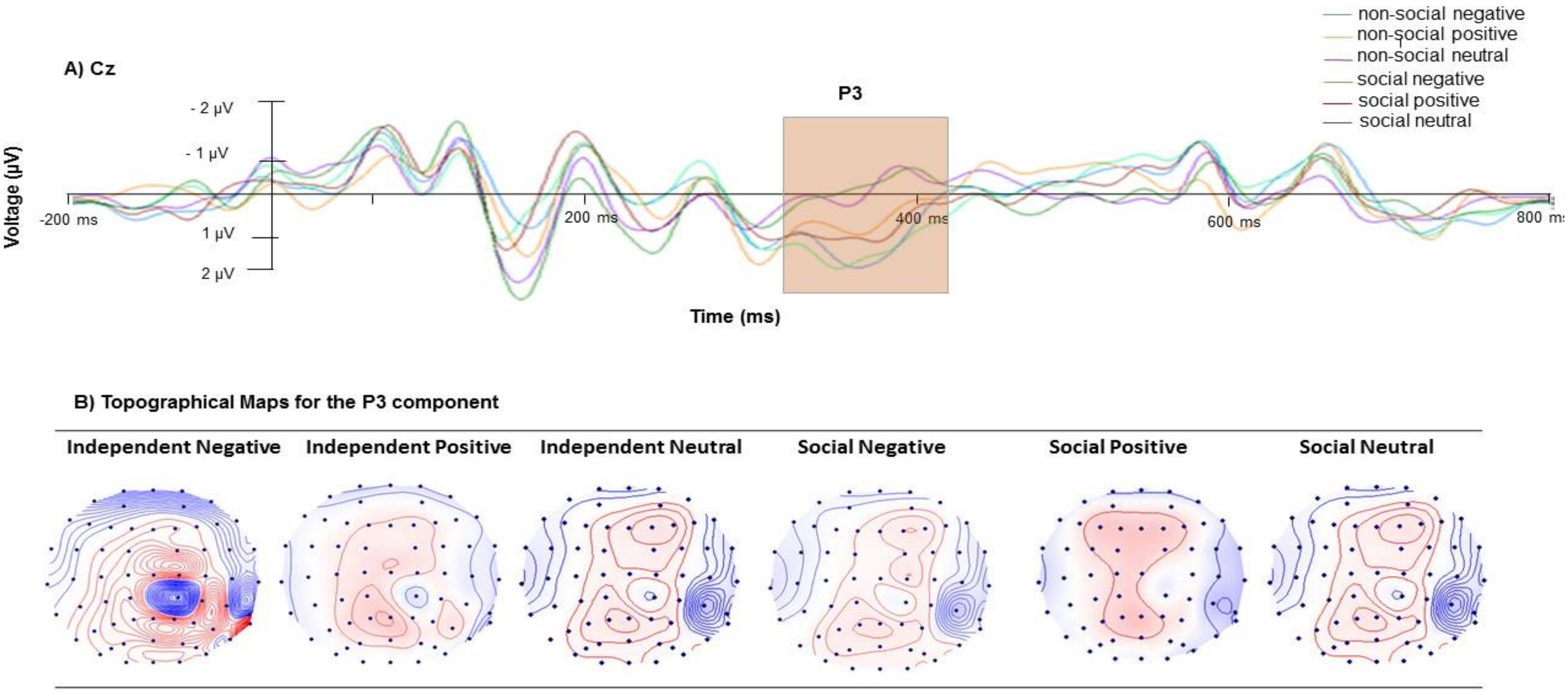


Figure 7-5. A) The grand-average ERPs over Pz electrode location reflecting the impact of affective nature of feedback outcome. P3 was measured between 320-420 ms, time 0 represents the onset of feedback. B) Topographical maps of the FRN for the different conditions.

LPP(500 - 750ms)

At LPP there was no significant main effect of sociality (F(1,19) = .52, p = .476, η^2_p = .027) or feedback valence (F(2, 38) = .18, p = .831, η^2_p = .010) or electrode location (F(1, 19) = .71, p = .410, η^2_p = .036). There was also no interaction effects for sociality x feedback valence (F(2, 38) = 1.34, p = .273, η^2_p = .066), feedback valence x electrode location (F(2, 38) = 1.76, p = .185, η^2_p = .085) and sociality x electrode location (F(1, 19) = 1.52, p = .232, η^2_p = .074).

Correlations with self-report measures

Table 7-3 presents participants' self-reported ratings for feelings towards winning, interest, and motivation relating to the task and feelings towards winning measured after the task was completed (i.e. relating to the whole task) and associations with FRN in both social and non-social conditions each condition.

Table 7-3. Mean scores of psychological measures and correlations with FRN amplitudes.

		Correlations with FRN	
	Scores (S.D.)	**Social**	**Non-social**
Motivation	3.9 (0.89)	.231	.200
Feelings towards winning	3.3 (1.05)	.407	-.391
Interest	3.85 (1.06)	.315	-.504*

Note: *significant at p < .05 level, note that motivation, interest and feelings towards winning where measured at the end of the task and relate to self-reporting across the task, rather than for each condition (social vs non-social) independently.

Scatterplots of psychological measures and correlations with FRN amplitudes in both social and non-social conditions are shown in Figure 7-6.

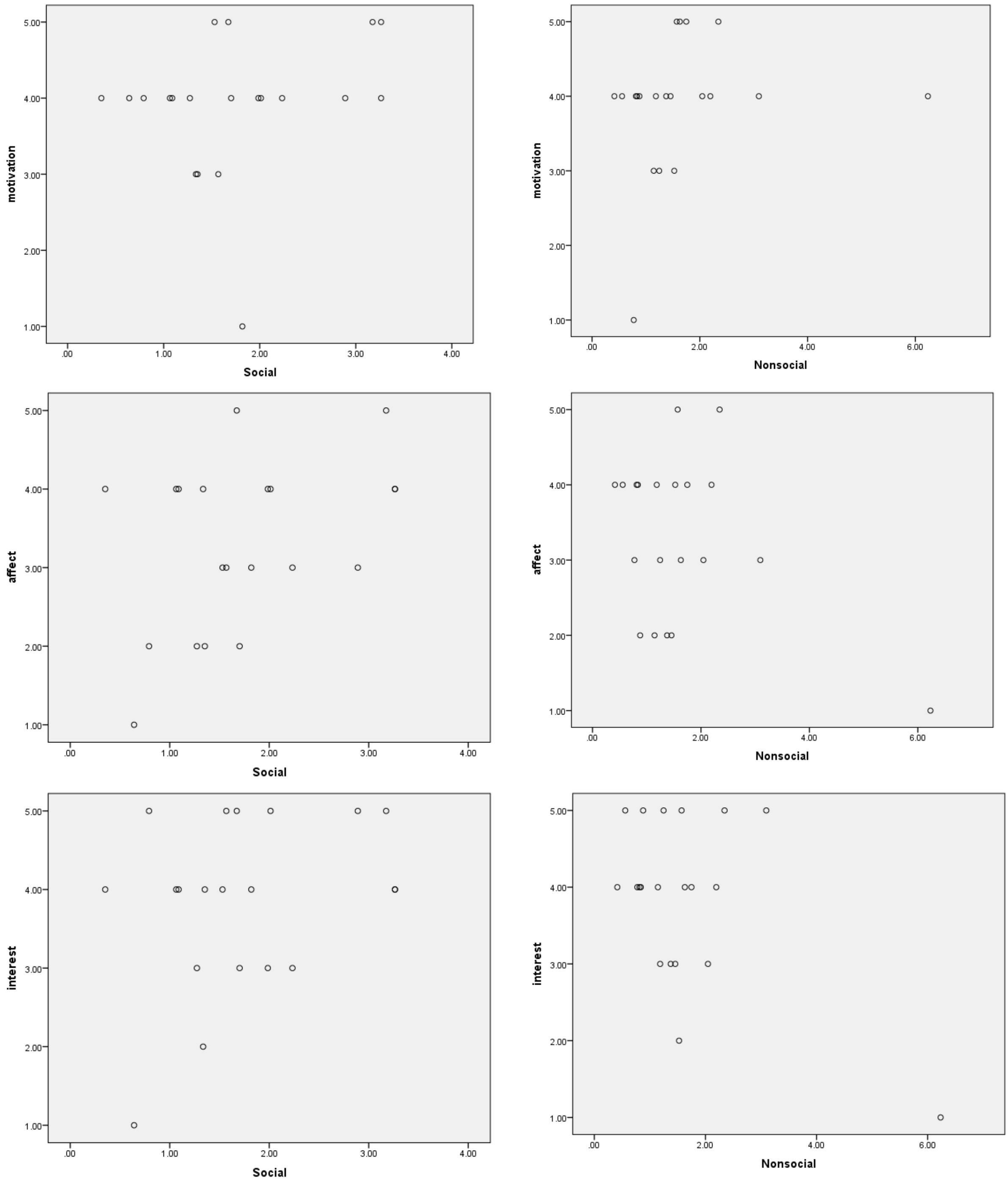


Figure 7-6. Scatterplots of the correlations with FRN amplitudes in both social and non-social conditions and the self-reported measures.

There were moderate positive association between FRN in the social condition and feeling towards winning and interest in the task and a moderate negative association between feelings towards winning and FRN in the non-social condition, but these did not approach significance (p = .075, p = .177 and p = .088 respectively). There was an association between the interest in the task and performance monitoring but only for the FRN in non-social condition (r(20) = -.504, p = .024).

7.5 Discussion

The current study addressed the gap in the existing literature that is, the scarce studies that examined the impact of social presence on the temporal dynamics of decision-making and performance monitoring. Building on previous studies of this thesis (outlined in Chapters 5 and 6) that examined the effect of social saliency on preference judgements and priming and by taking a gradual approach into investigating the effect of social saliency on simple perceptual decision-making tasks, the current study adds to the literature by employing an illusory conjunction task to investigate the temporal dynamics relating to decision-making and performance monitoring in social (mere presence) and non-social context (alone).

The influence of social saliency was evident in the behavioural results; reaction times were faster during the non-social condition compared to the social condition which supports the social inhibition theory. This result is in line with the findings in Study 3 (Chapter 6) and might indicate that social presence could have acted as a distraction for participants which led to slower reaction times in the social condition compared to non-social condition. The analysis of the speed-trade off accuracy revealed that there is a very low accuracy rate for the task used. Given that the task used relatively simple, this finding might indicate that participants were not engaged in the task.

Accuracy, although very low, was found to be equivalent between social and non-social condition. These findings indicate that in the current study, mere presence of another individual inhibited the performance of the players as discussed in the literature (Bond & Titus, 1983; Muller et al., 2004). In terms of the illusory conjuction effect of the task, social saliency influenced the task as seen in other studies (Muller et al., 2004). So, a previous study that used similar task has found that social presence leads to a cognitive overload that produces attentional focusing. Attentional focusing is defined as a narrowing of attention: More attention is allocated to central cues while peripheral cues are neglected (Cohen, 1978; Geen, 1976). Hence, in the current study, performance was impaired since peripheral cues are necessary to perform. Given that for the completion of the task used in this study both peripheral and central cues are necessary, mere presence was seen as a distraction for the player which led to a social inhibition phenomenon.

There was no impact of affect on the temporal dynamics of decision-making and feedback monitoring during the sensory processing stages in the current study. However, affective nature of feedback outcomes influenced the FRN and P3 amplitudes. The FRN component was found to be more sensitive to negative and neutral feedback than positive feedback. The mid-range P3 component was found to have larger amplitudes for neutral feedback compared to negative and positive feedback. This finding is consistent with the initial predictions, and similar to findings in Chapter 6, that there was no sociality or affect effect during the sensory processing and attentional focus stages. This finding supports the claim made in Chapter 6 that differences in the sensory stages (P1, N1) reflect the processing of the physical characteristics of the face (Key, et al., 2005; Lu, et al., 2011). Also, this finding is consistent with previous studies that have used affective feedback outcome (Chen et al., 2012; Li, Yuan, Jia et al., 2009; Tian et al., 2015; Qu et al., 2013; Zhang et al., 2012; Yeung & Sanfey, 2014), and found an effect in mid-range rather than sensory stages of processing.

Social saliency was manipulated in the current study, but in contrast to Study 2 and 3 in this thesis that manipulated the social content of the task stimuli and the word-primes, social presence was manipulated. Findings of previous studies in this thesis reported an influence of social saliency during the early and mid-range processing stages when a preference choice task was used (Study 2) whereas there was no effect of social saliency when a priming task was used (Study 3). In the current study, social presence induced only a trend on the temporal dynamics of decision-making and feedback monitoring during the P3 amplitude with more negative amplitudes for negative feedback only.

Feedback-related negativity

As expected there was an impact of affect on the FRN component. As predicted and discussed previously in the methodology chapter (Chapter 3), FRN amplitudes were larger for negative and neutral feedback than positive feedback. This finding replicates previous findings from a vast literature that have shown that the motivational/affective significance of negative and neutral feedback outcomes is higher than positive feedback outcomes (Hewig, Trippe, & Hecht, et al., 2007; Holroyd, Nieuwenhuis, & Yeung, 2004; Holroyd, Hajcak, Larsen et al., 2006; Gehring & Willoughby, 2002; Goyer, Woldorff, & Hettel, 2008; Leng & Zhou, 2010; Nieuwenhuis et al., 2004; Villuendas-Gonzalez & Gonzalez-Gorriado, 2016; Yeung & Sanfey, 2004). Another important finding of the current study is that ERP signals for both negative and neutral feedback outcomes were found to be increased at frontocentral electrode locations compared to positive feedback outcome. This is consistent with existing literature (Hobson & Inzlicht, 2016; Tian et al., 2015) and indicates that negative feedback outcomes are processed more in frontocentral brain areas.

In the current study, apart from focusing solely on objective factors that influence ERP amplitudes, self-reported ratings of interest, motivation and feelings towards winning during the task were also included. Interest towards the task was negatively associated with the FRN amplitude, but only when participants completed the task alone. This finding indicates that interest in the task was negatively associated with the FRN amplitude in the alone condition, indicating a lower interest in the alone condition. There are only a few other studies that have examined subjective feelings relating to the task and researchers did not find an association between FRN and interest (Fukushima et al., 2006; Yeung et al., 2005). Importantly these studies differed from the current study because they employed interactive paradigms where two players were taking turns to play a competitive game, whereas in the social presence condition in the current study mere presence was manipulated with an unfamiliar individual observing the participant. Interest was not measured for social and non-social condition separately, so it is difficult to explain the findings. But one explanation for this finding may be that participants were found to be distracted by mere presence in the social condition as explained by the social inhibition theory and therefore were less interested in the task in the social condition (Sharma, Booth, Brown, & Huguet 2010).

P3

As predicted there was an impact of affect on the P3 component, with larger P3 amplitude in response to neutral outcomes than positive and negative outcomes. Previous literature suggests that the P3 component has been associated with high levels of arousal, increased attentional focus and unexpected outcomes (Herrmann & Knight, 2001; Rozenkrants & Polich, 2008; Yeung & Sanfey, 2004; Nieuwenhuis et al., 2005), so this finding indicates that neutral feedback might have been unexpected compared to positive and negative and thus more arousing for the participants.

In Study 3 (Chapter 6) affect of stimuli also modulated P3 amplitudes and similar patterns were found as in the current study. In Study 3, affect of the word-primes influenced trustworthiness judgements with positive word-primes eliciting higher trustworthiness ratings. At temporal level, larger P3 amplitudes for negatively-valenced word primes than positive word primes were observed. The results across both studies in the thesis indicate that the P3 is sensitive to affect across a range of task stimuli (words or feedback). This finding is consistent with prior reports linking P3 to prolonged and elaborative evaluation of ongoing events (Philiastides, Biele, Vavatzanidis et al., 2010; Schupp, Cuthbert, Bradley et al., 2004; Tian et al., 2015).

LPP

Consistent with the initial predictions and similar to findings in Chapter 5 (Study 2), there was no effect of social saliency of context or affect of feedback outcome in the late processing stages of ERP amplitudes. This finding is consistent with previous studies (Bell, et al., 2016; Hajcak, et al., 2006; Wu & Zhou, 2009) that have only reported effects of social presence and affective nature of feedback outcome on the FRN and P3 components. Across all the studies in the current thesis, social saliency did not influence the late possessing stages that have been associated with decision-related processing. In terms of the effect of affect, only Study 3 showed greater LPP amplitudes for negatively-valenced word primes compared to positive word primes.

The effect of social presence in the temporal dynamics of decision-making and feedback monitoring

In the current study, there was a social inhibition effect in the behavioural results demonstrating that social presence might have decreased participants’ performance in the task.

In the FRN amplitude, social saliency of the context (social presence) was not found to have an effect, as negative and neutral feedback outcome modulated the FRN amplitude independent of the social context. This finding is similar to a recent study that obtained the same FRN voltages for both social and non-social condition (Gonzalez & Gonzalez-Garrido, 2016). However, the effect of social saliency elicited a trend of significance during the P3 amplitudes with more negative amplitudes for negative feedback in the alone condition compared to the social presence condition. This finding may indicate that more attention was given to negative feedback in the alone condition than in the presence of another person. One reason for this may be that in the social presence condition attention is distracted away from the task by being observed by another person (Baron, 1986). This is similar to previous studies (Gonzalez & Gonzalez-Garrido, 2016; Leng & Zhou, 2010) that reported increased allocation of attentional resources during P3 in the alone condition (non-social condition).

This finding might be due to a number of reasons. First, the findings in the current study differ from those obtained by Tian et al. (2015) that observed an enlarged FRN signal during social presence compared to the alone condition. The task used in the current study was a target discrimination task, whereas in Tian's et al. (2015) study, participants played a gambling game, so the difference in the results may be reflected in task differences. The gambling game used by Tian et al. is a goal directed, competitive task which might have further reinforced the impact of the observer on the person's performance, the sense of being evaluated and the fear of being negatively judged by the observers, thus, differences in temporal dynamics based on social presence were evident. In contrast, in the current study the task was simple and perhaps less important to participants. Thus, the task was not sufficient to warrant fear of negative evaluation based on performance (less cost to the participant) and hence no temporal differences were evident.

Another potential reason for the lack of social facilitation effect during FRN in the current study, could relate to the lack of a close interpersonal relationship between the confederate and the player. Familiarity with the confederate has been found to modulate neural feedback evaluation (Hobson et al., 2016; Ma et al., 2011). Specifically, ERP studies have found larger FRN amplitudes in response to observation by a familiar observer than a stranger (Hobson & Inzlicht, 2016). In another study, participants performed a gambling task with a friend and a stranger. Increased P3 and FRN amplitudes were observed during the friend's performance compared to stranger's performance. These results indicate that familiarity is a factor that influences performance monitoring. A sociality effect in the FRN may be sensitive to familiarity of the observer which indicates that the mere presence effect may only be present when the observer is a familiar person or a person whom they have a close relationship too.

Strengths and Weaknesses

The current study makes an important contribution to the literature by exploring the temporal dynamics of decision-making and feedback monitoring in a task that social presence was manipulated. The findings showed an effect of social saliency at the behavioural level with a social inhibition effect in the behavioural performance and a trend towards significance during the P3 amplitude for negative feedback only. But social presence did not have an effect during FRN and P3 amplitudes.

However, a few limitations of the current study should be outlined. In this study, self-reported measures regarding participants' state were acquired for the whole task retrospectively rather that independently for each condition. Future studies should examine self-reported states independently for each condition to explore the contribution of interest and motivations of the participants in the neural processing of performance outcome in each condition (social and non-social). In the current study, a negative association between interest and FRN amplitudes was observed which warrants further investigation in future studies with larger sample sizes.

As discussed above, familiarity has been found to influence performance monitoring (Hobson et al., 2016; Ma et al., 2011). So, future studies should consider exploring further the contribution of familiarity of the observer on task performance and temporal dynamics by examining differences between results obtained when friends, strangers and familiar people are used as observers.

For the purposes of the current study predetermined feedback was used in accordance with the previous literature (Chen et al., 2012; Li, Yuan, Jia et al., 2009; Tian et al., 2015; Qu et al., 2013; Zhang et al., 2012; Yeung & Sanfey, 2014). Future studies should consider including actual feedback based on the participants' performance as false feedback might have influenced the temporal properties of decision-making in the current study due to uncontrolled expectation violation and/or uninformative feedback.

Previous studies have shown that individual differences influence task performance (Fukushima et al., 2006; Meconi, et al. 2014) therefore, another avenue for future research in this area would be to explore how individual traits including anxiety levels, depression and loneliness might contribute to the influence of social presence on feedback processing and whether heightened levels of anxiety or depression might alter the performance monitoring processes when a person is observed.

7.6 Conclusion and links to other chapters

The current study examined the temporal dynamics of decision-making and feedback monitoring by manipulating both the social saliency of the context and the affect of the feedback outcome. The current study provides evidence that the affect of feedback outcome influences both behavioural performance and temporal dynamics of decision-making. Affect of word-primes was found to modulate the neural underpinnings of trustworthiness judgements in Study 3 (outlined in Chapter 6), providing further evidence about the influences on the temporal dynamics of decision-making. Also, the current study provides evidence about the effect of social saliency at behavioural level but not in the temporal dynamics. These findings are in line with the results in Study 3 that reported the impact of social saliency on the trustworthiness judgements but not for the temporal dynamics of affective priming. But these findings are in contrast to the results in Study 2 (outlined in Chapter 5) which revealed the effect of social saliency during the sensory processing and attentional focus stages. These findings demonstrate that the influence of social saliency on temporal dynamics may be dependent on task characteristics, presence of other individuals and affect of the stimuli used. The next chapter (Chapter 8) summarises the findings across all the studies in this thesis and outlines impacts on the existing literature.

Chapter 8. Discussion

8.1. Introduction

The main focus of this thesis was to examine the influence of social saliency and affect on the underlying temporal dynamics of perceptual decision-making. Three conceptually similar studies were designed involving simple perceptual decision-making tasks in which both social saliency and affect were manipulated to contrast differences in stages of processing dependent on social saliency and affect. Thus, in each of the studies in the thesis social saliency was manipulated: social saliency of the task stimuli (Study 2), social saliency of word-primes (Study 3) and social saliency of context (i.e. mere observation, Study 4). In addition, affect was also manipulated in each study: affect of the task stimuli in Study 2, affect of the the primes in Study 3 and affect of the feedback outcome in Study 4.

This chapter will initially provide a summary of the findings from each study and then discuss the contribution of the findings in relation to the research questions as outlined in Chapter 1.

8.2. Summary of Studies

The work in the thesis commenced with a systematic review of the literature (Chapter 4, Study 1) which synthesised existing neurophysiological evidence from studies that directly compared the neural basis of social and non-social decision-making involving all neuroimaging paradigms and task design to examine patterns in brain correlates and temporal dynamics relating to social saliency and establish gaps in the literature. Therefore, all neuroimaging and electrophysiological studies that explicitly examined differences/similarities in studies involving diverse tasks (i.e. interactive, non-interactive, theory of mind, social cognition), social saliency manipulations (i.e. stimuli type, reward type and social presence) and methodologies (i.e. fMRI, EEG) were included in this review. The main finding of the systematic review is that diverse social saliency manipulations and tasks were used in the included studies which influenced the results of the individual studies. Certain brain areas were activated in a task dependent way (i.e. ACC, insula, VTA, amygdala), other areas were activated across the range of tasks (i.e. the ventral striatum was active across all tasks independent of the social saliency of the stimuli or the tasks used) indicating that the area was associated with decision processing. Also, the manipulation of social saliency involved varying the type of stimuli and reward used as well as the effect of social presence on the decision process. Studies without rewards find enhanced activation at vmPFC, TPJ, dlPFC and PFC, fusiform area and IPS whereas studies that used rewards find enhanced activation at ventral striatum, insula, ACC, caudate nucleus, putamen, vmPFC and thalamus (Heekeren et al., 2004; Mitchell et al., 2008; Pegors et al., 2015; Rademacher et al., 2010; 2014; Saxe et al., 2003). Across all studies, either using rewards or not, the vmPFC was consistently activated, potentially representing the decision value (Behrens et al., 2009; Pegors et al., 2012; Janowski et al., 2013). Also, across the studies involving social presence, the ventral striatum and amygdala were implicated depending on the type of task.

Another important finding of the systematic review is that a vast literature has used fMRI to contrast the different types of decision-making, thus, most of existing findings relate to spatial characteristics, rather than temporal properties of decision-making. So, the review highlighted that there was scarce electrophysiological literature examining differences in temporal charactersitics between social and non-social decision-making. A further limitation was that there were only a few studies that examined simple perceptual decision-making tasks.

To address the gaps highlighted by the systematic review in Chapter 4, a series of conceptually similar empirical studies were conducted involving simple perceptual decision-making tasks in which the social saliency and affect were manipulated to contrast differences in temporal stages of decision-making dependent on social saliency and affect. The first empirical study in the thesis (Study 2, Chapter 5) examined the influence of social saliency on temporal dynamics of perceptual decision-making by mainuplating the task stimuli. The task stimuli used were faces (social) and landscapes (non-social) presented in pairs, one happy and one sad. In that study, social saliency influenced only the sensory stages and the attentional focus stages with higher amplitudes for social stimuli compared to non-social stimuli. The mid-range, affective evaluation stage was found to have higher amplitudes for non-social stimuli. During the late processing stages social saliency did not influence evaluative processing (i.e. there was no difference in processing based on social saliency).

In Study 3 a priming paradigm was used, and the social saliency of primes was manipulated. Study 3 examined priming effects in trustworthiness judgements using ERPs. In that study, social and non-social word-primes were used, and affect was also manipulated (positive and negative). Word-primes were presented briefly before participants made a trustworthiness judgement of a neutral face. There was no impact of social saliency or affect during the sensory processing or attentional focus stage, however, negative word primes elicited higher amplitudes during the mid-range processing stage (around 300 ms) which continued into the evaluative processing stage (around 600 ms) for the negatively-valenced primes trials independent of social saliency.

In study 4, social saliency was manipulated by having the participant complete the task with an observer. In contrast to the first two studies, which manipulated the social saliency and affect of the task stimuli and word-primes, Study 4 manipulated the social saliency of context in which the task took place: participants either completed the task in the presence of an observer (social) or alone (non-social). In this study, affect was manipulated by giving participants feedback through the task itself (i.e. via the computer) that varied in affect (i.e. positive, negative, and neutral). Findings of Study 4 demonstrated that social presence and affect influenced the mid-range and late processing stages. Similar to Study 3, there was no impact of social saliency or affect during the sensory processing and attentional focus stages, but negative and neutral feedback outcomes elicited higher amplitudes during the feedback related stages and neutral feedback elicited larger ERP amplitudes during the mid-range stages. In Study 4 there was also an interaction of social saliency and affect, with higher mid-range amplitudes for non-social condition only for the trials where negative feedback was given.

Taken together, the results of this thesis further support the proposition made in the systematic review that both the task type used and the social saliency manipulation influence the underlying temporal processing of decisions. Given that social saliency only influenced the temporal dynamics in Study 2 results indicate that early sensory processing is sensitive to social stimuli compared to non-social stimuli when faces are used as physical stimuli. But, findings of Study 3 show that the manipulation of social saliency of word primes has an effect on higher cognitive processing stages during the mid-range and late more evaluative stages. The findings of Study 4 are in line with Study 2 that found an effect of social saliency during the P3 stage with higher amplitudes for non-social images but in contrast to Study 3 that did not report any effect of social saliency. These apparent differences could be due to the variability in the social saliency manipulation; in Study 2 the social saliency of the stimuli was manipulated, in Study 3 the social saliency of the word primes was manipulated and in Study 4 the social saliency of the context was manipulated.

Table 8-1 provides a summary of findings across all studies in relation to the influence of social saliency on the temporal dynamics of decision-making. In terms of the impact of affect on the decision process, the findings from Study 3 and Study 4 suggest that the affective nature of word-primes and feedback outcome may moderate higher-cognitive time-windows. The sensitivity towards negatively-valenced primes and negative and neutral feedback found during the feedback-related stages, the mid-range and late processing stages suggests that participants might have been more motivated by the negative and neutral stimuli than the positive one and oriented their attention towards it.

Table 8-1. Summary of findings across all studies of the thesis.

ERP Components	**Study 2**	**Study 3**	**Study 4**
Details of Studies	Preference judgements • Social saliency manipulation	Priming effects on trustworthiness judgements • Social saliency manipulation • Affect manipulation (negative vs. positive stimuli)	Social presence effects on performance • Social saliency manipulation • Affect manipulation (negative vs. positive vs. neutral feedback)
Social saliency manipulation	social vs. non-social stimuli	social vs. non-social stimuli	Social presence vs. alone
N1/P1 (100-200 ms)	Higher amplitudes for social	No differences observed	No differences observed
P2/N2/FRN (200-300ms)	Higher amplitudes for social	No differences observed	No differences observed Higher amplitudes for neutral & negative feedback
P3 (300-600ms)	Higher amplitudes for non-social	No differences observed Higher amplitudes for negative primes	Higher amplitudes for non-social Higher amplitudes for negative feedback
LPP (600-800ms)	No differences observed	No differences observed Higher amplitudes for negative primes	No differences observed

8.3. Contribution to Knowledge

The work in the current thesis investigates the temporal dynamics of decision-making. The work in this thesis is unique because it adds to the limited literature that examines simple perceptual decision-making using tasks that involve an overt judgement rather than passive viewing and investigates the effect of social saliency and affect on the decision process. The series of studies in the current thesis address gaps in the literature by examining different aspects of social saliency on decision-making and provide electrophysiological insights into the neural representation of social decisions in the human brain. The thesis makes an important contribution to existing knowledge about social decision-making in three ways: 1) by providing insights into the influence of social saliency on the temporal dynamics of simple decision-making, 2) highlighting the importance of affect as a potential moderator of the decision-making process, and 3) demonstrates the influence of task and stimuli type in the results of the individual empirical studies. Overall, the findings of the thesis reveal that the final choice outcome of a decision is influenced by a number of diverse factors including, social saliency of stimuli, social context, affective nature of the stimuli and feedback outcome.

8.3.1. The influence of social saliency on the temporal dynamics of decision-making

The current thesis addresses the lack of ERP studies that contrast social and non-social decision-making. This was achieved by manipulating social saliency and builds on findings from fMRI studies by providing information about temporal dynamics of perceptual decision-making. The findings of the thesis demonstrate some important differences in social and non-social domains relating to sensory and late processing based on the manipulation of social saliency. Study 2 found that sensory and attentional focus ERP components are sensitive to the social saliency of images, reflecting a sensitivity towards social images compared to non-social images as a result of biologically relevant stimuli (humans) (Proverbio et al., 2009). This finding is in line with current literature suggesting preferential processing of faces during the sensory processing stages (Batty & Taylor, 2003; Halgren, Raij, Marinkovic, Jousmaki, & Hari, 2000; Junghöfer, Bradley, Elbert, & Lang, 2001; Pizzagalli et al., 2002). This result was observed only in Study 2 because it is the only study in this thesis that manipulated the social saliency of task stimuli using faces.

But, the influence of social saliency on trustworthiness judgements was not evident in Study 3. Findings in that study only showed a trend towards significance during the late stages of processing for social word-primes. The lack of sensory processing activation for word-primes in Study 3 might be explained by literature suggesting that word-primes as stimuli require enhanced elaborative processing hence elicit activation during the later, more elaborative ERP stages (Paller, Kutas, & McIsaac, 1995) reflecting evaluation and categorical decision (Leppanen & Hietanen, 2004, 2005).

This finding is in contrast with results from Study 2 that found activation in sensory processing and attentional focus ERP components in response to face-stimuli. Therefore, in the current thesis the apparent differences that were observed between Study 2 and 3 could be attributed to the different type of stimuli used (face or word). Current literature suggests differential processing of pictures and words (Herbert et al., 2006; Liu et al., 2010; Zhang, Lawson, Guo, & Jiang, 2006). This is because pictures lead to a more direct access to meaning representations than word stimuli (de Houwer & Hermans, 1994; Kouider & Dehaene, 2007) which is potentially the reason that word-primes do not affect sensory and attentional focus components. Thus, it is not surprising that face-primes influence amplitudes during sensory processing components relative to word-primes and led to differences in the underlying temporal activation between Study 2 and Study 3 of this thesis.

Moreover, literature suggests that stimuli which are biologically relevant to humans (such as pictures with human faces that were used in Study 2) elicit higher levels of arousal compared to verbal information or shapes (Hinosa, Carretie, Valcarcel, et al., 2009; Keil, 2006; Kissler et al., 2006; Mogg & Bradley, 1998). This finding is supported by a recent study that compared priming effect from words and emoticons (Comesana et al., 2013). The study showed that early ERP components have been associated with the presentation of emoticons rather than emotional words (Comesana et al., 2013) and affective priming effects in attentional focus electrophysiological components (N2) for negative words and during LPP for positive words.

But there are also similarities in the way the human organism deals with pictorial and word emotional stimuli. Processing of emotional words and pictures has been found to be associated with event-related P3 and LPP responses compared to processing neutral stimuli (Chapman, McCrary, Chapman & Martin, 1980; Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Keil et al., 2002; Naumann, Bartussek, Diedrich & Laufer, 1992).

Similar to Study 3, Study 4 which manipulated the social saliency of context did not find an influence of social saliency on in the sensory processing and attentional focus stages but social saliency (i.e. presence of an observer) modulated P3 amplitudes for negative feedback. The significant interaction shown indicates that during the mid-range time window more attention is given to negative feedback in the alone condition than in the presence of another person. This finding aligns with current literature and indicates that in the social presence condition attention is distracted away from the task by being observed by another person (Baron, 1986; Gonzalez & Gonzalez-Garrido, 2016; Leng & Zhou, 2010). Also, this finding could be explained by the lack of familiarity between the player and the observer. There are a number of studies that suggest that familiarity is a factor that influences performance monitoring. These studies reported increased P3 and FRN amplitudes when the observer is a familiar person compared to a stranger (Hobson et al., 2016; Ma et al., 2011).

Overall, social saliency influenced different temporal stages of decision-making depending on the type of stimuli and task type used in each of the empirical studies of this thesis. From the findings it was evident that faces because they possess physical characteristics and emotional properties (a happy and sad face have different characteristics which can be distinguished visually), are efficient in inducing effects on sensory processing and attention allocation ERP components as seen in Study 2. Whereas social saliency manipulation of context did not have an effect on the decision process as seen in Study 4.

8.3.2. The influence of affect on the temporal dynamics of decision-making

The studies in this thesis offer important insights into existing theoretical understanding of social decision-making because the findings provide evidence that affect of the stimuli or feedback influence the temporal dynamics of decision-making. The results across Studies 3 and 4 indicate that the P3 is sensitive to affect across a range of task stimuli (words or feedback). More specifically, negative word-primes elicit larger mid-range and late processing amplitudes and neutral and negative feedback outcomes elicit larger feedback-related and mid-range processing amplitudes hence, influence the temporal dynamics associated with decision-making.

Study 3 provided electrophysiological evidence about the effect of negative word-primes on subsequent trustworthiness judgements. Findings of Study 3 showed that both mid-range P3 component and late processing LPP component were larger for negatively-valenced word-primes than positive word-primes which might indicate stronger encoding of the negatively-valenced sensory information rather than positive and reflect the motivational/affective evaluation of negative words. This finding is similar to previous studies that have used word-primes (Li et al., 2008; Comesana et al., 2013) and extends existing knowledge about unconscious influences on trustworthiness judgements.

Results of Study 4 provide further evidence that the affective nature of the stimuli plays an important role in the decision-making process, influencing the cognitive processes. Specifically, affective nature of feedback outcomes influenced the FRN and P3 amplitudes. The FRN component was found to be more sensitive to negative and neutral feedback than positive feedback outcomes. The mid-range P3 component was found to have larger amplitudes for neutral feedback compared to negative and positive feedback outcomes. This finding is consistent with previous studies that have used affective feedback outcome (Chen et al., 2012; Li, Yuan, Jia et al., 2009; Tian et al., 2015; Qu et al., 2013; Zhang et al., 2012; Yeung & Sanfey, 2014), and found an effect in mid-range rather than sensory and attentional focus stages of processing.

This finding is also in line with prior reports linking mid-range, P3, amplitudes to prolonged and elaborative evaluation of ongoing events (Philiastides, Biele, Vavatzanidis et al., 2010; Schupp, Cuthbert, Bradley et al., 2004; Tian et al., 2015). However, as Study 4 included the manipulation of affect in feedback outcome an additional component was examined only in Study 4, the FRN. So, the difference between Study 3 and Study 4 is that in Study 4, both negative and neutral feedback outcomes were found to elicit larger FRN amplitudes consistent with the feedback monitoring literature (Hewig, Trippe, & Hecht, et al., 2007; Holroyd, Nieuwenhuis, & Yeung, 2004; Holroyd, Hajcak, Larsen et al., 2006; Gehring & Willoughby, 2002; Goyer, Woldorff, & Hettel, 2008; Leng & Zhou, 2010; Nieuwenhuis et al., 2004; Villuendas- Gonzalez & Gonzalez-Gorriado, 2016; Yeung and Sanfey, 2004). Also, the influence of affect sustained until the LPP amplitudes in

Study 3 which was not evident for Study 4. This apparent difference might be due to the type of stimuli used. So, across the feedback monitoring studies effects of affective nature of feedback outcome are reported mainly in the FRN and P3 components (Bell, et al., 2016; Hajcak, et al., 2006; Wu & Zhou, 2009).

Taken together, the studies in this thesis are the first to examine the impact of social saliency and affect together; Study 3 was the first to examine the impact of affect of social and non-social stimuli on trustworthiness judgements and Study 4 examined the impact of affective feedback outcome on the neural feedback processing when a simple perceptual task was completed in the presence of an observer and when alone. The influence of affect was independent of social saliency in Study 3. These findings are consistent with the findings in Study 4, that there was no sociality or affect impact during the sensory processing and attentional focus ERP components. This finding supports the claim made in Chapter 6 that differences in the sensory processing stage (P1, N1) reflect the processing of the physical characteristics of the face (Key, et al., 2005; Lu, et al., 2011). But, in Study 4 the effect of social saliency elicited a trend of significance during the P3 amplitudes with more negative amplitudes for negative feedback in the alone condition compared to the social presence condition. This finding may indicate that more attention was given to negative feedback in the alone condition than in the presence of another person. One reason for this may be that in the social presence condition attention is distracted away from the task by being observed by another person (Baron, 1986). This is similar to previous studies that reported increased allocation of attentional resources during P3 in the alone condition (non-social condition) (Gonzalez & Gonzalez-Garrido, 2016; Leng & Zhou, 2010).

Overall the findings of the current thesis provide electrophysiological evidence that both social saliency and affect of stimuli/context moderate temporal dynamics of processing decisions in the brain. Differences were evident at electrophysiological levels and demonstrate that the affect of information modulated the processing of stimuli in Studies 3 and 4 and was particularly associated with three ERP components: FRN, P3 and LPP. Existing literature has associated FRN specifically with feedback outcome evaluation and P3 and LPP with motivational/affective evaluation of sensory information and decision-related processing (Hinosa, Carretie, Valcarcel, et al., 2009).

Current literature rarely examines affect in social and non-social decision-making studies. The findings in this thesis indicate that future research in decision-making should measure both social saliency and affect because in some conditions (i.e. social presence) interactions between social saliency and affect may influence the temporal dynamics of decision-making. This is important because affect is embedded in all types of social information and therefore are interrelated when it comes to influencing decision-making.

8.3.3. Overall Findings

Extant literature is scarce on the influence of social saliency and affect on the temporal dynamics of perceptual decision-making. Both factors appear to influence simple perceptual decision-making tasks at different processing stages. Sensory processing and attentional focus components (less than

<200ms after stimulus onset) are sensitive to the social saliency but this is stimuli dependent: faces as a form of social stimuli demonstrated an influence on the temporal charactertistics. This was demonstrated in Study 2 (Chapter 5) that sensory processing was found to be sensitive to faces, reflecting encoding of sensory information of the physical characteristics of the stimuli. However, when it comes to processing words (as seen in Study 3- Chapter 6) and feedback outcome (as seen in Study 4- Chapter 7) this effect on sensory processing is not evident. This finding suggests that there is a sensitivity in the sensory processing and attentional focus stages for the encoding of physical properties of the stimuli (for face-stimuli) and initial processing of the affective nature of stimuli which has been shown to be <200ms after stimulus onset. Both mid-range and late processing stages were moderated by the affect of stimuli, with negative word-primes and non-social negative feedback outcomes modulating temporal activation. These findings indicate that ERP amplitudes around 300-600ms in the mid-range stages are sensitive to non-social information and modulated by the affect of stimuli/feedback with sensitivity towards negatively-valenced stimuli. Interaction effects between social saliency and affect were observed during mid-range stages in Study 4. Social presence induced only a trend on the temporal dynamics of decision-making and feedback monitoring during the P3 amplitude with more negative amplitudes for negative feedback only.

Finally, during the late ERP stages (around 600-800 ms) representing the LPP component, there was no effect of social saliency across all studies which might indicate no differences in the decision-related mechanism based on social saliency. There was an impact of affect as negatively-valenced word primes moderated amplitudes during late processing stages in Study 3.

Findings of this thesis suggest that during the first stage, encoding of physical only information takes place through processing of the different characteristics of stimuli (around 100 - 200ms), followed by the second stage (around 200 - 300ms) that attentional resources required to process the task accurately are engaged only when physical stimuli is encoded (i.e. faces) or when feedback outcome is available with a sensitivity towards negatively-valenced feedback, then during mid-range stages (around 300 - 600ms) affective evaluation takes places which is moderated by negatively-valenced stimuli and finally decision-related processes reflecting evaluative judgements take place (around 600 - 800ms) which were not found to differ between social and non-social domains in the present thesis. Overall, findings of the current thesis demonstrate that depending on the type of stimuli there are different stages of information processing.

8.4. Further Research

Research studies in this thesis have shown that depending on the social saliency of stimuli or context (social or non-social) the processing of information takes place at different temporal stages. The studies in this thesis only examined simple perception decision-making, future research should examine the impact of interactions between social saliency and affect in more complex decisions. This would be important to fully understand the temporal characterisation of social decision-making and similarities and differences with non-social decision-making.

It is important that future studies should combine fMRI with EEG techniques using pre-defined highly discriminating EEG components to provide insights about the spatiotemporal dynamics of social decision-making and describe the neural dynamics of decision-making. The work in this thesis indicates that combination of ERP and fMRI data can provide a more complete map regarding the underlying neural association between social and non-social decision-making and the influence of affective states in the decision process.

Research to date has begun to examine the online interaction of two different brains (Astolfi et al., 2011; Burgess, 2013; Funane, Kiguchi, Atsumori, Sato et al., 2011; Montague, et al., 2002), a methodological tool which has been relatively neglected until now. Future research should explore further whether the neural processing of social cooperation between two and/or multiple people simultaneously influences decision-making using complex perceptual decision-making tasks that involve competition and cooperation. This is important in order to build on work in this thesis and generate a more complete model of the influence of the social nature of information in decisions and the social context that decisions are made on the underlying temporal characteristics.

Individual variations in psychopathology including depression, social anxiety, and loneliness might also influence the way individuals make decisions and the structural organisation of the brain areas related to decision-making. Evidence has shown that social anxiety is associated with different amygdala activity (Rilling, Winslow & Kilts 2004) and lonely people were found to have less activation in ventral striatum compared to non-lonely people when viewing happy social pictures (Cacioppo, Norris, Decety, Monteleone et al., 2009) indicating that further research is necessary. Therefore, an exploration of whether individual variability interacts and moderates the influence of social saliency and affect would be important in future research to fully understand the neural system of decision-making and the structural organisation of the brain areas related to decision-making.

The systematic review in this thesis indicated that age and gender may influence the neural processing of social decisions (see Chapter 4). There are a few studies that have examined gender and age differences in relation to social decision-making (Proverbio et al., 2009; Rademacher et al., 2014; Spreckelmeyer et al., 2009) so future research should ensure that age and gender is measured and examined in order to account for potential differences in findings based on age and gender.

8.5. Summary of Findings & Contributions

The work in the current thesis sheds light on the understanding of the influence of social saliency on the temporal dynamics of perceptual decision-making. Social saliency (i.e. task stimuli, unconscious influences, social presence) has been shown to influence behaviour, performance and temporal dynamics of individual perceptual decision-making tasks.

The findings in the thesis demonstrate that social saliency influences the way people weigh different options and make choices and impact on the way that information is processed in the brain. So, examining decision-making without an appreciation of social saliency only results in a limited understanding of the temporal mechanisms underlying decision-making.

Moving forward, research into decision-making must examine both social saliency and affect of the stimuli and context in which it occurs to fully understand the complexity of this cognitive process.

8.6 Conclusion

The aim of this thesis was to investigate the influence of social saliency on temporal dynamics of simple perceptual decision-making tasks through a series of conceptually studies. At the same time, affect of the stimuli was also manipulated and its impact on decision-making was examined. The findings demonstrate that these factors influence the underlying temporal processing of decision-making at different stages depending on the task/stimuli used. The findings of the current thesis provide valuable insights regarding the effect of social saliency on temporal dynamics of decision-making demonstrating differences between social and non-social decision-making. The findings also establish links between social saliency and affect and their combined impact on decision-making, which is a novel approach in this research area, providing valuable information regarding the temporal dynamics of decision-making. Overall the findings of the current thesis highlight the complex nature of social decision-making which makes it challenging to accurately establish its temporal underpinnings especially when compared with non-social decision-making and the importance of continuing research in this challenging field.

References

Adolphs, R, Tranel, D, Damasio, A. R. (1998). The human amygdala in social judgement. *Nature,* 393, 470–474, doi: 10.1038/30982.

Adolphs, R. (2009). The social brain: neural basis of social knowledge. *Annual review of psychology*, 60, 693-716. doi: 10.1146/annurev.psych.60.110707.163514.

Aiello, J. R., & Douthitt, E. A. (2001). Social facilitation from Triplett to electronic performance monitoring. *Group Dynamics: Theory, Research, and Practice*, *5*(3), 163. doi: 10.1037//1089.2699.5.3.163.

Alicke, M. D., Davis, T. L., & Pezzo, M. V. (1994). A posteriori adjustment of a priori decision criteria. *Social Cognition*, 12(4), 281-308.

Allison, S. T., Mackie, D. M., & Messick, D. M. (1996). Outcome biases in social perception: Implications for dispositional inference, attitude change, stereotyping, and social behavior. In Advances in experimental social psychology (Vol. 28, pp. 53-93). Academic Press.

Allport, F. H. (1924). The group fallacy in relation to social science. *American Journal of Sociology*, 29(6), 688-706.

Amft, M., Bzdok, D., Laird, A. R., Fox, P. T., Schilbach, L., & Eickhoff, S. B. (2015). Definition and characterization of an extended social-affective default network. *Brain Structure and Function, 220*(2), 1031-1049. doi: 10.1007/s00429-013-0698-0.

Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: the medial frontal cortex and social cognition. *Current Opinion Neurobiology, 7*, 268-277. doi: 10.1038/nrn1884.

Amodio, D. M., & Harmon-Jones, E. (2011). Trait emotions and affective modulation of the startle eyeblink: On the unique relationship of trait anger. *Emotion*, 11(1), 47. doi: 10.1037/a0021238.

Amodio, D. M., Bartholow, B. D., & Ito, T. A. (2013). Tracking the dynamics of the social brain: ERP approaches for social cognitive and affective neuroscience. *Social Cognitive and Affective Neuroscience*, 9(3), 385-393. doi: 10.1093/scan/nst177.

Anderson, B. A. (2016). The attention habit: How reward learning shapes attentional selection. *Annals of the new York Academy of Sciences*, *1369*(1), 24-39. doi: 10.1111/nyas.12957.

Andreassi, J. L. (2000). *Psychophysiology: Human Behavior & Physiological* Response (4th Ed.). Mahwah, NJ: L. Erlbaum Associates.

Andrews, V., Lipp, O. V., Mallan, K. M., & König, S. (2011). No evidence for subliminal affective priming with emotional facial expression primes. *Motivation and Emotion*, 35, 33-43. doi: 10.1007/s11031-010-9196-3.

Antonakis, J., Dalgas, O., (2009). Predicting elections: child's play. *Science*, 323, 1183, doi: 10.1126/science.1167748.

Arterberry, M. E., Cain, K. M., & Chopko, S. A. (2007). Collaborative Problem Solving in Five-Year-Old Children: Evidence of social facilitation and social loafing. *Educational Psychology*, *27*(5), 577-596. doi: 10.1080/01443410701308755.

Astolfi, L., Toppi, J., Fallani, F. D. V., Vecchiato, G., Cincotti, F., Wilke, C. T., ... & Babiloni, F. (2011). Imaging the social brain by simultaneous hyperscanning during subject interaction. *IEEE intelligent systems*, *26*(5), 38. doi: 10.1109/MIS.2011.61.

Augustine, A. A. and Larsen, R., J. (2011). Affect regulation and temporal discounting: Interactions between primed, state, and trait affect. *Emotion*, 11, 403-412. doi: 10.1037/a0021777.

Bartles, A., & Zeki, S. (2004). The neural correlates of maternal and romantic love. *Neuroimage*, 21, 1155–1166, doi:10.1016/j.neuroimage.2003.11.003.

Benning, S. D., Kovac, M., Campbell, A., Miller, S., Hanna, E. K., Damiano, C. R., ... & Kinard, J. (2016). Late positive potential ERP responses to social and non-social stimuli in youth with autism spectrum disorder. *Journal of autism and developmental disorders*, *46*(9), 3068-3077.

Bar, M., Neta, M., & Linz, H. (2006). Very first impressions. *Emotion*, 6, 269–278, doi: 10.1037/1528-3542.6.2.269.

Barker, A. T., Jalinous, R., & Freeston, I. L. (1985). Non-invasive magnetic stimulation of human motor cortex. *The Lancet,* 325(8437), 1106-1107.

Baron, R. S. (1986). *Distraction-conflict theory: Progress and problems.* In Advances in experimental social psychology (Vol. 19, pp. 1-40). Academic Press.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of personality and social psychology,* 51(6), 1173.

Baron, J., & Hershey, J. C. (1988). Outcome bias in decision evaluation. *Journal of personality and social psychology,* 54(4), 569.

Batty, M., & Taylor, M. J. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research,* 17(3), 613-620. doi: 10.1016/S0926-6410(03)00174-5.

Baumeister, R. F., & Finkel, E. J. (Eds.). (2010). Advanced social psychology: The state of the science. OUP USA.

Bault, N., Joffily, M., Rustichini, A., & Coricelli, G. (2011). Medial prefrontal cortex and striatum mediate the influence of social comparison on the decision process. Proceedings of the national Academy of sciences, 108(38), 16044-16049. doi:10.1073/pnas.1100892108/-/DCSupplemental.

Baxter, J. S., Manstead, A. S., Stradling, S. G., Campbell, K. A., Reason, J. T., & Parker, D. (1990). Social facilitation and driver behaviour. *British Journal of Psychology, 81*(3), 351-360. doi: 10.1111/j.2044-8295.1990.tb02366.x.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*, 7-15.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science, 27*, 1293-1295.

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, Decision-making and the Orbitofrontal Cortex. *Cerebral Cortex*, 295-307.

Bechara A (2004a): The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain Cognition,* 55, 30 – 40. doi: 10.1016/j.bandc.2003.04.001.

Behrens, T. E., Hunt, L. T., Woolrich, M. W., and Rushworth, M. F. (2008). Associative learning of social value. *Nature* 456, 245–249. doi: 10.1038/nature07538.

Bell, R., Sasse, J., Möller, M., Czernochowski, D., Mayr, S., & Buchner, A. (2015). Event-related potentials in response to cheating and cooperation in a social dilemma game. *Psychophysiology*. doi: 10.1111/psyp.12561.

Bengtsson, S. L., Dolan, R. J., & Passingham, R. E. (2010). Priming for self-esteem influences the monitoring of one’s own performance. *Social cognitive and affective neuroscience*, *6*(4), 417-425. doi: 10.1093/scan/nsq048.

Berger, H. (1929). *Electroencephalogram in humans.* Archiv für Psychiatrie und Nervenkrankheiten, 87, 527 – 570.

Blank, H., Biele, G., Heekeren, H. R., & Philiastides, M. G. (2013). Temporal characteristics of the influence of punishment on perceptual decision making in the human brain. *Journal of Neuroscience*, *33*(9), 3939-3952. doi:10.1523/JNEUROSCI.4151-12.2013

Brédart, S., Delchambre, M., & Laureys, S. (2006). One's own face is hard to ignore. *Quarterly Journal of Experimental Psychology*, 59, 46–52.

Brédart, S., Delchambre, M., & Laureys, S. (2006). Short article one's own face is hard to ignore. *The Quarterly Journal of Experimental Psychology*, 59(1), 46-52. doi: 10.1080/17470210500343678.

Bradley, M. M., & Lang, P. J. (1999). *Affective norms for English words (ANEW): Instruction manual and affective ratings* (pp. 1-45). Technical report C-1, the center for research in psychophysiology, University of Florida.

Breitmeyer, B. G., Ogmen, H., & Chen, J. (2004). Unconscious priming by color and form: Different processes and levels. *Consciousness and cognition*, *13*(1), 138-157. doi: 10.1016/j.concog.2003.07.004.

Briggs, K. E., & Martin, F. H. (2009). Affective picture processing and motivational relevance: arousal and valence effects on ERPs in an oddball task. *International Journal of Psychophysiology*, *72*(3), 299-306. doi: 10.1016/j.ijpsycho.2009.01.009.

Bry, C., Follenfant, A., & Meyer, T. (2008). Blonde like me: When self-construals moderate stereotype priming effects on intellectual performance. *Journal of Experimental Social Psychology*, *44*(3), 751-757. doi: 10.1016/j.jesp.2007.06.005.

Bodenhausen, G. V., Kramer, G. P., & Süsser, K. (1994). Happiness and stereotypic thinking in social judgment. *Journal of personality and social psychology*, *66*(4), 621.

Bond, C. F., & Titus, L. J. (1983). Social facilitation: a meta-analysis of 241 studies. *Psychological bulletin*, *94*(2), 265.

Bolton, G. and Ockenfels, A. 1998. Strategy and Equity: An ERC-Analysis of the Güth-van Damme Game. *Journal of Mathematical Psychology*, 62, 215–226.

Borod, J. C., Bloom, R. L., Brickman, A. M., Nakhutina, L., & Curko, E. A. (2002). Emotional processing deficits in individuals with unilateral brain damage. *Applied neuropsychology*, *9*(1), 23-36. doi: 10.1207/S15324826AN0901_4.

Burgess, A. P. (2013). On the interpretation of synchronization in EEG hyperscanning studies: a cautionary note. *Frontiers in Human Neuroscience*, 7. doi: 10.3389/fnhum.2013.00881.

Cacioppo, J. T., & Berntson, G. G. (1992). Social psychological contributions to the decade of the brain: Doctrine of multilevel analysis. *American Psychologist,* 47(8), 1019.

Cacioppo, J. T., Crites, S. L., Jr., Berntson, G. G., & Coles, M. G. H. (1993). If attitudes affect how stimuli are processed, should they not affect the event-related brain potential? *Psychological Scienc*e, 4, 108–112, doi: 10.1111/j.1467-9280.1993.tb00470.x.

Cacioppo, J. T., Petty, R. E., Feinstein, J. A., & Jarvis, W. B. G. (1996). Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. *Psychological bulletin*, *119*(2), 197. doi: 10.1037/0033-2909.119.2.197.

Cacioppo, J. T., & Hawkley, L. C. (2009). Perceived social isolation and cognition. *Trends in cognitive sciences*, 13(10), 447-454. doi: 10.1016/j.tics.2009.06.005.

Cacioppo, J. T., Norris, C. J., Decety, J., Monteleone, G., & Nusbaum, H. (2009). In the eye of the beholder: individual differences in perceived social isolation predict regional brain activation to social stimuli. *Journal of cognitive neuroscience*, *21*(1), 83-92. doi: 10.1162/jocn.2009.21007.

Cacioppo, J. T., & Decety, J. (2011). Social neuroscience: challenges and opportunities in the study of complex behavior. *Annals of the New York Academy of Sciences,* 1224(1), 162-173. doi: 10.1111/j.1749-6632.2010.05858.x..

Camerer, C. F., & Fehr, E. (2004). Measuring social norms and preferences using experimental games: A guide for social scientists. *Foundations of human sociality: Economic experiments and ethnographic evidence from fifteen small-scale societies*, 97, 55-95.

Campanella, S., Quinet, P., Bruyer, R., Crommelinck, M., & Guerit, J. M. (2002). Categorical perception of happiness and fear facial expressions: an ERP study. *Journal of cognitive neuroscience*, *14*(2), 210-227, doi: 10.1162/089892902317236858.

Campanella, S., Rossignol, M., Mejias, S., Joassin, F., Maurage, P., Debatisse, D., et al. (2004). Human gender differences in an emotional visual oddball task: An event-related potentials study. *Neuroscience Letters*, 367, 14–18, doi:10.1016/j.neulet.2004.05.097.

Carretié, L., Mercado, F., Tapia, M., & Hinojosa, J. A. (2001). Emotion, attention, and the ‘negativity bias’, studied through event-related potentials. *International journal of psychophysiology*, 41(1), 75-85. doi: 10.1016/S0167-8760(00)00195-1

Carter, M., & Shieh, J. C. (2010). Visualizing nervous system function. *Guide to Research Techniques in Neuroscience*, Elsevier Inc., Canada, 169-189.

Cartmell, S. C. D., Chun, M., Vickery, T. J. (2014). Neural antecedents of social decision-making in a partner choice task. *Social Cognitive Affective Neuroscience*, 9, 1722-1729, doi: 10.1093/scan/nst168.

Crites Jr, S. L., & Cacioppo, J. T. (1996). Electrocortical differentiation of evaluative and nonevaluative categorizations. *Psychological science*, *7*(5), 318-321, doi: 10.1111/j.1467-9280.1996.tb00381.x.

Chang S. W. C., Gariépy J.-F., Platt M. L. (2013). Neuronal reference frames for social decisions in primate frontal cortex. *Nature Neuroscience*, 16, 243–250. doi: 10.1038/nn.3287.

Chen, J., Zhong, J., Zhang, Y., Li, P., Zhang, A., Tan, Q., & Li, H. (2012). Electrophysiological correlates of processing facial attractiveness and its influence on cooperative behavior. Neuroscience letters, 517(2), 65-70. doi: 10.1016/j.neulet.2012.02.082.

Chib, V. S., Rangel, A., Shimojo, S., & O'Doherty, J. P. (2009). Evidence for a common representation of decision values for dissimilar goods in human ventromedial prefrontal cortex. *Journal of Neuroscience*, *29*, 12315-12320. doi: 10.1523/JNEUROSCI.2575-09.2009.

Choi, D., & Watanuki, S. (2014). Effect of empathy trait on attention to faces: an event-related potential (ERP) study. *Journal of physiological anthropology*, 33(1), 1, doi: 10.1186/1880-6805-33-4.

Clark, L., Manes, F., Antoun, N., Sahakian, B. J., Robbin,s T. W. (2003). The contributions of lesion laterality and lesion volume to decision-making impairment following frontal lobe damage. *Neuropsychologia*, 41, 1474 –1483. doi: 10.1016/S0028-3932(03)00081-2.

Clark. L., Cools, R., Robbins, T. W. (2004). The neuropsychology of ventral prefrontal cortex: Decision-making and reversal learning. *Brain Cognition,* 55, 41–53. doi: 10.1016/S0278-2626(03)00284-7.

Cohen, S. (1978). Environmental load and the allocation of attention. in a. baum, je singer, & s. valins (eds.), Advances in environmental psychology (Vol. 1, pp. 1-29).

Cohen, M. X., & Ranganath, C. (2007). Reinforcement learning signals predict future decisions. *Journal of Neuroscience,* 27(2), 371-378. doi: 10.1523/JNEUROSCI.4421-06.2007.

Comesaña, M., Soares, A. P., Perea, M., Piñeiro, A. P., Fraga, I., & Pinheiro, A. (2013). ERP correlates of masked affective priming with emoticons. Computers in Human Behavior, 29(3), 588-595. doi: 10.1016/j.chb.2012.10.020.

Compton, R.J. (2003). The interface between emotion and attention: a review of evidence from psychology and neuroscience. *Behavioural Cognitive Neuroscience Reviews*, 2, 115–129.

Cottrell, N. B., Wack, D. L., Sekerak, G. J., & Rittle, R. H. (1968). Social facilitation of dominant responses by the presence of an audience and the mere presence of others. *Journal of personality and social psychology,* 9(3), 245.

Crisp, R. J., & Turner, R. N. (2010). Have confidence in contact. *American Psychologist*. doi: 10.1037/a0018437.

Crites Jr, S. L., & Cacioppo, J. T. (1996). Electrocortical differentiation of evaluative and nonevaluative categorizations. *Psychological science*, 7(5), 318-321, doi: 10.1111/j.1467-9280.1996.tb00381.x.

Cunningham, W. A., Espinet, S. D., De Young, C. G., & Zelazo, P. D. (2005). Attitudes to the right-and left: frontal ERP asymmetries associated with stimulus valence and processing goals. *NeuroImage*, *28*(4), 827-834, doi: 10.1016/j.neuroimage.2005.04.044.

Cuthbert B. N., Schupp H. T., Bradley M. M., Birbaumer N., Lang P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*, 52, 95–111. doi: 10.1016/S0301-0511(99)00044-7.

Damasio, A. R., Damasio, H., Christen, Y. (Eds.). (1996). *Neurobiology of decision-making.* Berlin: Springer-Verlag.

de Bruijn, E. R., Miedl, S. F., & Bekkering, H. (2011). How a co-actor's task affects monitoring of own errors: evidence from a social event-related potential study. *Experimental brain research*, 211(3-4), 397. doi: 10.1007/s00221-011-2615-1.

Deen, B., Koldewyn, K., Kanwisher, N., & Saxe, R. (2015). Functional organization of social perception and cognition in the superior temporal sulcus. *Cerebral Cortex*, *25*(11), 4596-4609. doi: 10.1093/cercor/bhv111.

de Lange, F. P., Rahnev, D. A., Donner, T. H., & Lau, H. (2013). Prestimulus oscillatory activity over motor cortex reflects perceptual expectations. *Journal of Neuroscience*, *33*(4), 1400-1410. doi: g/10.1523/JNEUROSCI.1094-12.2013.

De Clercq, R. (2005). Aesthetic terms, metaphor, and the nature of aesthetic properties. *The Journal of Aesthetics and Art Criticism*, *63*(1), 27-32. doi: 10.1111/j.0021-8529.2005.00178.x

deFilipo, D., Grose-Fifer, J. (2016). An Event-Related Potential Study of Social Information Processing in Adolescents. *PloS one*, 11(5), e0154459, doi: 10.1371/journal.pone.0154459.

Delgado, M. R., Frank, R. H., & Phelps, E. A. (2005). Perceptions of moral character modulate the neural systems of reward during the trust game. *Nature Neuroscience*, *8*(11), 1611–1618. doi: 10.1038/nn1575.

Dijksterhuis, A., & Van Knippenberg, A. (1998). The relation between perception and behavior, or how to win a game of trivial pursuit. *Journal of personality and social psychology*, *74*(4), 865.

Domenech, P., & Dreher, J. C. (2010). Decision threshold modulation in the human brain. *Journal of Neuroscience*, *30*(43), 14305-14317. doi: 10.1523/JNEUROSCI.2371-10.2010

Dijksterhuis, A., & Aarts, H. (2003). On Wildebeests and Humans The Preferential Detection of Negative Stimuli. *Psychological Science*, *14*(1), 14-18. doi: 10.1111/1467-9280.t01-1-01412.

Dunbar, R.I. (1998). The social brain hypothesis. *Evolutionary Anthropology 6*, 178 190.

Eimer, M. (2000). Effects of face inversion on the structural encoding and recognition of faces: Evidence from event-related brain potentials. *Cognitive Brain Research*, 10(1-2), 145-158. doi: 10.1016/S0926-6410(00)00038-0.

Eimer, M., & Schlaghecken, F. (2003). Response facilitation and inhibition in subliminal priming. Biological psychology, 64(1), 7-26. doi: 10.1016/S0301-0511(03)00100-5.

Ekman, P. (2007). *Emotions revealed: Recognizing faces and feelings to improve communication and emotional life.* Macmillan.

Engelmann, J. B., Damaraju, E., Padmala, S., & Pessoa, L. (2009). Combined effects of attention and motivation on visual task performance: transient and sustained motivational effects. *Frontiers in human neuroscience,* 3, 4. doi: 10.3389/neuro.09.004.2009.

Ernst, M., & Paulus, M. P. (2005). Neurobiology of decision making: a selective review from a neurocognitive and clinical perspective. *Biological psychiatry*, *58*(8), 597-604. doi: 10.1016/j.biopsych.2005.06.004.

Fareri, D. S., Niznikiewicz, M. A., Lee, V. K., & Delgado, M. R. (2012). Social network modulation of reward-related signals. *Journal of*

Neuroscience, *32*(26), 9045-9052. doi: 10.1523/JNEUROSCI.0610-12.2012.

Fehr, E., & Fischbacher, U. (2004). Third-party punishment and social norms. *Evolution and human behavior*, *25*(2), 63-87. doi: 10.1016/S1090-5138(04)00005-4.

Ferdinand, N. K., & Opitz, B. (2014). Different aspects of performance feedback engage different brain areas: Disentangling valence and expectancy in feedback processing. *Scientific Reports*, 4, 5986. doi:10.1038/srep05986

Fischbacher, U., Gächter, S., & Fehr, E. (2001). Are people conditionally cooperative? Evidence from a public goods experiment. *Economics letters*, 71(3), 397-404. doi: 10.1016/S0165-1765(01)00394-9.

Fiske, S. T., Gilbert, D. T., & Lindzey, G. (Eds.). (2010). Handbook of social psychology (Vol. 2). John Wiley & Sons.Fisch, B. J. (1999). *The source of the EEG. In Fisch and Spelhmann's EEG Primer*, chapter 1, pages 3–17. Elsevier, third edition.

Fleming, S. M., Huijgen, J., & Dolan, R. J. (2012). Prefrontal contributions to metacognition in perceptual decision making. *Journal of Neuroscience*, 32(18), 6117-6125. doi: 10.1523/JNEUROSCI.6489-11.2012.

Flores, A., Münte, T. F., & Doñamayor, N. (2015). Event-related EEG responses to anticipation and delivery of monetary and social reward. *Biological psychology*, 109, 10-19, doi: 10.1016/j.biopsycho.2015.04.005.

Foti, D., & Hajcak, G. (2008). Deconstructing reappraisal: Descriptions preceding arousing pictures modulate the subsequent neural response. *Journal of Cognitive Neuroscience*, 20(6), 977-988, doi: 10.1162/jocn.2008.20066.

Forgas, J. P., Brennan, G., Howe, S., Kane, J. F., & Sweet, S. (1980). Audience effects on squash players' performance. *The Journal of Social Psychology*, *111*(1), 41-47.

Forgas JP. (2000). *Feeling and thinking: the role of affect in social cognition.* New York, NY, US: Cambridge University Press, xvi, 421 p. 2000.

Frith, U., & Frith, C. (2010). The social brain: allowing humans to boldly go where no other species has been. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 365(1537), 165-176. doi: 10.1098/rstb.2009.0160.

Fukushima, H., & Hiraki, K. (2006). Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity. *Social cognitive and affective neuroscience*, *1*(2), 149-157. DOI: 10.1093/scan/nsl020.

Funane T., Kiguchi M., Atsumori H., Sato H., Kubota K., Koizumi H. (2011). Synchronous activity of two people’s prefrontal cortices during a cooperative task measured by simultaneous near-infrared spectroscopy. *Journal of Biomedical Optics,* 16(7):077011. doi: 10.1117/1.3602853.

Gallagher, H. L., Happe, F., Brunswick, N., Fletcher, P., C., Frith, U., & Frith, C. D. (2000). Reading the mind in cartoons and stories: An fMRI study of "theory of mind" in verbal and nonverbal tasks. *Neuropsychologia, 38*, 11-21. doi: 10.1016/S0028-3932(99)00053-6.

Garrigan, B., Adlam, A. L., & Langdon, P. E. (2016). The neural correlates of moral decision-making: A systematic review and meta-analysis of moral evaluations and response decision judgements. *Brain and cognition*, 108, 88-97. doi: 10.1016/j.bandc.2016.07.007.

Geen, R. G. (1976). Test anxiety, observation, and range of cue utilization. *British Journal of Social and Clinical Psychology*, 15(3), 253-259.

Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science*, 295(5563), 2279-2282. doi: 10.1126/science.1066893.

Gibbons, H. (2009). Evaluative priming from subliminal emotional words: insights from event-related potentials and individual differences related to anxiety. *Consciousness and Cognition,* 18(2), 383-400, doi: 10.1016/j.concog.2009.02.007.

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The Karolinska directed emotional faces: a validation study. *Cognition and emotion*, 22(6), 1094-1118.

Gold, J. I., Shadlen, M. N. (2001). Neural computations that underlie decisions about sensory stimuli. *Trends in Cognitive Science,* 5, 10 –16. doi: 10.1016/S1364-6613(00)01567-9.

Goldstein, R. Z., Cottone, L. A., Jia, Z., Maloney, T., Volkow, N. D., & Squires, N. K. (2006). The effect of graded monetary reward on cognitive event-related potentials and behavior in young healthy adults. *International Journal of Psychophysiology*, 62(2), 272-279. doi: 10.1016/j.ijpsycho.2006.05.006.

Goyer, J. P., Woldorff, M. G., & Huettel, S. A. (2008). Rapid electrophysiological brain responses are influenced by both valence and magnitude of monetary rewards. *Journal of Cognitive Neuroscience*, 20(11), 2058-2069. doi: 10.1162/jocn.2008.20134.

Gratton, G. (1998). Dealing with artifacts: The EOG contamination of the eventrelated brain potential. *Behavior Research Methods, Instruments, & Computers*, 30, 44-53.

Gray, H. M., Ambady, N., Lowenthal, W. T., & Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of experimental social psychology, 40*(2), 216-224. doi: 10.1016/S0022-1031(03)00092-1.

Griffin, M. (2001). The phenomenology of the alone condition: More evidence for the role of aloneness in social facilitation. *The Journal of psychology*, *135*(1), 125.

Griffin, I. C., Miniussi, C., & Nobre, A. C. (2002). Multiple mechanisms of selective attention: differential modulation of stimulus processing by attention to space or time. *Neuropsychologia,* 40(13), 2325-2340, doi: 10. 1016/S0028-3932(02)00087-8.

Greene, J. D., Sommerville, R. B., Nystrom, L. E., Darley, J. M., & Cohen, J. D. (2001). An fMRI investigation of emotional engagement in moral judgement. *Science, 293,* 2105-2108. doi: 10.1126/science.1062872.

Groen, Y., Wijers, A. A., Tucha, O., & Althaus, M. (2013). Are there sex differences in ERPs related to processing empathy-evoking pictures?. *Neuropsychologia*, *51*(1), 142-155. doi: 10.1016/j.neuropsychologia.2012.11.012.

Gruendler TOJ, Ullsperger M, Huster RJ (2011). Event-Related Potential Correlates of Performance-Monitoring in a Lateralized Time-Estimation Task. *PLoS ONE,* 6(10): e25591. doi: 10.1371/journal.pone.0025591.

Gui, X. U. E., Chuansheng, C. H. E. N., Zhong-Lin, L. U., & Qi, D. O. N. G. (2010). Brain imaging techniques and their applications in decision-making research. *Xin li xue bao. Acta psychologica Sinica*, *42*(1), 120. doi: 10.3724/SP.J.1041.2010.00120.

Gutnik, L. A., Hakimzada, A. F., Yoskowitz, N. A., & Patel, V. L. (2006). The role of emotion in decision-making: A cognitive neuroeconomic approach towards understanding sexual risk behavior. *Journal of biomedical informatics*, *39*(6), 720-736. doi: 10.1016/j.jbi.2006.03.002.

Hanks, T. D., & Summerfield, C. (2017). Perceptual decision making in rodents, monkeys, and humans. *Neuron*, *93*(1), 15-31. doi: 10.1016/j.neuron.2016.12.003.

Hajcak, G., Moser, J. S., Yeung, N., & Simons, R. F. (2005). On the ERN and the significance of errors. *Psychophysiology*, *42*(2), 151-160. doi: 10.1111/j.1469-8986.2005.00270.x.

Hajcak, G.,Moser, J. S., Holroyd, C. B., and Simons, R. F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biological Psychology,* 71, 148–154. doi:10.1016/j.biopsycho.2005.04.001.

Hajcak, G., Moser, J. S., Holroyd, C. B., and Simons, R. F. (2007). It's worse than you thought: the feedback negativity and violations of reward prediction in gambling tasks. *Psychophysiology* 44, 905–912. doi:10.1111/j.1469-8986.2007. 00567.x.

Halgren, E., Raij, T., Marinkovic, K., Jousmäki, V., & Hari, R. (2000). Cognitive response profile of the human fusiform face area as determined by MEG. *Cerebral cortex*, *10*(1), 69-81. doi: 10.1093/cercor/10.1.69.

Hare, T. A., Camerer, C. F., Knoepfle, D. T., O'Doherty, J., & Rangel, A. (2010). Value computations in ventral medial prefrontal cortex during charitable decision making incorporate input from regions involved in social cognition. *Journal of Neuroscience,* 30, 583-590. doi: 10.1523/JNEUROSCI.4089-09.2010.

Harkins, S. G. (2006). Mere effort as the mediator of the evaluation-performance relationship. *Journal of personality and social psychology,* 91(3), 436. doi: 10.1037/0022-3514.91.3.436.

Harmon-Jones, E., & Sigelman, J. (2001). State anger and prefrontal brain activity: Evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of personality and social psychology, 80*(5), 797. doi: 10.1037//0022-3514.80.5.797.

Harmon-Jones, E., & Beer, J. S. (2009). *Introduction to social and personality neuroscience methods.* In E. Harmon-Jones & J. S. Beer (Eds.), Methods in social neuroscience (pp. 1-9). Guilford Publications: New York.

Harris, L. T., McClure, S. M., Van den Bos, W., Cohen, J. D., & Fiske, S. T. (2007). Regions of the MPFC differentially tuned to social and nonsocial affective evaluation. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 309-316. doi: rg/10.3758/CABN.7.4.309

Hauser, T. U., Iannaccone, R., Stämpfli, P., Drechsler, R., Brandeis, D., Walitza, S., & Brem, S. (2014). The feedback-related negativity (FRN) revisited: new insights into the localization, meaning and network organization. *Neuroimage*, *84,* 159-168. doi: 10.1016/j.neuroimage.2013.08.028.

Häusler, A. N., Becker, B., Bartling, M., & Weber, B. (2015). Goal or gold: overlapping reward processes in soccer players upon scoring and winning money. *PloS one,* 10(4), e0122798. doi: 10.1371/journal.pone.0122798.

Heekeren, H. R., Marrett, S., & Ungerleider, L. G. (2008). The neural systems that mediate human perceptual decision making. *Nature reviews neuroscience*, *9*(6), 467. doi: 10.1038/nrn2374.

Herbert, C., Kissler, J., Junghöfer, M., Peyk, P., & Rockstroh, B. (2006). Processing of emotional adjectives: Evidence from startle EMG and ERPs. *Psychophysiology*, *43*(2), 197-206. doi: 10.1111/j.1469-8986.2006.00385.x

Herrmann, C. S., & Knight, R. T. (2001). Mechanisms of human attention: event-related potentials and oscillations. *Neuroscience & Biobehavioral Reviews*, *25*(6), 465-476. doi: 10.1016/S0149-7634(01)00027-6.

Hewig, J., Trippe, R., Hecht, H., Coles, M. G., Holroyd, C. B., & Miltner, W. H. (2006). Decision-making in Blackjack: an electrophysiological analysis. *Cerebral Cortex*, 17(4), 865-877. doi: 10.1093/cercor/bhk040.

Hillyard, S. A., & Picton, T. W. (1987). *Electrophysiology of cognition*. In F. Plum (Ed.), Handbook of physiology: Sec. 1. The nervous system: Vol. 5. Higher functions of the brain, part 2 (pp. 519-584). Bethesda, MD: Waverly Press.

Hinojosa, J. A., Carretié, L., Valcárcel, M. A., Méndez-Bértolo, C., & Pozo, M. A. (2009). Electrophysiological differences in the processing of affective information in words and pictures. *Cognitive, Affective, & Behavioral Neuroscience*, *9*(2), 173-189. doi:10.3758/CABN.9.2.173.

Hobson, N. M., & Inzlicht, M. (2016). The mere presence of an outgroup member disrupts the brain's feedback-monitoring system. *Social Cognitive and Affective Neuroscience*, *11*(11), 1698-1706. doi: 10.1093/scan/nsw082.

Höfel, L., & Jacobsen, T. (2007). Electrophysiological indices of processing aesthetics: Spontaneous or intentional processes? *International Journal of Psychophysiology*, *65*(1), 20-31, doi: 10.1016/j.ijpsycho.2007.02.007.

Hogg, M. A., & Smith, J. R. (2007). Attitudes in social context: A social identity perspective. *European Review of Social Psychology*, *18*(1), 89-131. doi: 10.1080/10463280701592070.

Holroyd, C. B., & Coles, M. G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. Psychological review, 109(4), 679. doi: 10.1037/0033-295X.109.4.679.

Holroyd, C. B., Nieuwenhuis, S., Yeung, N., Nystrom, L., Mars, R. B., Coles, M. G., & Cohen, J. D. (2004). Dorsal anterior cingulate cortex shows fMRI response to internal and external error signals. *Nature neuroscience*, *7*(5), 497. doi:10.1038/nn1238.

Holroyd, C. B., Hajcak, G., & Larsen, J. T. (2006). The good, the bad and the neutral: electrophysiological responses to feedback stimuli. *Brain research,* 1105(1), 93-101. doi: 10.1016/j.brainres.2005.12.015.

Horgan T. G., McGrath M. P., Long J. A. (2009). The relevance of people versus objects in explaining females' advantage over males in appearance accuracy. *Sex Roles,* 60: 890–899, doi: 10.1037/a0020630.

Houwer, J. D., & Hermans, D. (1994). Differences in the affective processing of words and pictures. *Cognition & Emotion, 8*(1), 1-20. doi: 10.1080/02699939408408925.

Hsu, M., Anen, C., Quartz, S. R. (2008). The right and the good: distributive justice and neural encoding of equity and efficiency. *Science,* 320, 1092-1295. doi: doi:10.3758/CABN.8.3.282.

Hugdahl, K. (1995). *Psychophysiology: The Mind Body Perspective*. Cambridge, MA: Harvard University Press.

Huguet, P., Galvaing, M. P., Monteil, J. M., & Dumas, F. (1999). Social presence effects in the Stroop task: further evidence for an attentional view of social facilitation. *Journal of personality and social psychology*, *77*(5), 1011.

Hull, J. G., Slone, L. B., Meteyer, K. B., & Matthews, A. R. (2002). The nonconsciousness of self-consciousness. *Journal of personality and social psychology*, *83*(2), 406.

Hruby, T., & Marsalek, P. (2002). Event-related potentials-the P3 wave. *Acta Neurobiologiae Experimentalis*, 63(1), 55-63.

Ito, T. A., & Cacioppo, J. T. (2000). Electrophysiological evidence of implicit and explicit categorization processes. *Journal of Experimental Social Psychology*, *36*(6), 660-676. doi: 10.1006/jesp.2000.1430

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology*, 75, 887–900.

Izard, C. E. (2009). Emotion theory and research: Highlights, unanswered questions, and emerging issues. *Annual review of psychology*, 60, 1-25. doi: 10.1146/annurev.psych.60.110707.163539.

Izuma, K., Saito, D. N., & Sadato, N. (2008). Processing of social and monetary rewards in the human striatum. *Neuron, 58*, 284-294, doi: 10.1016/j.neuron.2008.03.020.

Izuma, K., Saito, D. N., & Sadato, N. (2010). Processing of the incentive for social approval in the ventral striatum during charitable donation. *Journal of Cognitive Neuroscience*, 22(4), 621-631. doi: 10.1162/jocn.2009.21228.

Izuma, K. (2013). The neural basis of social influence and attitude change. *Current opinion in neurobiology*, *23*(3), 456-462. doi: 10.1016/j.conb.2013.03.009.

Jacobs, C., & Sack, A. T. (2012). Behavior in oblivion: the neurobiology of subliminal priming. *Brain sciences*, *2*(2), 225-241. doi: 10.3390/brainsci2020225.

Jacobsen, T., & Höfel, L. (2003). Descriptive and evaluative judgement processes: behavioral and electrophysiological indices of processing symmetry and aesthetics. *Cognitive, Affective, & Behavioral Neuroscience*, 3(4), 289-299, doi: 10.3758/CABN.3.4.289.

Jasper, H.A. (1958). The ten-twenty system of the international federation. *Electroencephalography & Clinical Neurophysiology*, 10, 371-375.

Jeffreys, D. A. (1996). Evoked potential studies of face and object processing. *Visual Cognition*, *3*(1), 1-38. doi: 10.1080/713756729.

Jones, R. M., Somerville, L. H., Li, J., Ruberry, E. J., Libby, V., Glover, G., et al. (2011). Behavioral and neural properties of social reinforcement learning. *Journal of Neuroscience* 31, 13039–13045. doi: 10.1523/JNEUROSCI.2972-11.2011.

Johnston, V.S., (2006). Mate choice decisions: the role of facial beauty. *Trends in Cognitive Science*, 10, 9–13, doi: 10.1016/j.tics.2005.11.003.

Junghöfer, M., Bradley, M. M., Elbert, T. R., & Lang, P. J. (2001). Fleeting images: a new look at early emotion discrimination. *Psychophysiology*, *38*(2), 175-178. doi: 10.1111/1469-8986.3820175.

Kahneman, D. (2003). A perspective on judgement and choice: mapping bounded rationality. *American Psychology, 58,* 697-720. doi: 10.1037/0003-066X.58.9.697.

Key, A. P. F., Dove, G. O., & Maguire, M. J. (2005). Linking brainwaves to the brain: an ERP primer. *Developmental neuropsychology, 27*(2), 183-215, doi: 10.1207/s15326942dn2702_1.

Kelly, S. P., & O'Connell, R. G. (2013). Internal and external influences on the rate of sensory evidence accumulation in the human brain. *Journal of Neuroscience, 33*(50), 19434-19441. doi: 10.1523/JNEUROSCI.3355-13.2013.

Keltner, D., Kogan, A., Piff, P. K., & Saturn, S. R. (2014). The sociocultural appraisals, values, and emotions (SAVE) framework of prosociality: Core processes from gene to meme. *Annual review of psychology*, *65*, 425-460. doi: 10.1146/annurev-psych-010213-115054.

Keltner, D., & Lerner, J. S. (2010). Emotion. *Handbook of social*

Kim, H., Adolphs, R., O'Doherty, J. P., & Shimojo, S. (2007). Temporal isolation of neural processes underlying face preference decisions. *Proceedings of the National Academy of Sciences*, *104*(46), 18253-18258. doi: 10.1073/pnas.0703101104.

Kittler, J. E., Menard, W., & Phillips, K. A. (2007). Weight concerns in individuals with body dysmorphic disorder. Eating Beahviors, 8, 115–120. doi: 10.1016/j.eatbeh.2006.02.006.

Klehe, U. C., Anderson, N., & Hoefnagels, E. A. (2007). Social facilitation and inhibition during maximum versus typical performance situations. *Human Performance*, *20*(3), 223-239. doi: 10.1080/08959280701333040.

Kleim, B., Thörn, H. A., & Ehlert, U. (2014). Positive interpretation bias predicts well-being in medical interns. *Frontiers in psychology*, *5*. doi: 10.3389/fpsyg.2014.00640.

Knost, B., Flor, H., Braun, C., & Birbaumer, N. (1997). Cerebral processing of words and the development of chronic pain. *Psychophysiology*, 34, 474 – 481. doi: 10.1111/j.1469-8986.1997.tb02392.x.

Knutson, B., Fong, G. W., Adams, C. M., Varner, J. L., & Hommer, D. (2001). Dissociation of reward anticipation and outcome with event-related fMRI. *Neuroreport*, *12*(17), 3683-3687.

Koban, L., Pourtois, G., Bediou, B., & Vuilleumier, P. (2012). Effects of social context and predictive relevance on action outcome monitoring. *Cognitive, Affective, & Behavioral Neuroscience,* 12(3), 460-478. doi: 10.1371/journal.pone.0156656.

Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review of visual masking. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 362*(1481), 857-875. doi: 10.1098/rstb.2007.2093.

Kringelbach, M. L., O'Doherty, J., Rolls, E. T., & Andrews, C. (2003). Activation of the human orbitofrontal cortex to a liquid food stimulus is correlated with its subjective pleasantness. *Cerebral cortex, 13*(10), 1064-1071. doi: 10.1093/cercor/13.10.1064.

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (2008). *International affective picture System (IAPS): Affective ratings of pictures and instruction manual.* Technical Report A-8. University of Florida, Gainesville, FL.

Le Bouc, R., & Pessiglione, M. (2013). Imaging social motivation: distinct brain mechanisms drive effort production during collaboration versus competition. *Journal of Neuroscience, 33*(40), 15894-15902. doi: 10.1523/JNEUROSCI.0143-13.2013.

Lee, D. (2008). Game theory and neural basis of social decision making. *Nature Neuroscience, 11*(4), 404-409. doi:10.1038/nn2065.

Lee, D., Seo, H., & Jung, M. W. (2012). Neural Basis of Reinforcement Learning and Decision Making. *Annual Review Neuroscience, 35*, 287-308. doi: 10.1146/annurev-neuro-062111-150512.

Lee, V., & Harris, L. (2013). How social cognition can inform social decision making. *Frontiers in Neuroscience*, *7*(259), 1-13. doi: 10.3389/fnins.2013.00259.

Leng, Y., & Zhou, X. L. (2009). Modulation of brain activities in outcome evaluation by interpersonal relationship: An ERP study. *NeuroImage*, *47,* S94. doi: 10.1016/j.neuropsychologia.2009.10.002.

Leng, Y., & Zhou, X. (2010). Modulation of the brain activity in outcome evaluation by interpersonal relationship: an ERP study. *Neuropsychologia*, *48*(2), 448-455. doi: 10.1016/j.neuropsychologia.2009.10.002.

Leng, Y., & Zhou, X. (2014). Interpersonal relationship modulates brain responses to outcome evaluation when gambling for/against others: an electrophysiological analysis. *Neuropsychologia*, *63*, 205-214. doi: 10.1016/j.neuropsychologia.2014.08.033.

Lerner JS, Keltner D. (2000). Beyond valence: Toward a model of emotion specific influences on judgement and choice. *Cognition and Emotion*, 14(4):473–93.

Levy, B. (1996). Improving memory in old age through implicit self-stereotyping. *Journal of personality and social psychology*, *71*(6), 1092.

Levy, D. J., & Glimcher, P. W. (2012). The root of all value: a neural common currency for choice. *Current Opinion in Neurobiology, 22*, 1027-1038. doi: 10.1016/j.conb.2012.06.001.

Lhermitte, F., Pillon, B., Serdaru, M. (1986). Human autonomy and the frontal lobes. Part I: Imitation and utilization behavior: A neuropsychological study of 75 patients. *Annual Neurology*, 19, 326 –334.

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and behavioral evidence for affective priming from unconsciously perceived emotional facial expressions and the influence of trait anxiety. *Journal of Cognitive Neuroscience*, 20, 1–13, doi: doi:10.1162/jocn.2008.20006.

Li, P., Yuan, J., Jia, S., Feng, T., Chen, A., & Li, H. (2009). Feedback-related negativity effects vanished with false or monetary loss choice. *Neuroreport*, *20*(8), 788-792. doi: 10.1097/WNR.0b013e32832b7fac.

Lin, A., Adolphs, R., & Rangel, A. (2012). Social and monetary reward learning engage overlapping neural substrates. *Social Cognitive and Affective Neuroscience, 7*, 274-281. doi: 10.1093/scan/nsr006.

Light, G. A., Williams, L. E., Minow, F., Sprock, J., Rissling, A., Sharp, R., Swerdlow, N. R., and Braff, D. L. (2010). Electroencephalography (EEG) and Event-Related Potentials (ERP's) with Human Participants. *Current Protocols in Neuroscience,* 6.2524. doi: 10.1002/0471142301.ns0625s52.

Linden, D. E. (2005). The P300: where in the brain is it produced and what does it tell us?. *The Neuroscientist,* 11(6), 563-576. ISSN 1073-8584.

Lindsen, J. P., Jones, R., Shimojo, S., & Bhattacharya, J. (2010). Neural components underlying subjective preferential decision making. *Neuroimage,* 50(4), 1626-1632, doi: 10.1016/j.neuroimage.2010.01.079.

Liu, J., Higuchi, M., Marantz, A., & Kanwisher, N. (2000). The selectivity of the occipitotemporal M170 for faces. *Neuroreport, 11*(2), 337-341.

Liu, B., Xin, S., Jin, Z., Hu, Y., & Li, Y. (2010). Emotional facilitation effect in the picture–word interference task: An ERP study. *Brain and cognition*, *72*(2), 289-299. doi: 10.1016/j.bandc.2009.09.013.

Liu, H. H., Hsieh, M. H., Hsu, Y. F., & Lai, W. S. (2015). Effects of affective arousal on choice behavior, reward prediction errors, and feedback-related negativities in human reward-based decision making. *Frontiers in psychology*, *6*, 592. doi: 10.3389/fpsyg.2015.00592.

Liu, A. K. (2000). *Spatiotemporal brain imaging* (Doctoral dissertation, Massachusetts Institute of Technology).

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin, 127*(2), 267-286. doi: 10.1037//0033-2909 127 2.267.

Loring-Meier, S., & Halpern, D. F. (1999). Sex differences in visuospatial working memory: Components of cognitive processing. *Psychonomic Bulletin & Review*, *6*(3), 464-471. doi: 10.3758/BF03210836.

Luu, P., Tucker, D. M., Derryberry, D., Reed, M. & Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. *Psychoogical Science*, 14, 47–53

Lu, Y., Zhang, W. N., Hu, W., & Luo, Y. J. (2011). Understanding the subliminal affective priming effect of facial stimuli: an ERP study. *Neuroscience letters*, *502*(3), 182-185, doi: 10.1016/j.neulet.2011.07.040.

Luck, S. J. (2005). An Introduction to the Event-Related Potential Technique MIT Press. *Cambridge, Ma.*

Luck, S. J. (2014). *An introduction to the event-related potential technique*. MIT press.

Lundqvist, D., Flykt, A., & Öhman, A. (1998). The Karolinska directed emotional faces (KDEF). CD ROM from Department of Clinical Neuroscience, *Psychology section*, Karolinska Institutet, 91-630.

Ma, Q., Shen, Q., Zu, Q., Li, D., Shu, L., Weber, B. (2011). Empathic responses to others' gains and losses: an electrophysiological investigation. *NeuroImage*, 54, 2472–80. doi: 10.1016/j.neuroimage.2010.10.045.

Marcos, J. L. & Redondo, J. (2005). Facilitation and Interference of the automatic information processing on a reaction task to threat-relevant stimuli. *Psicothema*, 17(002), 332-337.

Mavrodiev, P., Tessone, C. J., & Schweitzer, F. (2013). Quantifying the effects of social influence. *Scientific reports*, *3*, 1360. doi: 10.1038/srep01360.

McCabe, K., Houser, D., Ryan, L., Smith, V., & Trouard, T. (2001). A functional imaging study of cooperation in two-person reciprocal exchange. *Proceedings of the National Academy of Sciences USA, 98*, 11832-11835. doi: 10.1073/pnas.211415698.

McClure, E.B. (2000). A meta-analytic review of sex differences in facial expression processing and their development in infants, children, and adolescents. *Psychological Bulletin*, 126(3), 424-453. doi: 10.1037/0033-2909.126.3.424.

McIntyre, R. B., Paulson, R. M., & Lord, C. G. (2003). Alleviating women's mathematics stereotype threat through salience of group achievements. *Journal of Experimental Social Psychology*, *39*(1), 83-90. doi: 10.1016/S0022-1031(02)00513-9.

McIntyre, R. B., Lord, C. G., Gresky, D. M., Ten Eyck, L. L., Frye, G. J., & Bond Jr, C. F. (2005). A social impact trend in the effects of role models on alleviating women's mathematics stereotype threat. *Current Research in Social Psychology*, *10*(9), 116-36.

Meconi, F., Luria, R., & Sessa, P. (2014). Individual differences in anxiety predict neural measures of visual working memory for untrustworthy faces. *Social cognitive and affective neuroscience*, nst189. doi: 10.1093/scan/nst189.

Mitchell, J. P., Neil Macrae, C., & Banaji, M. R. (2005). Forming impressions of people versus inanimate objects: Social-cognitive processing in the medial prefrontal cortex. *NeuroImage,* 26(1), 251-257. doi: 10.1016/j.neuroimage.2005.01.031.

Mobbs, D., Yu, R., Meyer, M., Passamonti, L., Seymour, B., Calder, A. J., ... & Dalgleish, T. (2009). A key role for similarity in vicarious reward. *Science*, *324*(5929), 900-900. doi: 10.1126/science.1170539.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of internal medicine*, *151*(4), 264-269. doi: 10.7326/0003-4819-151-4-200908180-00135.

Monfardini, E., Redouté, J., Hadj-Bouziane, F., Hynaux, C., Fradin, J., Huguet, P., ... & Meunier, M. (2016). Others' sheer presence boosts brain activity in the attention (but not the motivation) network. *Cerebral Cortex*, *26*(6), 2427-2439. doi: 10.1093/cercor/bhv067.

Montague, P. R., Berns, G. S., Cohen, J. D., McClure, S. M., Pagnoni, G., Dhamala, M., ... & Fisher, R. E. (2002). Hyperscanning: simultaneous fMRI during linked social interactions. *Neuroimage,* 16(4):1159-64. doi: 10.1006/nimg.2002.1150.

Moll, J., Krueger, F., Zahn, R., Pardini, M., de Oliveira-Souza, R., Grafman, J. (2006) Human fronto-mesolimbic networks guide decisions about charitable donation. *Proceedings of National Academy of Sciences USA,* 103, 15623-15628. doi: 10.1073/pnas.0604475103.

Molina, G. N. G., Tsoneva, T. K., Baldo, D., Danhua, Z., & Gabrielsson, P. H. A. (2012). *U.S. Patent Application No. 13/981,096.*

Muller, D., Atzeni, T., & Butera, F. (2004). Coaction and upward social comparison reduce the illusory conjunction effect: Support for distraction–conflict theory. *Journal of Experimental Social Psychology*, *40*(5), 659-665. doi: 10.1016/j.jesp.2003.12.003.

Naumann, E., Bartussek, D., Diedrich, O., & Laufer, M. E. (1992). Assessing cognitive and affective information processing functions of the brain by means of the late positive complex of the event-related potential. *Journal of Psychophysiology*, 6, 285–298.

Nawa, E. N., Nelson, E. E., Pine, D.S., Ernst, M. (2008). Do you make a difference? Social context in a betting task. *Social Cognitive and Affective Neuroscience*, 3(4), doi: 10.1093/scan/nsn032.

Neumann, O., Esselmann, U., & Klotz, W. (1993). Differential effects of visual-spatial attention on response latency and temporal-order judgement. *Psychological Research*, *56*(1), 26-34. doi:10.1007/BF00572130.

Nicolle, A., Klein-Flügge, M. C., Hunt, L. T., Vlaev, I., Dolan, R. J., & Behrens, T. E. (2012). An agent independent axis for executed and modeled choice in medial prefrontal cortex. *Neuron*, *75*(6), 1114-1121. doi: 10.1016/j.neuron.2012.07.023.

Nieuwenhuis S., Yeung N., Holroyd C. B., Schurger A., Cohen J. D. (2004). Sensitivity of Electrophysiological Activity from Medial Frontal Cortex to Utilitarian and Performance Feedback. *Cerebral Cortex*, 14(7), 741–747. doi: 10.1093/cercor/bhh034.

Nobre A. C, Rao A., Chelazzi L. (2006). Selective attention to specific features within objects: Behavioral and electrophysiological evidence. *Journal of Cognitive Neuroscience,* 18, 539–561. doi: 10.1162/jocn.2006.18.4.539.

Nomura, M., Ohira, H., Haneda, K., Lidaka, T., Sadato., N., Okada, T., Yonekura, Y. (2004). Functional association of the amygdala and ventral prefrontal cortex during cognitive evaluation of facial expressions primed by masked angry faces: an event-related fMRI study. *NeuroImage,* 21(1), 352-63. doi: 10.1016/j.neuroimage.2003.09.021.

Nuwer, M. R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guérit, J. M., Hinrichs, H., ... & Rappelsburger, P. (1998). IFCN standards for digital recording of clinical EEG. *Electroencephalography and clinical Neurophysiology, 106*(3), 259-261.

O'connell, Redmond G., Paul M. Dockree, and Simon P. Kelly. (2012). A supramodal accumulation-to-bound signal that determines perceptual decisions in humans. *Nature neuroscience,* 15, 12-1729. doi: 10.1038/nn.3248.

O'Doherty, J. P., Dayan, P., Friston, K., Critchley, H., & Dolan, R. J. (2003). Temporal difference models and reward-related learning in the human brain. *Neuron,* 38, 329-337. doi: 10.1016/S0896-6273(03)00169-7.

Öhman, A., & Wiens, S. (2001). To think and to feel: nonconscious emotional activation and consciousness. In *Emotions, qualia, and consciousness* (pp. 363-385). doi: 10.1142/9789812810687_0029.

Olofsson, J., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology,* 77, 247–265, doi: 10.1016/j.biopsycho.2007.11.006.

Otto, T. U., & Mamassian, P. (2012). Noise and correlations in parallel perceptual decision making. *Current Biology*, 22(15), 1391-1396. doi: 10.1016/j.cub.2012.05.031.

Paller, K. A., Kutas, M., & McIsaac, H. K. (1995). Monitoring conscious recollection via the electrical activity of the brain. *Psychological Science*, *6*(2), 107-111.

Pascual-Leone, A. (1999). Transcranial magnetic stimulation: studying the brain--behaviour relationship by induction of ‘virtual lesions’. Philosophical Transactions of the Royal Society B: Biological Sciences, 354(1387), 1229-1238. doi: 10.1098/rstb.1999.0476.

Paulus, M. P., Hozack, N., Frank, L., Brown, G. G., Schuckit, M. A. (2003). Decision making by methamphetamine-dependent subjects is associated with error-rate-independent decrease in prefrontal and parietal activation. *Biological Psychiatry,* 53, 65–74. doi: 10.1016/S0006-3223(02)01442-7.

Pegors, T. K., Kable, J. W., Chatterjee, A., & Epstein, R. A. (2015). Common and unique representations in pFC for face and place attractiveness. *Journal of cognitive neuroscience*, 27(5), 959-73, doi: 10.1162/jocn_a_00777.

Phelps, E. A., Lempert, K. M., & Sokol-Hessner, P. (2014). Emotion and decision making: multiple modulatory neural circuits. *Annual Review of Neuroscience, 37,* 263-287. doi: 10.1146/annurev-neuro-071013-014119.

Philiastides, M, & Sajda, P. (2006). Temporal characterization of the neural correlates of perceptual decision making in the human brain. *Cerebral Cortex,* 16 (4), 509-518. doi: 10.1093/cercor/bhi130.

Philiastides, M., Ratcliff, R., Sajda, P. (2006). Neural representation of task difficulty and decision making during perceptual categorization: a timing diagram. *Journal of Neuroscience,* 26, 8965 – 8975. doi: 10.1523/JNEUROSCI.1655-06.2006.

Philiastides, M. G., Biele, G., Vavatzanidis, N., Kazzer, P., & Heekeren, H. R. (2010). Temporal dynamics of prediction error processing during reward-based decision making. *Neuroimage*, *53*(1), 221-232. doi: 10.1016/j.neuroimage.2010.05.052.

Pizzagalli, D. A., Lehmann, D., Hendrick, A. M., Regard, M., Pascual-Marqui, R. D., & Davidson, R. J. (2002). Affective judgments of faces modulate early activity (~ 160 ms) within the fusiform gyri. *Neuroimage,* 16(3), 663-677. doi: 10.1006/nimg.2002.1126.

Platt, M. L., Glimcher, P. W. (1999). Neural correlates of decision variables in parietal cortex. *Nature,* 400, 233–238. doi: 10.1038/22268.

Poldrack, R. A., Fletcher, P. C., Henson, R. N., Worsley, K. J., Brett, M., & Nichols, T. E. (2008). Guidelines for reporting an fMRI study. Neuroimage, 40(2), 409-414. doi: 10.1016/j.neuroimage.2007.11.048.

Polich J. (1999). *P300 in clinical applications. In: Electroencephalography: basic principles, clinical applications and related fields* (Eds. E. Niedermayer and F. Lopes de la Silva). Urban and Schwartzenberger, Baltimore-Munich. p. 1073-1091.

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, *32*(1), 3-25.

Potts, G. F., Liotti, M., Tucker, D. M., & Posner, M. I. (1996). Frontal and inferior temporal cortical activity in visual target detection: Evidence from high spatially sampled event-related potentials. *Brain Topography*, *9*(1), 3-14. doi: 10.1007/BF01191637.

Potts, G. F. (2004). An ERP index of task relevance evaluation of visual stimuli. *Brain and cognition*, *56*(1), 5-13. doi: 10.1016/j.bandc.2004.03.006.

Potts, G. F., Martin, L. E., Burton, P., & Montague, P. R. (2006). When things are better or worse than expected: the medial frontal cortex and the allocation of processing resources. *Journal of cognitive neuroscience*, *18*(7), 1112-1119. doi: 10.1162/jocn.2006.18.7.1112.

Proverbio, A. M., Zani, A., Adorni, R. (2008). Neural markers of a greater female responsiveness to social stimuli. *BMC Neuroscience*, 9, 56, doi: 10.1186/1471-2202-9-56.

Proverbio A. M,. Adorni R., Zani A., Trestianu L. (2009). Sex differences in the brain response to affective scenes with or without humans. *Neuropsychologia*, 47, 2374–2388, doi: 10.1016/j.neuropsychologia.2008.10.030.

Qu, C., Huang, Y., Wang, Y., & Huang, Y. (2013). The delay effect on outcome evaluation: results from an event-related potential study. *Frontiers in human neuroscience*, *7*, 748. doi: 10.3389/fnhum.2013.00748.

Rademacher, L., Krach, S., Kohls, G. I., Grunder, G., & Spreckelmeyer, K. (2010). Dissociation of neural networks for anticipation and consumption of monetary and social rewards. *NeuroImage*, *49*, 3276-3285, doi: 10.1016/j.neuroimage.2009.10.089.

Rademacher, L., Salama, A., Gründer, G., & Spreckelmeyer, K. N. (2014). Differential patterns of nucleus accumbens activation during anticipation of monetary and social reward in young and older adults. *Social cognitive and affective neuroscience*, nst047, doi:10.1093/scan/nst047.

Ratner, R. K., & Herbst, K. C. (2005). When good decisions have bad outcomes: The impact of affect on switching behavior. *Organizational Behavior and Human Decision Processes*, 96(1), 23-37. doi: 10.1016/j.obhdp.2004.09.003.

Ratcliff, R., Hasegawa, Y. T., Hasegawa, R. P., Smith, P. L., & Segraves, M. A. (2007). Dual diffusion model for single-cell recording data from the superior colliculus in a brightness-discrimination task. Journal of neurophysiology, 97(2), 1756-1774. doi: 10.1152/jn.00393.2006.

Ratcliff, R., Philiastides, M. G., & Sajda, P. (2009). Quality of evidence for perceptual decision making is indexed by trial-to-trial variability of the EEG. *Proceedings of the National Academy of Sciences*, 106(16), 6539-6544. doi: 10.1073/pnas.0812589106.

Resulaj, A., Roozbeh, K., Wolpert, D., & Shadlen, M. (2009). Changes of mind in decision-making. *Nature Letters, 461*(10), 263-266. doi:10.1038/nature08275.

Richards, J. M., Plate, R. C., & Ernst, M. (2013). A systematic review of fMRI reward paradigms used in studies of adolescents vs. adults: the impact of task design and implications for understanding neurodevelopment. *Neuroscience & Biobehavioral Reviews, 37*(5), 976-991. doi: 10.1016/j.neubiorev.2013.03.004.

Rilling, J., Gutman, D. A., Zeh, T. R., Pagnoni, G., S., B. G., & Kilts, C. D. (2002). A neural basis for social cooperation. *Neuron, 35*, 395-405. doi: 10.1016/S0896-6273(02)00755-9.

Rilling, J., & Sanfey, G. (2011). The Neuroscience of Social Decision-Making. *Annual Rev. Psychol., 62,* 23-48. doi: 10.1146/annurev.psych.121208.131647.

Rozenkrants, B., & Polich, J. (2008). Affective ERP processing in a visual oddball task: arousal, valence, and gender. *Clinical Neurophysiology*, *119*(10), 2260-2265. doi: 10.1016/j.clinph.2008.07.213

Rowan, A. J., & Tolunsky, E. (2003). *A primer of EEG: with a mini-atlas.* Butterworth-Heinemann Medical.

Rugg, M. D., & Coles, M. G. H. (1995). The ERP and cognitive psychology: Conceptual issues. In M. D. Rugg & M. G. H. Coles (Eds.), *Oxford psychology series, No. 25. Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 27-39). New York, NY, US: Oxford University Press.

Rullen, R. V., & Thorpe, S. J. (2001). Rate coding versus temporal order coding: what the retinal ganglion cells tell the visual cortex. *Neural computation*, *13*(6), 1255-1283. doi: 10.1162/08997660152002852.

Sanfey, A. G., Rilling, J. K., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2003). The neural basis of economic decision-making in the ultimatum game. *Science,* 300(5626), 1755-1758. doi: 10.1126/science.1082976.

Sanfey, A. (2007). Social Decision-Making: Insights from Game Theory and Neuroscience. *Science,* 318, 598-602. doi: 10.1126/science.1142996.

Sanfey, A. (2007). Decision neuroscience: New directions in studies of judgements and decision making. *Current Direction in*

Psychological Science, 16, 151-155. doi: 10.1111/j.1467-8721.2007.00494.x.

Sanfey, A. G., & Stallen, M. (2016). Neurosciences Contribution to Judgement and Decision Making. *The Wiley Blackwell Handbook of Judgement and Decision Making*, 268-294.

Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people: the role of the temporo-parietal junction in "theory of mind". *Neuroimage*, 19(4), doi: 10.1016/S1053-8119(03)00230-1.

Schaul, N. (1998). The fundamental neural mechanisms of electroencephalography. *Electroencephalography and clinical neurophysiology*, 106, 101–107.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Hillman, C. H., Hamm, A. O., & Lang, P. J. (2004). Brain processes in emotional perception: Motivated attention. *Cognition & Emotion*, 18, 593-611. doi: 10.1080/02699930341000239.

Schwarz, N., & Clore, G. L. (1983). Mood, misattribution, and judgments of well-being: informative and directive functions of affective states. *Journal of personality and social psychology*, *45*(3), 513.

Sescousse, G., Redouté, J., & Dreher, J. C. (2010). The architecture of reward value coding in the human orbitofrontal cortex. *The Journal of Neuroscience,* 30(39), 13095-13104, doi: 10.1523/JNEUROSCI.3501-10.2010.

Sessa, P., & Meconi, F. (2015). Perceived trustworthiness shapes neural empathic responses toward others' pain. *Neuropsychologia*, 79, 97-105. doi: 10.1016/j.neuropsychologia.2015.10.028.

Shallice, T., Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain*, 114, 727–741.

Sharma, D., Booth, R., Brown, R., & Huguet, P. (2010). Exploring the temporal dynamics of social facilitation in the Stroop task. *Psychonomic bulletin & review*, 17(1), 52-58. doi: 10.3758/PBR.17.1.52.

Sheeran, P., Aarts, H., Custers, R., Rivis, A., Webb, T. L., & Cooke, R. (2005). The goal-dependent automaticity of drinking habits. British *Journal of Social Psychology*, 44(1), 47-63. doi: 10.1348/014466604X23446.

Shenhav, A., & Greene, J. D. (2014). Integrative moral judgement: dissociating the roles of the amygdala and ventromedial prefrontal cortex. *The Journal of Neuroscience*, 34(13), 4741-4749. doi:10.1523/JNEUROSCI.3390-13.2014.

Simon, D., Becker, M. P., Mothes-Lasch, M., Miltner, W. H., & Straube, T. (2014). Effects of social context on feedback-related activity in the human ventral striatum. *NeuroImage*, 99, 1-6. doi: 10.1016/j.neuroimage.2014.05.071.

Singer, T., & Lamm, C. (2009). The social neuroscience of empathy. *Annals of the New York Academy of Sciences*, 1156(1), 81-96. doi: 10.1111/j.1749-6632.2009.04418.x.

Slovic, P., Finucane, M., Peters, E., MacGregor, D. G. (2002). The affect heuristic. In: Gilovich T, Griffin D, editors. *Heuristics and biases: The psychology of intuitive judgement.* New York: Cambridge University Press, pp 397– 420.

Smith, C. A., & Ellsworth, P. C. (1985). Patterns of cognitive appraisal in emotion. *Journal of personality and social psychology*, *48*(4), 813.

Smith, P. L., & Ratcliff, R. (2004). Psychology and neurobiology of simple decisions. *Trends in neurosciences*, *27*(3), 161-168. doi: 10.1016/j.tins.2004.01.006.

Smith, D. V., Hayden, B. Y., Truong, T. K., Song, A. W., Platt, M. L., & Huettel, S. A. (2010). Distinct value signals in anterior and posterior ventromedial prefrontal cortex. *The Journal of neuroscience*, 30(7), 2490-2495, doi: 10.1523/JNEUROSCI.3319-09.2010.

Smith, D. V., & Huettel, S. A. (2010). Decision Neuroscience: neuroeconomics. *WIREs Cognitive Science*, 1(6), 854–871. doi: 10.1002/wcs.73.

Smith E.M., Halgren E., Sokolik M., Baudena P., Musolino A., Liegeois-Chauvel C., Chauvel P. (1990). The intracranial topography of the

P3 event-related potential elicited during auditory oddball. *Electroencephalography Clinical Neurophysiology*, 76, 235-248.

Snodgrass, J. G. (1972). Matching patterns vs matching digits: The effect of memory dependence and complexity on “same”-“different” reaction times. *Perception & Psychophysics*, 11(5), 341–349. doi: 10.3758/BF03206264.

Srinivasan, R., Russell, D. P., Edelman, G. M., & Tononi, G. (1999). Increased synchronization of neuromagnetic responses during conscious perception. *The Journal of Neuroscience*, 19(13), 5435-5448.

Speckmann, E., J. and Elgar, C., E. (1987) Introduction to the neurophysiology, *basis of the eeg and dc potentials*. In E. Niedermeyer and F. Lopes da Silva, Basic principles, clinical applications and related fields, chapter 1, (pg 1–13) 2nd edition.

Spreckelmeyer, K. N., Krach, S., Kohls, G., Rademacher, L., Irmak, A., Konrad, K., Grunder, G. (2009). Anticipation of monetary and social reward differently activates mesolimbic brain structures in men and women. *Social Cognitive Affective Neuroscience, 4*, 158-165, doi: 10.1093/scan/nsn051.

Srinivasan, R. (1999). Methods to improve the spatial resolution of EEG. *International Journal of Bioelectromagnetism*, 1(1), 102-111.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta psychologica*, *30*, 276-315.

Sucksmith, E., Allison, C., Baron-Cohen, S., Chakrabarti, B., & Hoekstra, R. A. (2013). Empathy and emotion recognition in people with autism, first-degree relatives, and controls. *Neuropsychologia*, 51(1), 98-105, doi: 10.1016/j.neuropsychologia.

Tallat, A., Shin, K., Lee, H., & Yasuda, H. (2011, November). Some remarkable property of the uniformly random distributed archive scheme. In *Computer Sciences and Convergence Information Technology (ICCIT), 2011 6th International Conference on* (pp. 586-591). IEEE.

Tian, T., Feng, X., Gu, R., Broster, L. S., Feng, C., Wang, L., ... & Luo, Y. J. (2015). Modulation of the brain activity in outcome evaluation by the presence of an audience: An electrophysiological investigation. *Brain research*, 1615, 139-147. doi: 10.1016/j.brainres.2015.04.040.

Treisman, A., & Paterson, R. (1984). Emergent features, attention, and object perception. *Journal of Experimental Psychology: Human Perception and Performance*, 10(1), 12.

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological review*, *95*(1), 15.

Triplett, N. (1898). The dynamogenic factors in pacemaking and competition. *The American journal of psychology, 9*(4), 507-533.

Trippe, R. H., Hewig, J., Heydel, C., Hecht, H., & Miltner, W. H. (2007). Attentional blink to emotional and threatening pictures in spider phobics: Electrophysiology and behavior. *Brain Research*, *1148*, 149-160. doi: 10.1016/j.brainres.2007.02.035.

Todorov, A., Mandisodza, A.N., Goren, A., Hall, C.C., (2005). Inferences of competence from faces predict election outcomes. *Science,* 308, 1623–1626, doi: 10.1126/science.1110589.

Todorov, A., Said, C.P., Oosterhof, N.N., Engell, A.D., (2011).Task-invariant brain responses to the social value of faces. *Journal of Cognitive Neuroscience,* 23, 2766–2781, doi: 10.1162/jocn.2011.21616.

Tversky, A., & Kahneman, D. (1974). Judgement under uncertainty: heuristics and biases. *Science,* 185, 1124–1131.

Utevsky, A. V., & Huettel, S. A. (2015). Social Decision Making. In *Brain Mapping: An Encyclopedic Reference* (pg. 231-234). Elesvier.

Van Den Bos, R., Jolles, J., & Homberg, J. (2013). Social modulation of decision-making: a cross-species review. *Frontiers in Human Neuroscience*, 7*,* 301.doi: 10.3389/fnhum.2013.00301.

Vanmarcke, S., Wagemans, J. (2015). Rapid gist perception of meaningful real-life scenes: Exploring individual and gender differences in multiple categorization tasks. *Perception*, 6: 19–37, doi: 10.1068/i0682.

Van Veen, V., Holroyd, C. B., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2004). Errors without conflict: implications for performance monitoring theories of anterior cingulate cortex. *Brain and cognition*, *56*(2), 267-276. doi:10.1016/j.bandc.2004.06.007.

Vespa, P. M., Nenov, V., & Nuwer, M. R. (1999). Continuous EEG monitoring in the intensive care unit: early findings and clinical efficacy. *Journal of Clinical Neurophysiology*, 16(1), 1-13.

Villuendas-González, E. R., & González-Garrido, A. A. (2016). Feedback-Related ERP Components Are Modulated by Social Distance during Non-Contingent Evaluation of Someone Else's Performance. *PloS one*, *11*(5), e0156656. doi: 10.1371/journal.pone.0156656.

Van't Wout, M., Kahn, R. S., Sanfey, A. G., & Aleman, A. (2005). rTMS over the right dorsolateral prefrontal cortex affects strategic decision making. *Neuroreport,* 16, 1849-1852. doi: 10.1097/01.wnr.0000183907.08149.14.

Vuilleumier, P., & Driver, J. (2007). Modulation of visual processing by attention and emotion: windows on causal interactions between human brain regions. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 362(1481), 837-855. doi: 10.1098/rstb.2007.2092.

Wagstaff, G. F., Wheatcroft, J., Cole, J. C., Brunas-Wagstaff, J., Blackmore, V., & Pilkington, A. (2008). Some cognitive and neuropsychological aspects of social inhibition and facilitation. *European Journal of Cognitive Psychology*, *20*(4), 828-846. doi: 10.1080/09541440701469749.

Ward, J. (2012). *The student's guide to social neuroscience*. Psychology Press.

Weinberg, A., & Hajcak, G. (2011). The late positive potential predicts subsequent interference with target processing. *Journal of cognitive neuroscience*, 23(10), 2994-3007, doi: 10.1162/jocn.2011.21630.

Weinberg, A., Hilgard, J., Bartholow, B. D., & Hajcak, G. (2012). Emotional targets: Evaluative categorization as a function of context and content. *International Journal of Psychophysiology*, 84(2), 149-154, doi: 10.1016/j.ijpsycho.2012.01.023.

Weinberg, A., & Hajcak, G. (2011). The late positive potential predicts subsequent interference with target processing. Journal of cognitive neuroscience, 23(10), 2994-3007. doi: 10.1162/jocn.2011.21630.

Werheid, K., Alpay, G., Jentzsch, I., & Sommer, W. (2005). Priming emotional facial expressions as evidenced by event-related brain potentials. *International journal of psychophysiology*, *55*(2), 209-219. doi: 10.1016/j.ijpsycho.2004.07.006.

Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences,* 11(2), 233-244. doi: 10.1017/S0140525X00049682.

Williamson, S. E., Harpur, T. J., & Hare, R. D. (1991). Abnormal processing of emotional words by psychopaths. *Psychophysiology*, 28, 260 – 273.

Willis, J., & Todorov, A. (2006). First impressions: Making up your mind after a 100-ms exposure to a face. *Psychological Science*, 17, 592–598, doi: 10.1111/j.1467-9280.2006.01750.x.

Willis, M. L., Dodd, H. F., & Palermo, R. (2013). The relationship between anxiety and the social judgements of approachability and trustworthiness. *PloS one*, 8(10), e76825. doi: 10.1371/journal.pone.0076825.

Winkielman, P., Berridge, K. C., & Wilbarger, J. L. (2005). Unconscious affective reactions to masked happy versus angry faces influence consumption behavior and judgements of value. *Personality and Social Psychology Bulletin*, 31(1), 121-135. doi: 10.1177/0146167204271309.

Winston, J. S, Strange, B. A, O’Doherty, J., Dolan, R. J. (2002). Automatic and intentional brain responses during evaluation of trustworthiness of faces. *Nature Neuroscience*, 5, 277–283, doi: 10.1038/nn816.

Woodman, G. F. (2010). A brief introduction to the use of event-related potentials in studies of perception and attention. *Attention, Perception, & Psychophysics*, *72*(8), 2031-2046. doi: 10.3758/BF03196680.

Wyart, V., De Gardelle, V., Scholl, J., & Summerfield, C. (2012). Rhythmic fluctuations in evidence accumulation during decision making in the human brain. *Neuron*, *76*(4), 847-858. doi: 10.1016/j.neuron.2012.09.015.

Wu, Y., and Zhou, X. (2009). The P3 and reward valence, magnitude, and expectancy in outcome evaluation. *Brain Research*, 1286, 114–122. doi: 10.1016/j.brainres.2009.06.032.

Xue, G., Chen, C., Lu, Z.-L., & Dong, Q. (2010). Brain Imaging Techniques and Their Applications in Decision-Making Research. Xin Li Xue Bao. *Acta Psychologica Sinica*, 42(1), 120–137.

Yeung N., Sanfey A. G. (2004). Independent Coding of Reward Magnitude and Valence in the Human Brain. *Journal of Neuroscience*, 24(28), 6258–6264. doi: 10.1523/JNEUROSCI.4537-03.2004.

Yeung, N., Holroyd, C. B., & Cohen, J. D. (2005). ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cerebral cortex*, *15*(5), 535-544. doi: 10.1093/cercor/bhh153.

Young, L., Dodell-Feder, D., & Saxe, R. (2010). What gets the attention of the temporo-parietal junction? An fMRI investigation of attention and theory of mind. *Neuropsychologia*, *48*(9), 2658-2664. doi: 10.1016/j.neuropsychologia.2010.05.012.

Zajonc, R. B. (1965). *Social facilitation*. Ann Arbor: Research Center for Group Dynamics, Institute for Social Research, University of Michigan.

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, 35(2), 151.

Zajonc RB. Feeling and thinking: closing the debate over the independence of affect. In: Forgas JP, editor. *Feeling and thinking: the role of affect in social cognition. Studies in emotion and social interaction.* NY, USA: Cambridge University Press; 2000.

Zeng, J., Wang, Y., & Zhang, Q. (2012). An ERP study on decisions between attractive females and money. *PLoS ONE*, 7(10). doi: 10.1371/journal.pone.0045945.

Zhang, Q., Lawson, A., Guo, C., & Jiang, Y. (2006). Electrophysiological correlates of visual affective priming. *Brain Research Bulletin*, 71, 316–323. doi: 10.1016/j.brainresbull.2006.09.023.

Zink, C. F., Chen, Q., Bassett, D. S., Stein, J. L., & Meyer-Lindenberg, A. (2008). Know your place: Neural processing of social hierarchy in humans. *Neuron, 58*, 273–283, doi: 10.1016/j.neuron.2008.01.025.

Appendices

1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Checklist
2. A) Checklist for Quality Assessment of fMRI studies
   B) Checklist for Quality Assessment of EEG studies
3. List of Studies included in the Systematic Review (Chapter 4, Study 1)
4. Words used in the priming task (Study 3)
5. Questionnaire for study 4

Appendix 1

Section/topic		**Checklist item**	**Reported on page #**
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	N/A
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	N/A
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	85-87
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	88
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	N/A
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	89
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	89
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	89
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	90

Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	90-91
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	90
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	91
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	N/A
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	N/A

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	91
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	91-92
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Table 4.2, 4.3 & 4.4
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	99 & Table 4.5 & 4.6
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	N/A
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	N/A
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	113-122
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	119
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	121-122
FUNDING			

Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	N/A

Appendix 2

A) EEG Quality assessment table

Are these criteria reported in the study?
1=sufficient evidence reported. 0=no evidence reported/unclear/not explicit
Reference……………………………………………………………………..
Total scores: 0-8=low quality, 9-16=medium quality, 17-24=high quality.

		Examples/notes	**Reported ?**
Experimental design	Number of blocks, trials or experimental units per session/subject	*Needs to report number of trials/blocks*	
	Length of each trial and interval between trials	*Both must be reported*	
	Total (out of 2)		
Task specification	Describes what subjects were asked to do	*E.g. Subjects read statements and instructed to press button to indicate if they agreed or disagreed*	
	Stimuli- describes what they were and how many	*E.g. 24 scenarios, 12 moral and 12 non moral. Explanation or example of content*	
	Total (out of 2)		
Subjects	Number of subjects		
	Age (mean and range)	*Both must be reported*	
	Handedness		
	Number of males/females		
	Inclusion/exclusion criteria	*Explicit inclusion and exclusion criteria, not just description of participant characteristics*	
	States which IRB approved the protocol	*Mark as not reported if just states 'local ethics committee' without giving name/institution*	
	Total (out of 6)		
Data acquisition *(these details need to be reported)*	EEG system Name	*Only give point if all info reported*	
	sampling rate, scalp electrodes	*All 2 must be reported* *e.g. sampled at 250 Hz with* *e.g. EEG data were recorded using an elastic cap with* *29 scalp tin electrodes*	
	Electrode System	*e.g. electrodes distributed based on the 10-20 system*	

	reference, amplifier	*e.g. mastoids, earlobes, both earlobes* *e.g. Synamps amplifier*	
	impedance (KΩ) and bandpass filter	*All 2 must be reported* *e.g. impedance was kept below 5* KΩ *band pass filter of 0.1-70 Hz*	
	Total (out of 5)		
Data pre-processing	Specifies order of pre-processing operations	*If in list format, assume that is order*	
	Reference	*e.g. left right earlobe, mastoids*	
	Filter	*e.g. -50 to 50 µV*	
	Epoch (in ms)	*e.g. data were segmented in -200 to 800 ms epochs including the baseline*	
	Total (out of 4)		
Analysis			
	Reports analysis software	*e.g. EEG signals were analysed with EEGLAB*	
	Specifies exactly the conditions included in the analysis	*e.g. stimuli, electrode, hemisphere*	
	Electrodes	*Reports which electrodes are analysed* *e.g. analysis was focused on the middle line electrodes Fz, Cz, Pz as the most representative or as FRN components shows maximal signal at Cz*	
	Statistical model reported	*E.g. Multiple regression, ANOVA, t-test*	
	significance level details		
	Total (out of 5)		
OVERALL TOTAL (out of 24)			

Appendix 2

B) fMRI Quality assessment table

Are these criteria reported in the study?

1=sufficient evidence reported. 0=no evidence reported/unclear/not explicit

Reference………

Total scores: 0-10=low quality, 11-20=medium quality, 21-30=high quality.

		Examples/notes	**Reported ?**
Experimental design	Number of blocks, trials or experimental units per session/subject		
	Length of each trial and interval between trials	*Both must be reported*	
	Total (out of 2)		
Task specification	Describes what subjects were asked to do	*E.g. Subjects read statements and instructed to press button to indicate if they agreed or disagreed*	
	Stimuli- describes what they were and how many	*E.g. 24 scenarios, 12 moral and 12 non moral. Explanation or example of content*	
	Total (out of 2)		
Subjects	Number of subjects		
	Age (mean and range)	*Both must be reported*	
	Handedness		
	Number of males/females		
	Inclusion/exclusion criteria	*Explicit inclusion and exclusion criteria, not just description of participant characteristics*	
	States which IRB approved the protocol	*Mark as not reported if just states 'local ethics committee' without giving name/institution*	
	Total (out of 6)		
Data acquisition *(these details need to be reported for functional imaging not just structural)*	MRI system manufacturer, field strength (Tesla), model name or EEG system Name	*Only give point if all info reported*	
	MRI acquisition (number of experimental sessions and volumes acquired per session)	*Needs to report both no. of volumes and sessions*	
	Field of view, matrix size, slice thickness	*All 3 must be reported*	

	Pulse sequence type	*E.g. gradient/spin echo, EPI/spiral*	
	TE/TR/flip angle	*All 3 must be reported*	
	Total (out of 5)		
Data pre-processing	Name and version number of pre-processing software used	*E.g. SPM5, FSL*	
	Specifies order of pre-processing operations	*If in list format, assume that is order*	
	Motion correction details *(not just stating that motion correction was performed)*	*E.g. Head motion corrected with FSL's MCFLIRT by maximizing the correlation ratio between each time point and the middle volume, using linear interpolation*	
	Slice timing correction (reference type of slice and interpolation)	*E.g. Slice timing correction to the first slice as performed, using SPM5's Fourier phase shift interpolation*	
	Size and type of smoothing kernel	*E.g 8mm FHWM Gaussian*	
	Total (out of 5)		
Analysis	Brain image template space, name, modality and resolution	*E.g. SPM2s MNI grey matter template 2x2x2mm' (not just MNI/Talairach space-see below)*	
	Coordinate space	*Reports if coordinates are reported as MNI or Talairach, not just which template normalised to (see above). In text not just tables*	
	Specifies exactly which conditions were subtracted from which condition		
	Statistical model reported	*E.g. Multiple regression, ANOVA, t-test*	
	Estimation method reported	*GLS or OLS. Tick as reported if e.g. 'A regression using 3dREMLfit in ANFI', as this is software for GLS or explicitly states 'according to SPM8s GLM '(uses OLS)*	
	Inference type	*Mixed or random effects*	

	Cluster-wise threshold and significance level details	*E.g. Group activation contrasts (uncorrected <.05 with a cluster-size threshold of 50 voxels)*	
	Total (out of 7)		
Tables	Labelled with coordinate space		
	Thresholds used to create tables	*P value/cluster threshold*	
	Statistics for each cluster in tables	*Must report X, y, z co-ordinates, cluster size and either a z or t value*	
	Total (out of 3)		
OVERALL TOTAL (out of 30)			

Appendix 3

List of Included Papers in Alphabetic Order

1. Behrens, T. E., Hunt, L. T., Woolrich, M. W., & Rushworth, M. F. (2008). Associative learning of social value. *Nature*, 456(7219), 245-249.
2. Flores, A., Münte, T. F., & Doñamayor, N. (2015). Event-related EEG responses to anticipation and delivery of monetary and social reward. *Biological psychology*, 109, 10-19.
3. Hare, T. A., Camerer, C. F., Knoepfle, D. T., O'Doherty, J. P., & Rangel, A. (2010). Value computations in ventral medial prefrontal cortex during charitable decision making incorporate input from regions involved in social cognition. *Journal of Neuroscience*, *30*(2), 583-590.
4. Harbaugh, W. T., Mayr, U., & Burghart, D. R. (2007). Neural responses to taxation and voluntary giving reveal motives for charitable donations. *Science*, *316*(5831), 1622-1625.
5. Häusler, A. N., Becker, B., Bartling, M., & Weber, B. (2015). Goal or gold: overlapping reward processes in soccer players upon scoring and winning money. *PloS one*, 10(4), e0122798.
6. Heekeren, H. R., Marrett, S., Bandettini, P. A., & Ungerleider, L. G.e (2004). A general mechanism for perceptual decision-making in the human brain. *Nature*, 431(7010).
7. Janowski, V., Camerer, C., & Rangel, A. (2013). Empathic choice involves vmPFC value signals that are modulated by social processing implemented in IPL. *Social cognitive and affective neuroscience*, 8(2), 201-208.
8. Izuma, K., Saito, D. N., & Sadato, N. (2008). Processing of social and monetary rewards in the human striatum. *Neuron*, 58(2), 284-294.
9. Izuma, K., Saito, D. N., & Sadato, N. (2010). Processing of the incentive for social approval in the ventral striatum during charitable donation. *Journal of Cognitive Neuroscience*, 22(4), 621-631.
10. Lin, A., Adolphs, R., & Rangel, A. (2012). Social and monetary reward learning engage overlapping neural substrates. *Social cognitive and affective neuroscience*, 7(3), 274-281.

11. Mitchell, J. P. (2008). Activity in right temporo-parietal junction is not selective for theory-of-mind. Cerebral cortex 18(2).
12. Moll, J., Krueger, F., Zahn, R., Pardini, M., de Oliveira-Souza, R., & Grafman, J. (2006). Human fronto–mesolimbic networks guide decisions about charitable donation. *Proceedings of the National Academy of Sciences*, 103(42), 15623-15628.
13. Nawa, E. N., Nelson, E. E., Pine, D.S., Ernst, M. (2008). Do you make a difference? Social context in a betting task. *Social Cognitive and Affective Neuroscience*, 3(4).
14. Pegors, T. K., Kable, J. W., Chatterjee, A., & Epstein, R. A.(2015). Common and unique representations in pFC for face and place attractiveness. *Journal of Cognitive Neuroscience*, 27(5)
15. Philiastides, M. G., & Sajda, P. (2006). Temporal characterization of the neural correlates of perceptual decision-making in the human brain. *Cerebral cortex,* 16(4).
16. Proverbio, A. M., Adorni, R., Zani, A., & Trestianu, L. (2009). Sex differences in the brain response to affective scenes with or without humans. Neuropsychologia, 47(12), 2374-2388.
17. Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people: the role of the temporo-parietal junction in “theory of mind”. *Neuroimage*, 19(4).
18. Rademacher, L., Krach, S., Kohls, G., Irmak, A., Gründer, G., & Spreckelmeyer, K. N. (2010). Dissociation of neural networks for anticipation and consumption of monetary and social rewards. *Neuroimage*, 49(4), 3276-3285.
19. Rademacher L, Salama A, Gründer G., Spreckelmeyer K. N. (2014). Differential patterns of nucleus accumbens activation during anticipation of monetary and social reward in young and older adults. *Social Cognitive Affective Neuroscience*, 9(6).
20. Rilling, J. K., Gutman, D. A., Zeh, T. R., Pagnoni, G., Berns, G. S., & Kilts, C. D. (2002). A neural basis for social cooperation. *Neuron,* 35(2), 395-405.
21. Rigoni, D., Polezzi, D., Rumiati, R., Guarino, R., & Sartori, G. (2010). When people matter more than money: An ERPs study. *Brain research bulletin,* 81(4), 445-452.
22. Sescousse, G., Redouté, J., & Dreher, J. C. (2010). The architecture of reward value coding in the human orbitofrontal cortex. *The Journal of Neuroscience,* 30(39), 13095-13104.
23. Smith, D. V., Hayden, B. Y., Truong, T. K., Song, A. W., Platt, M. L., & Huettel, S. A. (2010). Distinct value signals in anterior and posterior ventromedial prefrontal cortex. *The Journal of neuroscience*, 30(7), 2490-2495.

24. Spreckelmeyer, K. N., Krach, S., Kohls, G., Rademacher, L., Irmak, A., Konrad, K., ... & Gründer, G. (2009). Anticipation of monetary and social reward differently activates mesolimbic brain structures in men and women. *Social cognitive and affective neuroscience*, 4(2), 158-165.

25. Zink CF, Tong Y, Chen Q, Bassett DS, Stein JL, Meyer-Lindenberg A. (2008). Know your place: neural processing of social hierarchy in humans. *Neuron,* 58(2).

26. Zeng, J., Wang, Y., & Zhang, Q. (2012). An ERP study on decisions between attractive females and money. *PloS one*, 7(10).

Appendix 4

Words used in the priming task (Study 3).

Social threat words	Social positive words	Non-social negative words	Non-social positive words
Shy	Honest	Vomit	Dazzle
Jealous	Loyal	Trauma	Lively
Useless	Brave	Bloody	Secure
Inferior	Polite	Poison	Carefree
Timid	Confident	Illness	Free
Guilty	Funny	Cemetery	Glamour
Hostile	Jolly	Coffin	Beautiful
Ignorant	Loving	Damage	Holiday
Obnoxious	Humane	Pain	Relax
Coward	Grateful	Ambulance	Abundant
Insane	Mighty	Fever	Peaceful
Stupid	Kindly	Crisis	Alive

Appendix 5

Questionnaires Study 4

Section A: (Tick where applicable)

Gender: Male ☐ Female ☐ Other ☐

Age: ______

Subjective Ratings

How to Fill Out the Questionnaire

Upon completion of the EEG session, please complete this 5-point scale to rate your subjective feeling of interest, willingness to the task, expectancy, attention and emotional response to the outcomes. Thank you.

Category	**Question**	**1**	**2**	**3**	**4**	**5**
Motivation	How much did you feel "I want to win in the task?"	Not at all				Very much
Feelings toward winning	How good(bad) did you feel that your choice resulted in a gain (loss)?	Very bad				Very good/happy
Interest	How much were you interested in the task?	Not at all				Very much

Thank you very much for taking part in my study! I appreciate your interest and time.