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**An electroencephalographic approach to the processing of
ambiguous stimuli under social influence: the role of
perception, attention, emotion and metacognition**

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Thèse de **Julie ZANESCO**

Intitulée: An electroencephalographic approach to the processing of ambiguous stimuli under social influence: the role of perception, attention, emotion and metacognition

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ABSTRACT

Humans, as social beings, are susceptible to social influence in their judgements, beliefs and behaviours. Over the last 70 years, a great wealth of data from experimental social psychology has demonstrated that social knowledge affects the way humans perceive and interpret their environment, giving rise to cognitive, perceptual, attentional and motivational biases. Already in the 1950's, Solomon Ash (1951), in a series of perceptual judgement experiments, demonstrated that humans could alter their responses when these differed from a majority. Moreover, the degree of uncertainty triggered by stimuli in the environment has been shown to increase human's vulnerability to social opinion. More recently, neuroscience began to explore automatic unconscious and controlled conscious brain responses to social stimuli, mainly face expressions. To date, however, the temporal unfolding of attentional and perceptual processes under uncertainty and social conflict remains unclear, particularly regarding the perception of ambiguous stimuli other than faces in a social context. Thus, the aim of the three studies in this thesis, was to investigate whether early perception and higher order cognitive processes were altered when healthy and socially anxious subjects were presented with ambiguous stimuli and when their responses were either endorsed or disputed. For this, a novel experimental paradigm was created allowing us to measure event-related potentials (ERPs) in response to visual stimuli, before and after social feedback indicated by a face displaying a happy (agreement) or disgusted expression (disagreement). Participants were asked to judge the colour of a square (the probe) that was either clearly blue or green (distinct probes) or were highly ambiguous bluish-green colour (ambiguous probes). They were also asked to indicate their level of confidence in those judgments, after which they received social feedback either endorsing or disputing the participants' responses. Participants were then presented the stimulus again and asked to reconsider their decision and subjective confidence level. Behavioural results showed that confidence levels decreased whereas the number of revisions increased, both with task difficulty

and with conflicting social feedback across healthy subjects. Moreover, this pattern was enhanced across socially anxious individuals. Event-related-potential data revealed differences beginning at already 100 ms after ambiguous stimuli presentations compared to distinct stimuli, as well as enhanced early amplitudes following disputed feedback. These findings are compatible with heightened sensory facilitation of visual information, demonstrating that uncertainty and social pressure modify early perceptual brain processes. The same pattern was reduced across socially anxious individuals suggesting a reduction in early attentional processes to external ambiguous stimuli due to excessive self-focusing and anticipation of the social situation. Additionally, later ERP components, starting at around 300 ms, were decreased for distinct stimuli compared to ambiguous probes in line with higher subjects' signal detection accuracy and metacognitive experiences.

Overall, findings indicate that unconscious perception to stimuli in social environments are modified when subjects are faced with uncertainty and social pressure and that these perceptual processes are diminished in the socially anxious population, whereas, self-awareness metacognitive processes begin at a later stage when subjects are certain about the physical attributes of the stimuli.

Key words: Event-related potentials, early visual perception, attentional mechanisms, uncertainty, social feedback, metacognition, social anxiety disorder

Résumé en français

Les êtres humains, en tant qu'êtres sociaux, sont susceptibles d'influence sociale dans leurs jugements, leurs croyances et leurs comportements. Au cours des 70 dernières années, une grande quantité de données issues de la psychologie sociale expérimentale a démontré que les connaissances sociales affectent la façon dont les humains perçoivent et interprètent leur environnement, ce qui entraîne des biais cognitifs, perceptuels, attentionnels et motivationnels. Déjà dans les années 50, Solomon Ash (1951), dans une série d'expériences de jugement perceptuel, démontrait que les humains pouvaient modifier leurs réponses lorsque celles-ci différaient de la majorité. De plus, il a été démontré que le degré d'incertitude provoqué par des stimuli environnementaux augmentait la vulnérabilité de l'homme à l'opinion sociale. Plus récemment, les neurosciences ont commencé à explorer les réponses cérébrales inconscientes et contrôlées aux stimuli sociaux, principalement les expressions de visages. À ce jour, toutefois, le déroulement temporel des processus d'attention et de perception dans des situations d'incertitude et de conflits sociaux reste flou, en particulier en ce qui concerne la perception de stimuli ambigus, autres que les visages, dans un contexte social. L'objectif des trois études de cette thèse était donc de déterminer si la perception précoce et les processus cognitifs d'ordre supérieur étaient altérés lorsque des sujets tout-venants ainsi que des sujets présentant une anxiété sociale, étaient face à des stimuli ambigus et que leurs réponses étaient soit approuvées, soit contestées. Pour cela, un nouveau paradigme expérimental a été créé, nous permettant de mesurer les potentiels évoqués (ERP) en réponse à des stimuli visuels, avant et après le retour social (expression heureuse/accord ou de dégoût/désaccord). Les participants ont été invités à juger la couleur d'un carré (la sonde) qui était soit clairement bleu ou vert (sondes distinctes), soit de couleur bleu-verte très ambiguë (sondes ambiguës). On leur a également demandé d'indiquer leur degré de confiance à l'égard de leurs jugements, après avoir reçu le feed-back social

approuvant ou contestant leurs réponses. Le même stimulus est ensuite présenté à nouveau et les participants sont invités à reconsidérer leur décision et leur niveau de confiance subjective.

Les résultats comportementaux chez les sujets sains, ont montré que les niveaux de confiance diminuaient alors que le nombre de révisions augmentait, à la fois en raison de la difficulté de la tâche et du feedback social. Cette tendance était renforcée chez les personnes socialement anxieuses. Les données de potentiels évoqués ont révélé des différences commençant déjà à 100ms après la présentation des stimuli ambigus. Ces résultats démontrent une modification précoce des processus visuels par une facilitation sensorielle accrue de l'information lorsque les sujets se trouvent en situation d'incertitude et sous pression sociale. Cette même configuration était réduite chez les sujets anxieux sociaux, ce qui suggère une réduction des processus attentionnels précoces aux stimuli ambigus externes en raison d'une focalisation excessive sur soi et d'une anticipation de la situation sociale. De plus, les composantes ERP tardives, commençant à environ 300 ms, étaient diminuées pour les stimuli distincts par rapport aux ambiguës, conformément à une plus grande détection de précision du signal de précision et à des expériences métacognitives.

Dans l'ensemble, les résultats indiquent que la perception inconsciente des stimuli dans l'environnement social est modifiée lorsque les sujets sont confrontés à l'incertitude et à la pression sociale. Ces processus perceptuels sont atténués dans la population socialement anxieuse, alors que les processus métacognitifs commencent plus tard, lorsque les attributs physiques des stimuli renvoient vers un sentiment de certitude

Mots-clés : potentiels évoqués, perception visuelle précoce, mécanismes attentionnels

incertitude, feedback social, métacognition, trouble de l'anxiété sociale.

1. GENERAL INTRODUCTION

The nature of human vision has been extensively investigated in cognitive psychology and more recently in the field of neurosciences. Cognitive models such as Marr's model of visual perception (Marr, 1982) or Humphreys & Riddoch's model (Humphreys & Riddoch, 1987a) showed that recognition of stimuli in our environment depends on a hierarchical processing of visual information involving sensory, perceptual and cognitive processing. The human brain, first analyses the visual elementary properties of stimuli, then forms a percept of the stimulus and finally, compare this percept to its memory representations in order to recognise the stimulus. Neuroscientific work, using structural and temporal methods, has focalised on these different stages of processing in the human brain. Typical questions that were raised have been for example, how low-level properties of a stimulus influence behavioural and neuronal outcomes. Findings showed that attentional mechanisms had a direct effect on how we perceive information in our environment. Since our attentional capacities are limited, salient or threatening stimuli capture our attention in an automatic bottom-up manner (e.g. LeDoux, 2000), whereas, controlled top-down attentional processes enable to direct our attention towards what we consider relevant at a certain time and location, thus involving more effortful orienting processes (e.g. Hopfinger & West, 2006). An important question raised in neurosciences, is how does top-down endogenous attention interact with bottom-up exogenous attention on visual processing. Results have shown that endogenous attention is enhanced in early processing when a stimulus discrimination is necessary to perform a task (e.g. Luck, Heinze, Mangun & Hillyard, 1990).

As social beings, humans are often obliged to perform under social pressure. The field of social psychology and social neuroscience, has been largely devoted to the neural and behavioural responses to environmental information under social pressure. Thus, the social context in which we live may affect, not only people's thoughts, but also the way we perceive physical stimuli.

Additionally, it has been demonstrated that when facing uncertain information, the influence of social context is increased (Cialdini & Goldstein, 2004), and that this effect is modulated by the ability of humans to reconsider their decisions. The latter suggests the involvement of metacognitive processes, that is, the processes by which we monitor and control our cognitive processes (Frith, 2012).

The general aim of this thesis is to investigate the electrophysiological correlates associated with the processing of ambiguous uncertain stimuli under social pressure. Thus, the early unconscious perception and the later metacognitive experiences have been explored under positive and negative social feedback within the healthy population as well as across socially anxious individuals.

The work in this thesis has been divided into three parts: a theoretical part, an experimental part and a general conclusion. In the theoretical part, we first give an overview of the electroencephalographic methodology and we review the main findings in neurosciences across the visual, attentional, metacognitive and social fields. At the end of this theoretical part, we report the effects of uncertainty and social pressure within socially anxious subjects, giving rise to attentional biases.

The second section of this thesis, the experimental part, includes the three studies that were conducted to investigate the temporal dynamics of early perception and metacognition under uncertainty and social feedback. The first study focalises on the modulation of early visual ERP (event-related potentials) when healthy subjects are under uncertainty and social influence. The second study looks at later components in response to this subjective feeling of uncertainty and social feedback in order to understand how these aspects influence metacognitive processes. Finally, the third study, using the same novel paradigm, explores early visual and attentional biases in socially anxious individuals compared to healthy subjects. In this last study, a stressor (speech induction) is added prior to the experimental task in order to enhance the effect of

uncertainty and social feedback and see the different consequences in these two groups of subjects.

Finally, a general conclusion is presented with the integration of the main findings of the experimental part, as well as an overview of the theoretical implications of this thesis.

2. THEORETICAL PART

2.1. EEG and ERP SPECIFICITIES

Although EEG (electroencephalography) is an old technique to measure brain neural activity discovered in the 1930s, the use of ERPs (event-related-potentials) has progressed over the last century. In 1929, Hans Berger, was the first to put two electrodes on the surface of the scalp. He looked at the difference between these two electrodes and found that there was a fluctuation of electrical activity across time (ms). He demonstrated that the human brain's electrical neuronal activity could be measured by placing an electrode on the surface of the scalp, and through the amplification of the signal, he could plot the changes in voltage (microvolts) over time (Berger, 1929) (Fig. 1). This electrical activity measured on the scalp is called an electroencephalogram. However, the EEG is a rough measure of neural brain activity and cannot be used in its raw form to measure specific neural processes (Fig. 2). In other words, the raw data obtained is made up of several different neural sources of activity (Luck, 2014). Thus, in order to isolate the different cognitive processes embedded within the EEG, the extraction of neural responses associated with sensory, motor and cognitive activity, is required. This is done through averaging techniques that enable to look at the potentials related to a particular event, called event-related-potentials (ERPs). The resulting averaged ERP waveforms consist of a sequence of positive and negative voltage deflections which are called peaks or components, and are labelled P1, N1, P2, N2, P3, N400...indicating positive (P) or negative (N) going peaks. The number next to the P or N indicates the position within the waveform or the latency of the peak in ms (Fig. 3).

EEG has a very precise temporal resolution (1ms) compared to hemodynamic measures (hundreds of ms), which have a strong spatial resolution in the mm range, but the latter cannot match the former in terms of timing (Fig. 4). Compared to behavioural measures, ERPs provide an online measure of processing when behaviour responses are impossible. This is

called covert measurement of processing. Thus, ERPs can be used to create models of distribution of activity over cortical surface.

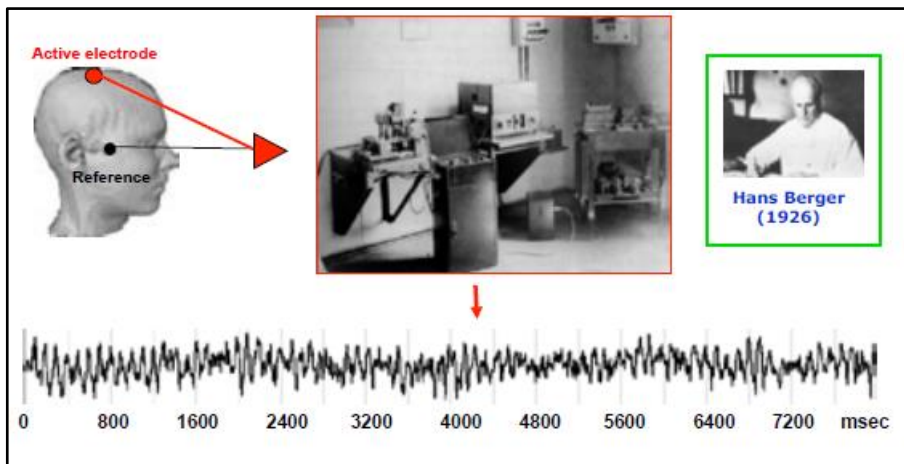


Figure 1. The discovery of the electroencephalogram (EEG) by Hans Berger in 1929.

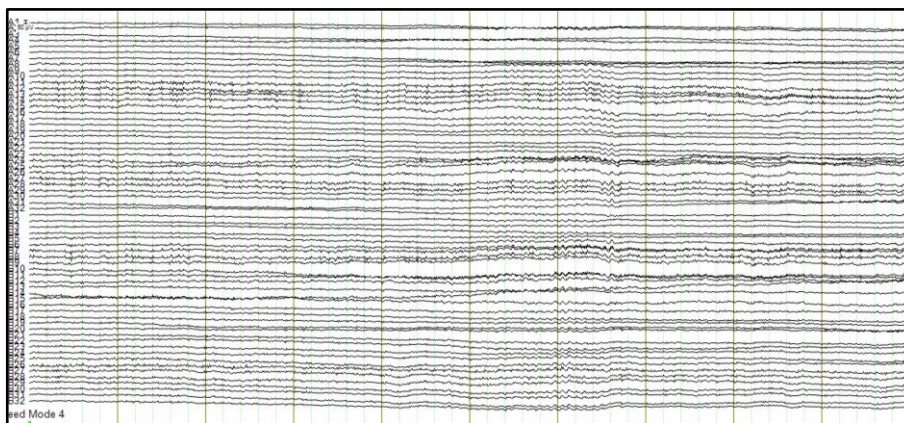


Figure 2. Example of EEG raw data

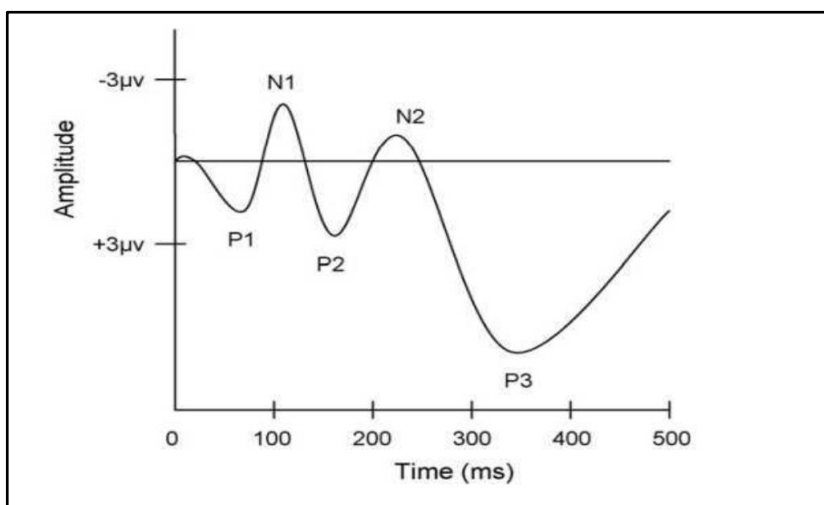


Figure 3. Event-related potentials main components.

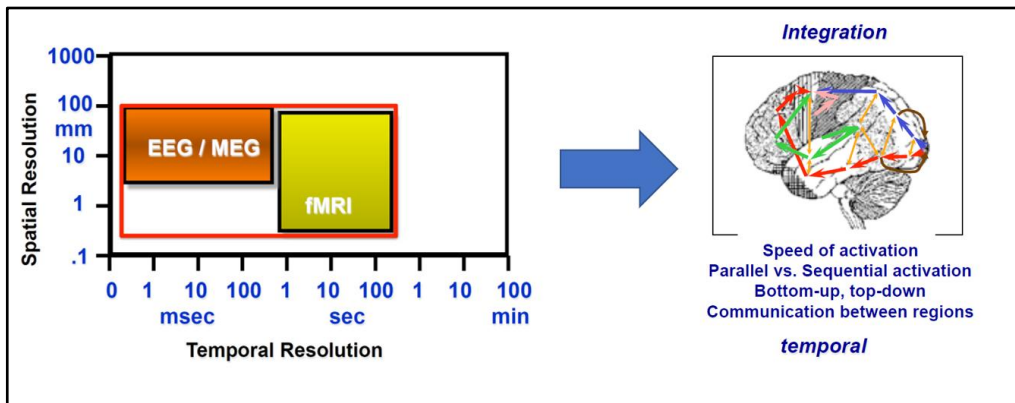


Figure 4. Temporal resolution in EEG compared to fMRI (functional magnetic resonance imaging).

2.1.1. PHYSIOLOGICAL BASIS OF ELECTROENCEPHALOGRAPHY

Neuronal activity is mainly characterised by electrical discharges. EEG measures fluctuations in electrical potential on the scalp's surface resulting from post-synaptic activity when the neurotransmitter binds to the receptor, thus changing the flow of ions across the cell membrane. Neurons in the brain have a resting potential which is characterised by negative potential inside and positive potential outside the cell (Fig. 5). When neurons are activated, actions potentials are coming in through the neuron, neurotransmitter is released and goes to the post-synaptic neuron (Fig. 6). This process will change the channels and make ions going in and out of the extra neuronal space. However, we do not have direct access to the electrical activity, as the distance between the electrode and the neuron is too large (Fig. 7). We have access to the voltage related to the electrical activity of synchronous activity of parallel organised pyramidal cells that together generate a sufficiently strong dipolar field. The electrical activity spreads through the brain and passes the skull to the scalp, where it can be picked up by electrodes. Scalp ERPs are not produced by action potentials. When postsynaptic potentials occur, they create an electrical dipole, thus ERPs can be measured when the dipoles of thousands of similarly oriented neurons sum together forming a vector sum. Because of this spatial arrangement, we can detect the activity of synchronously firing neurons. The

voltage recorded on the surface of the scalp will be positive on one side of the dipole and negative on the other side with a line zero voltage separating the positive and negative sides (Luck, 2014).

As discussed, it is erroneous to attribute any change in potential to the tissue beneath the electrode. Nevertheless, the entire neuronal population contributes to produce changes in the electrical field measured at the surface of the skull, leading to temporally precise measurements of brain activity, while spatial resolution remains quite poor (e.g. Michel, Murray, Lantz, Gonzalez, Spinelli & Peralta, 2004).

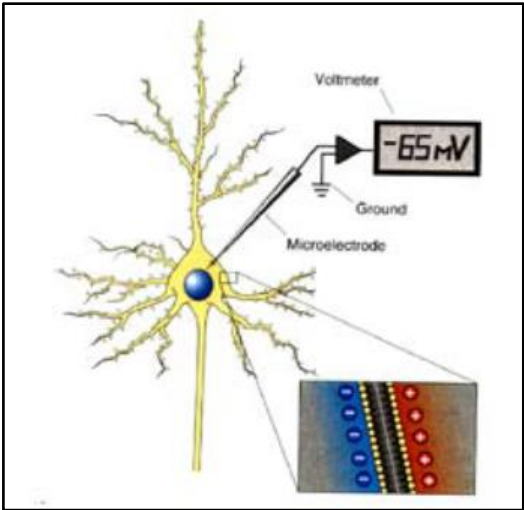


Figure 5. The resting potential of neurons

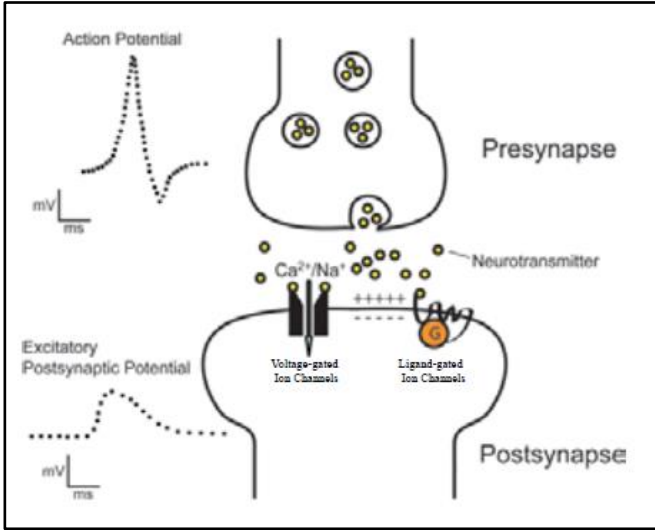


Figure 6. Neuronal activity: synaptic transmission

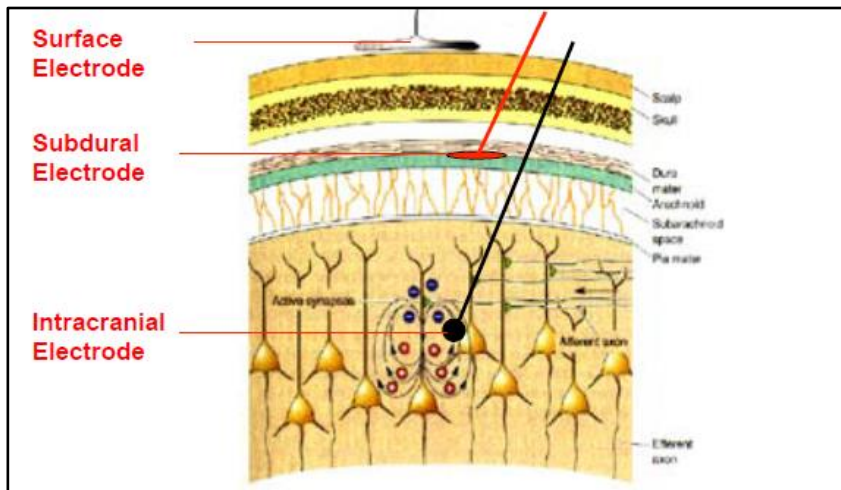


Figure 7. Large distance between electrode and neuron: activation of a few neurons is not observable on the surface. Large areas need to be active to be seen on the surface.

In sum, EEG is recorded from multiple electrodes distributed across the scalp with a conductive gel between each electrode and the skin to make a stable electrical connection. The electrical potential (voltage) is recorded from each electrode resulting in a separate waveform for each electrode site. This waveform is a mixture of actual brain activity, biological electrical potential produced outside the brain (skin, eyes, muscles) and induced activity from external devices that is picked up by the head. Thus, in order to get what is related to the task, we need to extract the evoked response linked to an event/stimulus (averaging technique). The event-related-potentials will enable to isolate the temporal activation of cortical processes associated with cognitive events (Fig. 8).

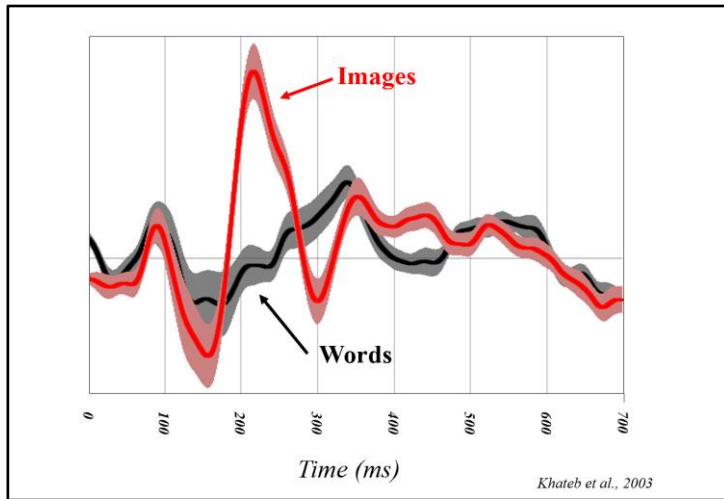


Figure 8. Example of ERPs. Comparison between two conditions (words vs. images)

2.1.2. EARLY ERP COMPONENTS

A distinction is made between early exogenous components and late endogenous components.

Early exogenous components vary according to the physical features of a stimulus and are observed early after the presentation of the stimulus. These responses mainly reflect sensory information (vision, audition and touch) (Fig. 9). These exogenous sensory components, although triggered by the presence of a stimulus, may be modulated by top-down processes.

The main visual, auditory and somatosensory ERPs are the P1, N1, N170 and P2/N2 components. The visual P1 and N1 are considered the earliest electrical markers of visual processing and are influenced both, by the low-level features of the stimuli (Johannes, Münte, Heinze & Mangun, 1995) and by attentional processes (Luck et al., 1990). The P1 is an occipital component peaking at around 100 ms after stimulus presentation. It is generated in the extrastriate visual area (V1) and reflects early sensory processing for stimuli presented in a location where attention is focused whereas, the N1, peaking between 100 ms and 200 ms, represents the orienting of attention to a task-relevant stimulus (Luck et al., 1990). However, there are several visual N1 subcomponents contributing to the same deflection. The anterior

N1 peaks earlier than the two posterior ones (parietal and lateral occipital), but both are influenced by spatial attention (e.g. Hillyard & Anllo-Vento, 1998) as well as task discrimination (e.g. Vogel & Luck, 2000).

The N170 component, peaking between 150 ms and 200 ms after stimulus onset, is a face-sensitive component assumed to be generated in occipito-temporal cortex and posterior fusiform gyrus (e.g. Bötzel, Schulze & Stodieck, 1995). It reflects sensory perceptual stages of face processing for subsequent face recognition (Eimer, 2000). Section 2.2.3 (ERP data from visual perception and early attention) will discuss the main visual components in further details. Section 2.2.4.2 (ERP data from face perception) discusses the main components in face recognition.

The P2 component, peaking between 200 ms and 300 ms, is at the boundary between exogenous and endogenous processes (Luck, 2014). This component is usually larger for target features and enhanced when targets are rare (Luck & Hillyard, 1994). This component indexes attention oriented towards certain features of objects (Hermann & Knight, 2001). Finally, the N2, peaking between 200 ms and 300 ms, is usually observed for deviant stimuli and auditory mismatches at anterior sites (for a review see: Folstein & Van Petten, 2008).

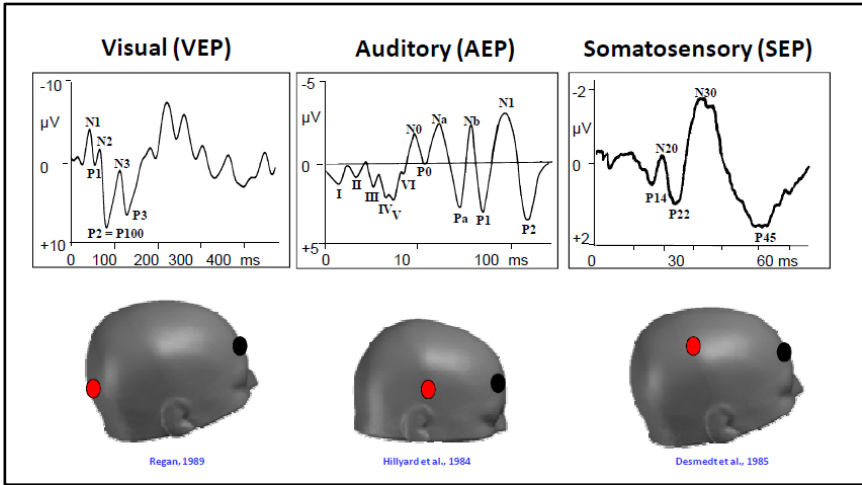


Figure 9. Sensory evoked potentials

2.1.3. LATE ERP COMPONENTS

Late endogenous components are observed at later stages of conscious processing and can or cannot take place for a particular stimulus depending on the degree of attention allocation of the subject. These responses reflect cognitive treatment (Fig. 10), and are entirely dependent on the task. The main endogenous components are the P3, N400 and the late posterior positivity (LPP). Concerning the P3, there are several components that have been identified in the time range between 300 ms and 450 ms (for a review, see: Polich 2004; 2012). Mainly, the P3, a positive-going deflection on midline sites (Donchi & Coles, 1988) has been associated with stimulus predictability (Picton, 1992), allocation of additional attentional resources and task difficulty (e.g. Isreal, Chesney, Wickens & Donchin, 1980), stimulus categorisation and post categorisation processes (Kutas, McCarthy & Donchin, 1977; Polich & Bondurant, 1997) and more recently, with expectancy towards outcome (Zhou, Yu & Zhou, 2010), feedback valence (Hajcak, Holroyd, Moser & Simons, 2005) and variations in perceptual certainty (Selimbeyoglu, Keskin-Ergen & Demiralp, 2012), as well as metacognitive awareness (Murphy, Robertson, Harty & O'Connell, 2015; Desender, Van Opstal, Hughes & Van den Bussche, 2016) and post-decision accumulation of sensory evidence that leads to a judgement (Murphy et al., 2015; Kelly & O'Connell, 2013; Twomey, Murphy, Kelly & O'Connell, 2015). Thus, P3 is highly dependent on the experimental manipulation.

Concerning the N400, this component has been associated to situations of semantic violations of meaning (Kutas & Hillyard, 1980). However, recent research in social neurosciences have found an N400 for context violations suggesting that this semantic-related component extends beyond language (e.g. Amaruso, Gelormini, Aboitiz, Gonzalez, Manes, Cardona & Ibanez, 2013).

The LPP, a midline ERP starting at around 300 ms after stimulus onset and lasting up to 600 ms, has mainly been linked to cognitive strategies of emotional regulation (e.g. Hajcak, MacNamara & Olvet, 2010). It reflects interactions of bottom-up attentional allocation and top-down sustained elaboration (e.g. Weinberg, Ferri & Hajcak, 2013).

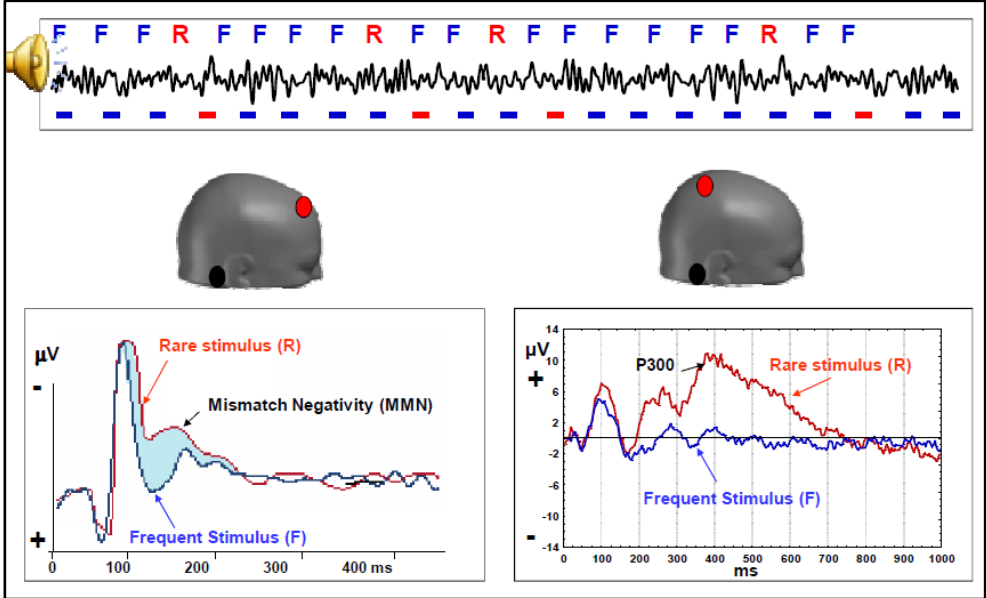


Figure 10. Example of cognitive evoked potentials: the brain can differentiate between what is regular (F; frequent stimulus), what is rare (R) and what is deviant (mismatch negativity).

2.2. VISUAL PERCEPTION AND ATTENTION

2.2.1. BRAIN STRUCTURES INVOLVED IN VISUAL PERCEPTION

Occipital structures are the beginning of visual processing but visual mechanisms extend beyond the striate cortex. Visual regions are hierarchically organised (Hubel & Wiesel, 1962) with parallel and interconnecting pathways at each level to account for a progressive increase in complexity (Felleman & Van Essen, 1991) (Fig. 11). The information spreads from the primary visual area V1 (striate cortex) to higher order visual areas. Thus, V1 is the first processing level in the distributed hierarchy. It receives the largest input from the lateral geniculate nucleus of the thalamus and projects to all other occipital areas. V2 (pre-striate cortex) is the second level and it is a mirror image map of V1. Striate and extra-striate areas in humans (V1 and V2) are sensitive to shapes and spatial orientations. After V2, parallel pathways go to the parietal cortex, inferior temporal cortex and superior temporal sulcus. Object recognition as well as colour recognition takes place in the ventral pathway (temporal lobe) whereas visual action takes place in the dorsal stream (parietal lobe) (Mishkin, Ungerleider & Macko, 1983) (Fig. 12). Accordingly, from V1 and V2 areas, the information either goes to V4, where cells respond to colour, or to V3, which is sensitive to the shape of objects in motion, or to V5, which hosts neurons sensitive to segments that move (Kolb & Wishaw, 2009). As we go forward towards anterior regions, neurons respond to more and more complex refined stimuli.

Neuropsychological research has shown that selective lesions in the hierarchy produce specific deficits in visual processing. For example, patients with damage to V4, will see the world in shades of grey and will not be able to recall colours neither to imagine them (Meadows, 1974; Sacks & Wasserman, 1987), whereas lesions to V5 will produce an inability to perceive objects in movement (Schenk, Ellison, Rice & Milner, 2005).

However, visual processing does not end in secondary areas (V3, V4, V5). Several visual regions in temporal and parietal lobes respond to complex stimuli. For instance, within the temporal lobe, the fusiform face area is responsible for face recognition, the extrastriate body area for body analysis, the superior temporal sulcus for biological motion, the lateral occipital area for object analysis and the parahippocampal place area for the analysis of landmarks (Kolb & Wishaw, 2009). Lesions to specific regions in temporal cortex will result in specific agnosia, this is the incapacity to analyse or recognise objects or familiar faces without any impairment of visual primary system. Nevertheless, I will not go into further details on these neuropsychological visual deficits as it is not relevant to the purpose of this thesis.

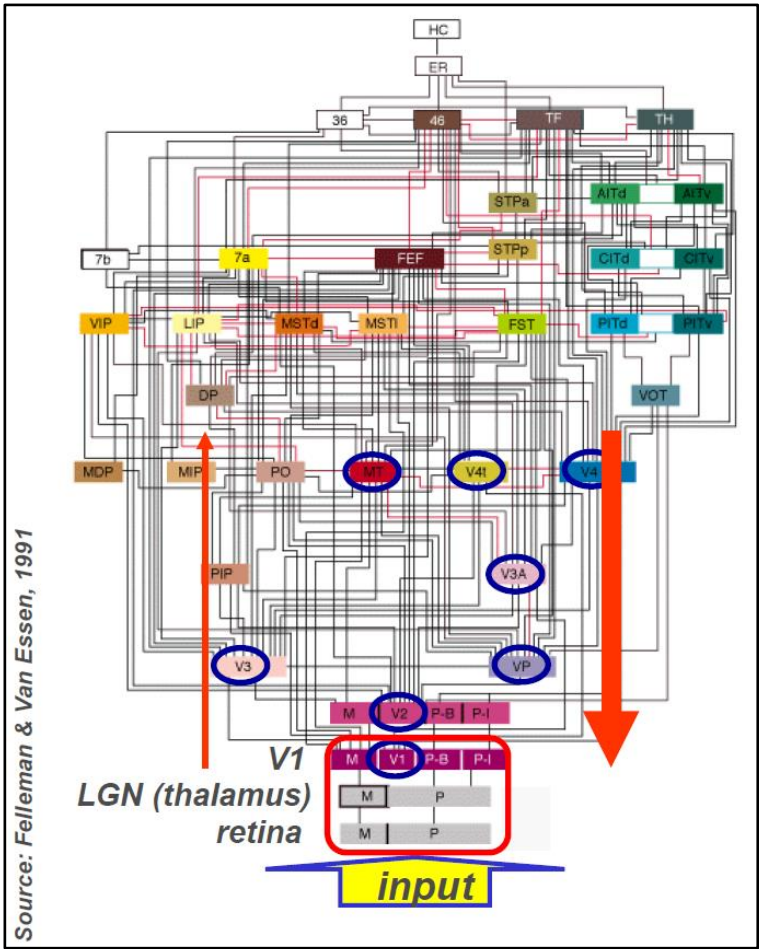


Figure 11. Hierarchy of visual regions showing a densely interconnected network hierarchically organised with feedforward and feedback connections. This hierarchy shows 32 visual cortical areas as well as subcortical visual stages (retinal ganglion cell layer and the lateral genicular nucleus) plus

several non-visual areas such as the somatosensory cortex (7b), perirhinal area (36), and the hippocampal complex. These areas are connected by 187 linkages, most of which have been demonstrated to be reciprocal pathways.

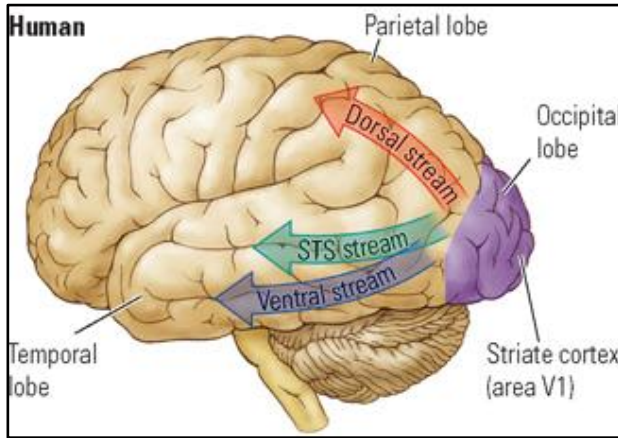


Figure 12. Visual pathways in the human brain. The parietal cortex (dorsal stream) controls the voluntary orienting of attention towards a location of interest. The ventral stream is involved with object and visual identification and recognition. The STS (superior temporal sulcus) separates the superior temporal gyrus from the middle temporal gyrus and it involved with the identification human biological motion and specific social inputs suggesting its role in social perception.

2.2.2. BRAIN STRUCTURES INVOLVED IN ATTENTION

Bottom-up attention or exogenous attention is captured by the stimuli features, as opposed to top-down attention (endogenous attention), in which visual attention will be oriented on the basis of our expectations, knowledge and objectives. Thus, there is a functional segregation of cortical pathways for bottom-up and top-down attention (Corbetta, Kincade, Ollinger, McAvoy & Shulman, 2000) (Fig. 13).

The ventral pathway responds to unexpected or deviant events. Regions within the ventral stream inhibit parietal regions, whereas, the dorsal pathway identifies the localisation (goal-oriented) and gets activated when attention is reoriented in space, as well as when a specific

localisation is selected. Thus, fronto-parietal regions are activated in focalised attention (Corbetta et al., 2000).

Visual search paradigms have been used to test attention competition in laboratory settings (e.g. Theeuwes, 1994). In these tasks, subjects are required to search for a target among distractors. When targets are salient in terms of shape and colour, bottom-up activations are generated based on the differences in stimulus features (singleton detection). When targets are similar to distractors, the searching is done in a serial manner involving top-down processes (Bacon & Egeth, 1994). Thus, the parietal cortex is activated for attention to location and the occipito-temporal cortex is activated for attention to features such as colour and shape (Treisman & Gelade, 1980). Moreover, several frontal regions, mainly the anterior cingulate, are involved when attentional effort is required (Kolb & Wishaw, 2009). Consequently, sensory processing is affected by early exogenous and late endogenous mechanisms of attention that interact according to task manipulations. Exogenous attention is oriented more rapidly whereas endogenous attention requires more cognitive resources involving a larger attentional network including frontal eye fields, intraparietal sulcus, superior temporal gyrus and anterior cingulate (Hopfinger & West, 2006).

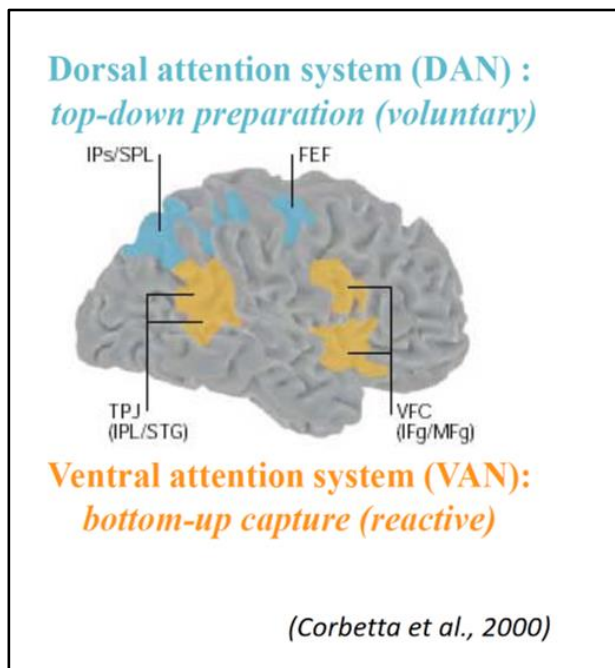


Figure 13. Cortical pathways involved in bottom-up and top-down- attention: The dorsal system is bilateral and composed of the intraparietal sulcus (IPS) and the junction of the precentral and superior frontal sulcus (frontal eye field, FEF) in each hemisphere. It is involved in voluntary (top-down) attention. The ventral system is right-lateralised and composed of the right temporo-parietal junction (TPJ) and the right ventral frontal cortex (VFC). This system is involved in bottom-up capture attention.

2.2.3. ERP DATA FROM VISUAL PERCEPTION AND EARLY ATTENTION

As mentioned in the previous section, regions activated during attention suggest separable endogenous and exogenous attentional systems implying different stages of processing that electroencephalography can clarify. Thus, we would expect to observe distinct stages of processing preceding conscious attention. Nevertheless, EEG studies have shown that both mechanisms interact (e.g. Desimone & Duncan, 1995; Hopfinger & West, 2006) as endogenous mechanisms modulate activity in neurons coding the spatial location (Bisley & Goldberg, 2003) suggesting a unitary focus of attention with top-down influences on

exogenous orientation (Folk, Remington & Johnston, 1992). For example, Hopfinger & Mangun (1998) showed that exogenous attention enhances the visual early P1 component and this same stage of processing can also be enhanced by endogenous attention when converged at the same location. These results suggest that visual ERPs are strongly modulated by attention-related activity. Consequently, top-down neural mechanisms such as directed attention may increase or decrease brain activity related to visual processing affecting the amplitudes of the visual P1 component, whereas, the N1 amplitudes are enhanced only by endogenous attention (Hopfinger & West, 2006). These findings are of great relevance for the upcoming studies of the present thesis and suggest a functional dissociation of P1 and N1 components. Indeed, Luck *et al.* (1990) showed that the P1 indexed a facilitation of sensory information for stimuli presented to a location where attention was focused, whereas, the N1 represented the orienting of attention to task-relevant stimuli.

Following the anterior N1 wave, two visual/attentional components are observed, the P2 and the N2. The P2 is a positive-going centro-parietal potential, peaking at around 200ms after stimulus onset, and represents some aspects of higher-order perceptual processes modulated by attention (Luck & Hillyard, 1994). This component is larger for targets and is enhanced for infrequent targets (Luck, 2004). Finally, the anterior N2 sensitive to the anterior cingulate, has been associated to conflicting responses. For instance, within a social context, the N2 is enhanced for negative or deviant feedback (e.g. Carretié, Hinojosa, Martin-Loeches, Mercado & Tapia 2004; Daffner, Scinto, Calvo, Faust, Mesulam, West & Holcomb, 2000).

2.2.4. EMOTIONAL FACE PERCEPTION

Face perception can be considered as the most developed visual perceptual skill in humans suggesting a special status for face processing (Ishai, 2008). Faces provide additional social information based on the perception of changeable aspects of the face such as the expression and eye gaze (Haxby, Hoffman & Gobbini, 2000). The face perception system encompasses invariant aspects of a face that allow to recognise the identity, and changeable aspects which facilitate social communication (gaze, expression and lip movement). Thus, the changeable aspects of faces underlie the perception of information that facilitates social communication. These two processes proceed in a relatively independent manner and constitute the core system. Thus, the core system is responsible for the visual analysis of faces whereas another system, the extended system, processes the meaning of information in a face such as the emotions (Haxby et al., 2000; Haxby, Hoffman & Gobbini, 2002). Bruce & Young (1986), proposed two parallel routes underlying face expressions and identity processing. These routes work independently allowing the processing of expression without the processing of identity (Breen, Caine & Colheart, 2000). Neuropsychological data supports this model by showing in some prosopagnosic patients an ability to recognise expressions (Damasio, Damasio & Van Hoesen, 1982), whereas other patients show intact identity recognition but impaired processing of facial expressions. For example, damage to the insula impairs recognition of disgust (Calder, Keane, Manes, Antoun & Young, 2000).

2.2.4.1. BRAIN STRUCTURES INVOLVED IN FACE PERCEPTION

The extraction of face information relies on the activation and interaction of several brain structures. The changing aspects in face perception generate activity in the superior temporal sulcus (STS), whereas the perception of identity activates the lateral fusiform gyrus whose

activation is usually bilateral and consistently on the right (Ishai, 2008; Hoffman & Haxby, 2000; Haxby et al., 2000) (see Fig. 14).

For the purpose of the studies completed in this thesis, I will focus on the brain regions activated during facial expressions. The expression on another's face provides information about the emotional state of that person and can trigger this emotion in oneself (Haxby et al., 2002). Hemodynamic responses show activation of the inferior occipital gyrus, fusiform gyrus, STS and inferior frontal gyrus when seeing facial expressions compared to neutral ones. Moreover, the right STS is more activated when perceiving averted gaze faces compared to direct gaze faces, suggesting distinct neural systems for gaze direction and expressions (Engell & Haxby, 2007). A significant enhanced activity in the fusiform extrastriate areas is associated with the four basic emotions (fear, disgust, happiness and sadness), and these responses are increased for fear and disgust compared to happiness and sadness. The perception of fear also evokes a response in the amygdala as well as in regions involved in social and cognitive responses, such as the STS, cingulate and parietal regions (Vuilleumier & Pourtois, 2007). The perception of disgust in the face of another activates the anterior insula but not the amygdala, and strong disgust also activates regions associated with the limbic cortico-striatal-thalamic circuit (Phillips, Young, Senior, Brammer, Andrews, Calder, Bullmore, Perret, Rowland, Williams, Gray & David, 1997). Another neural system involved in the perception of happy emotions is the orbitofrontal cortex associated with reward and social reinforcement (Haxby et al., 2002).

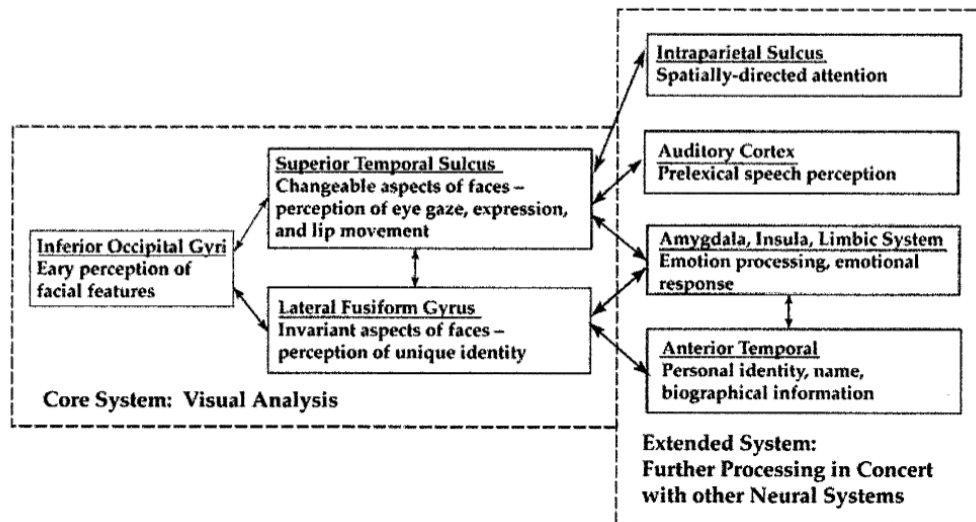


Figure 14. Model of the distributed human neural system for face perception (Haxby et al 2000). Interaction of two systems: the core system enabling visual analysis of faces with activity in superior temporal sulcus for the encoding of changeable aspects and activity in lateral fusiform gyrus for the encoding of identity; the extended system allowing the extraction of complementary features.

2.2.4.2. ERP DATA FROM FACE PERCEPTION

From an electroencephalographic point of view, a wealth of ERP studies of face perception has consistently shown an evoked potential at around 170 ms at posterior sites called the N170. This component is observed after the presentation of human upright faces as well as for inverted faces but not for non-face stimuli such as cars, butterflies or animal faces. Inverted faces show a delay in the N170 response relative to upright faces. This response to faces is larger over right hemisphere leads. The fact that the N170 is present for both, upright and inverted faces suggests that this response is not associated with face recognition, as it is not modulated by familiarity neither by emotional expressions, but only by the structural encoding of visual stimuli that enable to categorise a stimulus as a face (Bentin, Allison, Puce, Perez & McCarthy, 1996). Additionally, when presenting isolated face components, the N170 is also enhanced corroborating the interpretation of this ERP as an early detection of structural features characterising human faces. Moreover, the N170 response is larger for isolated eyes

relative to the whole face indicating that the neural mechanisms generating N170 responses are specific to eyes.

When presenting famous and non-famous faces, the N170 is unaffected. Face recognition occurs later, at around 250 ms (N250) over lateral occipito-temporal sites and is only observed for known faces compared to familiar ones (Gosling & Eimer, 2011). Thus, the N170 precedes face recognition and the N250 underlies neural generators in the face specific regions of the fusiform gyrus (Schweinberger, Pickering, Jentzsch, Burton & Kaufmann, 2002) suggesting an activation of stored long-term representations of famous faces. Additionally, famous faces elicit a sustained positivity around 600 ms. This longer latency positivity for famous faces is not linked to familiarity but to explicit face identification (Gosling & Eimer, 2011).

Concerning emotional expressions, ERP results are contradictory. Some authors have shown an enhanced frontocentral P200 for fearful expressions and an enhanced P3 for disgusted face expressions, but no N170 modulations (Ashley, Vuilleumier & Swick, 2004). These findings suggest that structural encoding and expression processing are independent processes (Eimer & Holmes, 2003). In contrast, other research (Batty & Taylor, 2003) have explored the timing of processing of basic emotions in implicit emotional tasks and observed significant effects starting at around 100 ms (P1) as well as differences in amplitude and latency at around 140 ms, indicating that the N170 is sensitive to emotions suggesting an early automatic encoding of emotional faces. The authors interpret these results as a facilitated identification due to the activation of a subcortical pathway when presented with relevant emotions. Moreover, they found later N170 latencies for negative emotions compared to neutral and positive ones which are explained by additional information sent from the subcortical pathway to ventral regions (Batty & Taylor, 2003; Garvert, Friston, Dolan & Garrido, 2014). It seems, though, that the experimental task as well as the instructions influence the processing of emotional faces. For example, Ratner & Amodio (2013) showed larger N170 amplitudes to ingroup faces compared

to outgroup faces, suggesting top-down effects on early perception when subjects are required to focus attention on the social significance of the stimuli compared to passive viewing. This interpretation is corroborated by Holmes *et al.* (Holmes, Vuilleumier & Eimer (2003) as they found an enhanced N170 for attended faces whereas emotional faces outside the attentional focus did not trigger any emotional expression effects at these early stages of processing. We can conclude that affective valence and arousal work independently (Olofsson, Nordin, Sequeira & Polich, 2008).

2.3. METACOGNITION AND UNCERTAINTY

Metacognition refers to the processes by which we monitor and control our cognitive processes (Frith, 2012). It represents the top of the hierarchy of control over cognitive processes. In our everyday life, we are constantly pushed to make decisions involving two or more options. It seems thus important to be able to quickly evaluate the adequacy of a response and monitor our behaviour accordingly. Evaluation and monitoring are two aspects underlying the concept of metacognition (Proust, 2014), defined as cognition about cognition (Shea, Boldt, Bang, Yeung, Heyes & Frith, 2014), which ranges on a continuum from total uncertainty to complete certainty. At these extremes lies pathological behaviour. Excessive doubt is related to mental disorders such as obsessive-compulsive disorder (OCD), while overconfidence, might be the manifestation of psychosis (Ron, Oren & Dar, 2016). In healthy individuals, such extremes are rarely reached but these reflective processes are nevertheless subject to inter-individual differences (Song, Kanai, Fleming, Weil, Schwarzkopf & Rees, 2011; Rouault, McWilliams, Allen & Fleming, 2018) and are sensitive to the degree of ambiguity of the stimulus sensory information (Selimbeyoglu et al., 2012; Yeung & Summerfield, 2012).

Recently, related metacognitive processes have been explored in signal detection and reaction time tasks (Fleming, Dolan & Frith, 2012) and focalised on error detection resulting in increased reaction times and behavioural measures such as judgment revisions. However, error detection may occur without explicit awareness. Thus, two forms of metacognition exist: an implicit form characterised by rapidity and automatism without awareness and an explicit form characterised by self-monitoring and awareness (Frith, 2012). The latter corresponds to reportable knowledge about our behaviour in decision making and represents the aspect of metacognition we are interested here, as it creates the experience of agency (Moretto, Walsh & Haggard, 2011), enhances social interactions by communicating our thoughts to others and

enables the engagement in mentalising, a crucial aspect of theory of mind (Wellman, Cross & Watson, 2001). For example, deficits in metacognitive ability have been observed in schizophrenia. These patients have difficulties in detecting whether they have made an error and present poor neurocognitive function resulting in a lack of social cognitive ability (Lysaker, Leonhardt, Pijnenborg, van Donkersgoed, de Jong & Dimaggio, 2014), as well as overconfidence and delusional symptoms. By opposition, patients suffering from obsessive compulsive disorder manifest acute doubt as a result of deficient conviction and feeling of knowing (Ron et al., 2016; Szechtman & Woody, 2004). Thus, judgements of uncertainty in humans involve metacognition (Fleming et al., 2012). In healthy adults, perceptual metacognitive efficiency declines with age which supports the link between metacognition and executive function (Palmer, David & Fleming, 2014).

2.3.1. BRAIN STRUCTURES INVOLVED IN METACOGNITION

Aspects of metacognition such as monitoring and control of cognitive processes are closely linked to working memory and executive control (Shimamura, 2000). These processes take place in prefrontal cortex. Indeed, activation in prefrontal medial cortex is associated with subsequent conforming behavioural adjustments (Shestakova, Rieskamp, Tugin, Ossadtchi, Krutitskaya and Klucharev, 2012). Neuropsychological data corroborates these findings as prefrontal lesions disrupt metacognitive judgements about perception (Shimamura, 2000; Del Cul, Dehaene, Reyes, Bravo & Slachevsky, 2009). However, recent research has shown that retrospective and prospective judgments are associated with distinct neural substrates (Fleming & Dolan, 2012). Retrospective monitoring refers to the ability to evaluate the adequacy of a response and is associated with activity in anterior and dorsolateral prefrontal cortex, whereas prospective judgements, that is, the ability to evaluate the capacity to perform

a future cognitive task, is linked to activity in medial prefrontal cortex (Proust, 2013; Fleming & Dolan, 2012). Methods for investigating the neural components of retrospective and prospective metacognition differ (Fleming et al., 2012; Fleming & Dolan, 2012). The former is measured with subjective confidence ratings about the decision whereas the latter is measured with subjective judgements about the ability to learn (see Arbuckle & Cuddy, 1969) and feelings of knowing (see Hart, 1965), occurring after task completion. Prospective metacognition involves memory processes and future imagery, thus, this aspect of metacognition also implies increased connectivity with medial temporal lobe (Schnyers, Nicholls & Verfaellie, 2005).

The contribution of prefrontal cortex to metacognition is associated with task uncertainty as a consequence of self-generated information processes and attention to internal representations (Yoshida & Ishii, 2006). Accordingly, the role of uncertainty to optimise decision making is crucial to metacognitive experiences (Fiser, Berkes, Orbán & Lengyel, 2010).

2.3.2. ERP DATA FROM METACOGNITION

Electrophysiologically, most studies have focalised exclusively on the error-related negativity (ERN), a negative ongoing wave appearing after the subjects' response and peaking at around 100 ms (for a review see: Larson, Clayson & Clawson, 2014). This ERP component originates in the anterior cingulate cortex (e.g. Holroyd & Coles, 2002). The ERN appears in speeded reaction time tasks in which errors are mostly caused by impulsive responding because of the limited response time (Selimbeyoglu et al., 2012). Thus, this ERP is associated with conflict detection but not with regulative control processes such as the allocation of attentional resources allowing dynamic behavioural adjustments. For that, other components, locked to the stimulus and associated with the processing of different stages of attention, such as the P2 and the P3 (Herman & Knight, 2001) need to be examined. As mentioned in the previous

section, evidence from neuropsychology shows that patients with damage to the anterior medial prefrontal cortex have impaired self-reflection, suggesting that this process relies strongly on anterior areas (Shimamura, 2000; Fleming et al., 2012). These studies showed that high executive control in terms of attentional resources lead to increased self-reflective processes.

Few studies have explored the temporal dynamics of metacognition indexed by an additional allocation of attentional resources internally oriented, that is, controlled attention leading to increased self-reflective processes. A recent study (Desender et al., 2016) investigated activity from metacognitive processes and showed that recategorising an ambiguous stimulus followed by a disputing social feedback required additional attention that is necessary for improved control over a response. The authors found an increased P3 amplitude and proposed that this component in situations of ambiguity and social conflict could be the neural correlate of metacognitive awareness as explicit awareness goes beyond one's ability to discriminate between one's correct and incorrect responses. Indeed, the P3 component has been shown to be increased under high demanding tasks and decreased under less demanding tasks (Kok, 2001; Olofsson & Polich, 2007). Studies investigating the relationship between the P3 and the participants' level of uncertainty/ certainty induced by task difficulty found that P3 builds up as sensory evidence increases (Kelly & O'Connell, 2013; Murphy et al., 2015; Twomey et al., 2015). Consequently, we can conclude that increased perceptual difficulty necessitates greater attentional engagement leading to an increased P3 component. In contrast, less demanding tasks would induce immediately a higher feeling of certainty preventing P3 amplitude to increase (ZanESCO, Tipura, Clément & Pegna, 2019).

2.4. SOCIAL INFLUENCE AND SOCIAL CONFLICT

The attempt to understand and explain how thoughts and behaviours of individuals are influenced by the presence of others started with the study of social influence about 70 years ago. Social life is characterised by conflict and controversy in which individuals try to change the thoughts and behaviours of others. The normative social aspects have regulated the behaviour in human interactions and yielded social pressure creating conformity at a public level, yet not always at a private level. Thus, in the recent years, researchers have tried to explore social influence processes that are indirect and nonconscious (for a review see: [Cialdini & Goldstein, 2004](#)). This work has been done in laboratory using neuroscientific methods, such as fMRI and electroencephalography.

2.4.1. BRAIN STRUCTURES INVOLVED IN SOCIAL CONFLICT

Over the course of the last decade, a large number of studies in social neurosciences have examined the neurocognitive correlates of social influence (for reviews see: [Izuma, 2013](#)). These studies have used functional magnetic resonance imaging (fMRI) and have focused on the brain networks implicated in social conformity- the act of changing one's behaviour to match the responses of others ([Cialdini and Goldstein, 2004](#)) - as well as in the subsequent changes in behaviour. Disagreement with group opinion is associated with activity in posterior medial frontal cortex (pmFC), specifically, the rostral cingulate and the anterior insula as well as deactivation of ventral striatum ([Klucharev, Hytönen, Rijpkema, Smidts and Fernández, 2009](#); [Berns, Capra, Moore and Noussair, 2009](#)). Individuals with a stronger tendency towards conformity show higher activation of pmFC and insula ([Berns et al., 2009](#)). Agreement with group opinion induces activity in ventral frontostriatal circuitry implicated in the anticipation of reward ([Wu & Zhi, 2016](#); [Galvan, Hare, Davidson, Spicer, Glover and Casey, 2005](#)), particularly the nucleus accumbens ([Knutson and Cooper, 2005](#)). This activity in the striatum

is selectively enhanced when participants conform to the ingroup as compared to the outgroup (Stallen, Smidts and Stanfey, 2013).

It is thought that pMFC activation reflects a prediction-error signal implicated in reinforcement learning (Klucharev et al., 2009; Shestakova et al., 2012; Kim, Liss, Rao, Singer and Compton, 2012; Campbell-Meiklejohn, Bach, Roepstorff, Dolan and Frith, 2010), which subjects try to decrease by adjusting their subsequent behaviour (Klucharev et al., 2009; Mars, Coles, Grol, Holroyd, Nieuwenhuis, Hulstijn and Toni, 2005; Holroyd and Coles, 2002; Ridderinkhof, Ullsperger, Crone and Nieuwenhuis, 2004).

An important point should be emphasised which is that, these studies have focused on the regulatory processes required when individuals are presented with incongruent social feedback. Such adaptive cognitive control suggests the implication of higher cortical areas associated with executive functions. However, to investigate whether a group opinion modulates not only self-reported preference but also its neural representation (Izuma, 2013), one needs to distinguish between private acceptance (i.e. genuine change in one's attitude to match the group) and public compliance (i.e. expressive form of conformity) (Cialdini and Goldstein, 2004). Changes in activation in the striatum and ventromedial prefrontal cortex (VMPFC) have been associated with changes in self-preference, reflecting private acceptance (Zaki, Schirmer and Mitchell, 2011). These regions track subjects' preferences for various stimuli (Klucharev et al., 2009; Campbell-Meiklejohn et al., 2010; Zaki et al., 2011; Izuma, Matsumoto, Murayama, Samejima, Sadato and Matsumoto, 2010). They seem to encode the subjective value associated with the processing of reward, thus constituting a valuation system (Bartra, McGuire and Kable, 2013).

One way by which neurosciences research may contribute to elucidate whether conformity occurs at an explicit level or whether it influences individuals' actual perception is by

investigating the effect of group opinion on the presentation of visual stimuli. Few studies have examined the impact of conformity at low-level perceptual and attentional processes as opposed to a decision taken at an executive level (Trautmann-Lengsfeld and Herrmann, 2013; Berns, Chappelow, Zink, Pagnoni, Martin-Skurski and Richards, 2005; Stapel and Koomen, 1997). Asch (1951) already raised the possibility that social pressure could alter perception (Asch, 1951). Berns *et al.* (2005), using fMRI, provided the first evidence for alterations in perceptual processes (i.e. in occipito-parietal networks) when subjects were confronted with incorrect peer feedback regarding the degree of rotation of an abstract figure. However, the limited temporal resolution of hemodynamic measures does not allow to determine if this posterior activation is associated with early or late processes. Yet the temporal characteristics would facilitate the understanding of this activity by indicating whether this activity arises rapidly, or long after higher cortical areas.

2.4.2. ERP DATA FROM SOCIAL CONFLICT

In line with this idea of conflict monitoring and error processing, recent electroencephalography (EEG) studies (Shestakova *et al.*, 2012; Chen, Wu, Tong, Guan and Zhou, 2012) showed that the activity in pMFC, sensitive to prediction error, generates a negative deflection, called feedback-related negativity (FRN) or medial frontal negativity (MFN), which peaks between 200 ms and 400 ms at frontocentral sites after the presentation of the social cue (Shestakova *et al.*, 2012; Chen *et al.*, 2012; Long, Jiang and Zhou, 2012). The FRN appears after negative feedback and is similar to the response-locked error-related negativity (ERN) which typically appears in speeded reaction time tasks following response errors (Walsh and Anderson, 2012). Dipole source models indicate that the topography of the

ERN and FRN components is consistent with activity in the anterior cingulate (Dehaene, Posner and Tucker, 1994; Gruendler, Ullsperger and Huster, 2011).

Substantial research has addressed how face processing can be biased by social factors. Results show that P1 and the face - sensitive N170 ERP components are maximum when the combination of co-emitted social cues clearly represent a threat for the participant (i.e. anger associated with direct gaze) suggesting a sensory system specifically optimised for biologically relevant stimuli (El Zein, Gamond, Conty and Grèzes, 2015). Similarly, group membership cues may change the way we see a face (Ratner & Amodio, 2013). Studies assessing the influence of social group membership (i.e. ingroup/outgroup) on early stages of face processing show a larger N170 to ingroup faces than to outgroup faces (Ratner & Amodio, 2013; Ibáñez, Gleichgerrcht, Hurtado, González, Haye and Manes, 2010). The differential and early effects of social cues and group membership on early ERP components suggest that relevant social information is analysed rapidly and effectively by the brain.

However, only two ERP studies have investigated the influence of social context on early perceptual processes for non-face stimuli (Trautmann-Lengsfeld & Herrmann, 2013; Zanesco, Tipura, Posadas, Clément & Pegna, 2018). The findings showed that social influence can have a top-down effect on these early perceptual processes. In Trautmann-Lengsfeld & Herrmann's (2013) study, participants showed a larger P1 amplitude when they conformed to the correct group opinion compared to situations where they conformed to the incorrect one. The authors did not find any significant differences in P1 amplitude when participants adapted to the incorrect opinion compared to conditions where they did not. The difference became evident at 150 ms, with the analysis of the N1 component, which reflects the orientation of attention towards task relevant stimuli (Luck et al., 1990). In our study (Zanesco et al., 2018), ERPs were measured to ambiguous and distinct stimuli before and after social feedback. Results showed an increase in P1 amplitude for ambiguous stimuli following a disputed feedback with

no effect on distinct stimuli, corroborating the fact that social influence is most effective under situations of uncertainty induced by task difficulty (Cialdini & Goldstein, 2004).

2.5. SOCIAL ANXIETY DISORDER

According to the categorical approach from the DSM-V (APA, 2013), social anxiety disorder is characterised by a constant and intense fear in social situation when the person is observed by others, a fear that others will notice their anxiety signs and an avoidance of social situations. These aspects persist more than six months and affect their daily functioning.

The DSM criteria represents social anxious responses to social situations but do not take into account the causes of the disorder. In order to understand the underlying mechanisms of social anxiety, several cognitive models have been proposed based on behavioural and neural responses during the performance of experimental tasks.

2.5.1. COGNITIVE MECHANISMS INVOLVED IN SOCIAL ANXIETY

Attentional bias towards threat is a key phenomenon observed in all experimental tasks and across all anxiety disorders (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg & van Ijzendoorn, 2007; MacLeod, Mathews & Tata, 1986; Mogg & Bradley, 1998; Williams, Mathews & MacLeod, 1996). An attentional bias towards threat refers to a strong selective and automatic attentional allocation to threatening social stimuli such as human face emotions. Different components of attentional bias can be observed in experimental tasks such as facilitated and faster detection of threatening social stimuli, difficulty to disengage attention from threatening social stimuli and a tendency to avoid the threatening stimuli by allocating attention towards an opposite location (for a review see: Cisler & Koster, 2010). Most ERP

studies in social anxious disorder (SAD) suggest that this early attentional bias is reflected by an enhanced P1 to socially threatening stimuli (e.g. Peschard, Philippot, Joassin & Rossignol, 2013; Rossignol, Philippot, Bissot, Rigoulot & Campanella., 2012; Rossignol, Campanella, Bissot, Philippot, 2013; Mueller, Hofmann, Santesso, Meuret, Bitran & Pizzagalli., 2009; Morel, George, Foucher, Chammat & Dubal, 2014). These studies have focalised on the response to emotional faces but haven't taken into account the anticipatory processing, which seems to play a role in SAD (Clark & Wells, 1995; Deiters, Stevens, Hermann & Gerlach, 2013; Sluis, Boschen, Neumann & Murphy, 2017).

The neurocognitive mechanisms underlying these attentional biases components include a rapid, automatic and unconscious fear pathway mediated by the amygdala (Ohman, 2005; LeDoux, 2000) which enhances selective attention towards threatening social stimuli. At a higher order strategic level, the attentional control theory (ACT; Eysenck, Derakshan, Santos & Calvo, 2007), postulates three executive components that seem to mediate the ability to disengage from threatening stimuli (Berggren & Derakshan, 2013). The first, inhibition, defined as the ability to suppress task-irrelevant information, whose impairment can be observed by an increased antisaccade latency in socially anxious individuals leading to a reduction in top-down control in inhibiting reflexive processes (Derakshan & Eysenck, 2009). Additionally, socially anxious individuals show an increased attentional capture by irrelevant stimuli (Poy, Eixarch & Avila, 2004) and an increased interference for task-irrelevant distractors (Pacheco-Unguetti, Acosta, Callejas & Lupiañez, 2010). The second executive aspect is shifting, this is, a reduced capacity to shift attention in a flexible manner between relevant task demands. In this sense, socially anxious individuals are slower in task requiring to switch (e.g. Wisconsin Card Sorting Task; Goodwin & Sher, 1992), thus showing a lower performance than non-anxious individuals. Finally, impaired updating is also observed in socially anxious subjects, which is the inability to update and monitor representation in

working memory. For example, in n-back tasks, socially anxious subjects make more errors than non-socially subjects (MacLeod & Donnellan, 1993).

Concerning threat avoidance in socially anxious individuals, only one cognitive model (Williams, Watts, McLeod & Mathews, 1998) includes this component in their predictions. The authors propose that a resource allocation mechanism (RAM) directs attention away from threat. Nevertheless, this may work for minor threats but not for severe threats, independently of a subject's level of anxiety.

While most of the findings agree with excessive attention to socially threatening information in socially anxious individuals when entering a social situation, Clark & Wells (1995) suggest that the attention is directed towards oneself creating behavioural and somatic symptoms, thus increasing self-awareness. Additionally, anticipatory processing prior to the social situation seems to play a greater role in socially anxious individuals than the social situation itself (e.g. Deiters et al., 2013; Nelson, Hodges, Hajcak & Shankman, 2015). Experimental tasks using speech anticipation have been used to demonstrate this aspect. Indeed, study 3 of this thesis focalises on this anticipation using electroencephalography and indicates a reduced sensory facilitation to threatening stimuli (Zanesco, under review).

2.5.2. UNCERTAINTY AND AMBIGUITY IN SOCIAL ANXIETY

Intolerance to uncertainty has been shown to be an important transdiagnostic variable in SAD (Oglesby, Raines, Short, Capron & Schmidt, 2016). Indeed, socially anxious individuals have a strong tendency to interpret ambiguous information as highly threatening compared to non-anxious subjects (Constans, Penn, Ihen & Hope, 1999).

Socially anxious subjects are not only characterised by attentional biases but also by interpretation biases as they perceive negatively the information from their environment

(Beard & Amir, 2008). For example, facial expressions of disgust are particularly threatening for individuals suffering from social anxiety (Rozin, Lowery & Ebert, 1994). Consequently, when socially anxious subjects are presented with ambiguous scenarios, they will fail to show a positive interpretation as observed in a non-socially anxious population (Constans et al., 1999), resulting in increased anxiety and subsequent avoidance (Clark & Wells, 1995). Therefore, anxious individuals are likely to make false positive judgements when facing ambiguity. This phenomenon has been shown with facial expressions, with ambiguous social vignettes as well as with words in tasks such as the emotional Stroop. However, no study has explored this effect in the socially anxious population with ambiguous visual non-face stimuli. Among healthy subjects, it has been shown that ambiguous or multistable visual stimuli such as the Necker cube give rise to different and mutually exclusive perceptual interpretations (for a review see: Klink, van Wezel & van Ee, 2012) with enhanced P2 and N2 amplitudes (Gole, Schäfer & Schienle, 2012). In the first study of this thesis, we observed a greater P1 and N1 amplitudes to ambiguous stimuli, suggesting enhanced sensory facilitation and selective attention to ambiguity compared to distinct stimuli. Moreover, the second study of this thesis provides evidence for a decreased P3 amplitude when facing distinct stimuli, suggesting that certainty manifested by the accumulation of sensory evidence could be indexed by the P3 component. However, no study has explored the perception of ambiguous non-face visual stimuli among the socially anxious population. This question was addressed in the last study of this thesis (ZanESCO, under review) and corroborated the findings that ambiguity required higher selective attention compared to non-ambiguous stimuli, although the pattern was significantly diminished in socially anxious individuals compared to non-socially anxious individuals. An explanation based on the role of anticipation and excessive self-focusing manifested by a reduction in attention to external stimuli in socially anxious individuals has been put forward.

3. EXPERIMENTAL PART

3.1. STUDY 1: SEEING IS BELIEVING: EARLY PERCEPTUAL BRAIN PROCESSES ARE MODIFIED BY SOCIAL FEEDBACK¹

Keywords: ERP, visual perception, P1, social feedback, uncertainty.

Abstract

Over 6 decades ago, experimental evidence from social psychology revealed that individuals could alter their responses in perceptual judgement tasks if they differed from the prevailing view emitted by a group of peers. Responses were thus modulated to agree with the opinion of the social group. An open question remains is whether such changes actually reflect modified perception, or whether they are simply the result of a feigned agreement, indicating submissive acceptance.

In this study, we addressed this topic by performing a perceptual task involving the assessment of ambiguous and distinct stimuli. Participants were asked to judge the colours of squares, before, and after receiving feedback for their response. In order to pinpoint the moment in time that social feedback affected neural processing, ERP components to ambiguous stimuli were compared before and after participants received supposed social feedback that agreed with, or disputed their response. The comparison revealed the presence of differences beginning already 100ms after stimulus presentation (on the P1 and N1 components) despite otherwise identical stimuli. The modulation of these early components, normally thought to be dependent on low-level visual features, demonstrate that social pressure tangibly modifies early perceptual brain processes.

(1) Reprint of: Zanesco, J., Tipura, E., Posada, A., Clément, F., & Pegna, A. J. (2019). Seeing is believing: Early perceptual brain processes are modified by social feedback. *Social neuroscience*, 14(5), 519-529.

3.1.1. INTRODUCTION

Almost 70 years ago, Solomon Asch ([Asch, 1951](#)), in a series of simple perceptual judgment experiments, observed that individuals would sometimes alter their responses to conform to the prevailing view emitted by their peers. Some 20 years later, Moscovici *et al.* ([Moscovici, Lage & Naffrechoux, 1969](#)), using a blue / green colour perception task, showed that even a minority expressing a consistent opinion, can lead participants to modify their responses in the long run. What is particularly significant in this latter study is the authors' conclusion that response modification appears best accounted for as a change in perception than a simple verbal agreement. However, whether social influence has an actual effect on perceptual processes per se, or whether such changes in representation affect later, higher-level processes associated with perception in a top-down manner, remains to be clarified with the methods of neuroscience.

One way by which neuroscientific research may inform us whether conformity acts on later, more elaborate cognitive levels, or whether it influences an individual's actual perception, is by investigating the effect of group opinion on neural processing of visual stimuli. Few studies have examined the impact of conformity on early levels of perceptual and attentional processes as opposed to later, post-perceptual (e.g., executive) effects ([Trautmann-Lengsfeld & Herrmann, 2013](#); [Berns et al., 2005](#); [Stapel and Koomen, 1997](#)), despite the suggestion already raised by Asch ([Asch, 1951](#)) that social pressure could alter perception. The first investigation in this area was provided by [Berns et al. \(2005\)](#) using fMRI, who found evidence of alterations in perceptual processing (i.e., in occipito-parietal networks) when subjects were confronted with incorrect peer feedback regarding the degree of rotation of an abstract figure. However, the limited temporal resolution of hemodynamic measures does not allow their finding to be identified as an early or late process. Determining its temporal characteristics would prove highly revealing as this would indicate whether this activity arises rapidly, during the visual

processing phase, or long after higher-order, top-down processing has begun (Henson and Rugg, 2003).

Electroencephalography (EEG) and event-related potentials (ERP) can extricate the temporal unfolding of this socially induced effect, and was consequently used by Trautmann-Lengsfeld & Herrmann (2013) to investigate whether social context affected early perceptual processes (see also: Herrmann & Knight, 2001) or not. In their study, participants were shown visual stimuli side by side and were asked to select one of the two on the basis of a perceptual criterion. Simultaneously, an indication was provided alongside the stimuli, informing the participants of the response given by the supposed social group. The findings revealed that the P1 (a positive deflection occurring over posterior electrodes at around 100ms in response to a visual stimulation) was smaller in amplitude when participants' response conformed with the group's incorrect response. This very interesting study therefore concluded that social influence acts on early levels of visual processing. However, the authors did not find any significant difference in P1 amplitude when participants adapted to the group's incorrect judgment compared to the condition where they refused to do so, thus mitigating the conclusions. Furthermore, the presentation of lateralised stimuli necessitated left vs. right-sided comparisons, which necessarily produces modulations of early ERP components sensitive to the direction of spatial attention (Luck et al., 1990). Additionally, the simultaneous presentation of competing stimuli and the group's decision does not allow, strictly speaking, the study of revised judgments by participants, which could be better investigated using sequential stimulus presentations with indications of social feedback presented in between.

The purpose of the present study was thus to address the question of whether social influence impacts on early perceptual processes in situations of uncertainty induced by ambiguous stimuli. For this, we recorded EEG while examining the effects of social feedback while participants performed a visual discrimination task. We manipulated stimulus ambiguity, as

previous studies have robustly demonstrated that social influence is most effective in situations of ambiguity and uncertainty (Cialdini and Goldstein, 2004). Inspired by a couple of studies that investigated the role of consensus in metacognition (Eskenazi, Montalan, Jacquot, Proust, Grèzes, and Conty, 2016; McCurdy, Maniscalco, Metcalfe, Liu, de Lange, and Lau, 2013), a novel experimental paradigm was created allowing us to measure event-related potentials (ERPs) in response to visual stimuli that were presented before and after social feedback, the latter being given by a face that either endorsed (i.e., displayed a happy face) or disputed (i.e., displayed a disgusted expression) the participant's judgment. Participants were asked to judge the colour of a square (the probe) that was either of a distinct blue or green colour (termed "distinct probe"), or was of a highly ambiguous bluish-green hue ("ambiguous probe"). They were also asked to indicate the level of confidence of their judgment. Participants then received social feedback and the probe was presented once again for re-evaluation and judgment.

We hypothesised that participants would adapt their response to the opinion of the purported group when the stimulus was ambiguous and the social group disputed the participant's response. We focused on the visual P1 and N1 components locked to the presentation of the probe stimuli (coloured squares), before and after social feedback. These components are considered to be the earliest electrical marker of visual processing, and are influenced both by the low-level features of the stimuli (Johannes, Münte, Heinze and Mangun, 1995), and by attentional processes (Luck et al., 1990). However, as low-level features were strictly controlled and no variations were operated on attention, any differences would only be attributable to an influence of social pressure. We predicted that if social influence acted directly on perceptual processes, changes should be observed on these early components, while changes on an explicit level would more likely be reflected on later components.

3.1.2. MATERIALS AND METHODS

3.1.2.1. PARTICIPANTS

Twenty-two students were recruited using posters placed at the University of Geneva (13 females, 9 males; mean age = 25.14, SD= 3.61). All the participants were right-handed (mean laterality coefficient = 71.96, SD = 20.97 (Oldfield, 1971)), had normal or a corrected-to-normal vision and had no self-reported psychiatric or neurological disorder. The participants all reported that they were heterosexual and were not colour blind. They were paid 50 Swiss francs for their participation.

3.1.2.2. STIMULI AND EXPERIMENTAL PROCEDURE

Participants were presented with stimuli that displayed either an unequivocal, distinct colour (blue or green), or an ambiguous one (greenish-blue). They were asked to respond by indicating the colour that they thought was presented. Subsequently, they were given alleged social feedback, which they were told was the response of the majority of a sample population of women and men, tested beforehand. They were told that a happy face would indicate that their response was consistent with the majority, while a face expressing disgust would indicate that their response was in disagreement with the majority of other participants. They were then shown the identical probe once again and were asked for a second judgment, either revising their initial response, or maintaining their decision.

The stimuli consisted of 32 coloured squares (probes) displaying different shades of blue and green, displayed on a white background. Eight distinct colours were clearly and unmistakably identifiable as green (hereafter distinct green), and 8 others as blue (hereafter distinct blue). The 16 remaining stimuli were made up of colours that were highly equivocal. These ambiguous probes were produced by changing the ratio of green, blue and red while maintaining overall luminance (minimum saturation: 28.17 cd/m²; maximum saturation: 30.73

cd/m²). As a result, for these 16 ambiguous, greenish-blue probes, 8 displayed a slightly greener hue (ambiguous green) and 8 a slightly bluer hue (ambiguous blue).

The faces used for social feedback in this experiment were 10 male and 10 female identities expressing happiness and disgust, taken from the Radboud Faces Database (Langner, Dotsch, Bijlstra, Wigboldus, Hawk, and van Knippenberg, 2010). All the stimuli measured 10 cm horizontally and 10 cm vertically and subtended a visual angle of 5.73° when seen from the participants' viewing distance of 100 cm.

Participants were given instructions regarding the task and gave their informed consent to participate in the study prior to electrode placement. The experiment began with a practice session. Once the task was fully understood, the experiment proper began.

The experiment was divided in three blocks of 160 trials, for a total of 480 trials. Each trial was composed of an initial evaluation of the probe, a social cue providing feedback, and a second (post-cue) presentation of the same probe for re-evaluation. Figure 1 illustrates the sequence of each trial in detail. These began with a fixation cross, presented for a random duration between 400 and 600ms. A coloured square was then presented for 800 ms and was followed again by a fixation cross (between 400 and 600 ms). The letters V (which stands for “vert”, or green in French) and B (blue) were then presented on the left and right of the fixation cross and participants were instructed to indicate the perceived colour of the stimulus as quickly as possible by means of a key press. If no response was given, the display disappeared after 3000ms. The response options were indicated by two stickers placed on the computer mouse, representing letters V and B that participants pressed with their right forefinger and middle finger. Correspondence between response finger and colour was counterbalanced across subjects. After the response, a fixation cross appeared for 400-600ms, this was followed by the self-confidence evaluation represented by a scale ranging from 1 (uncertain) to 5 (certain). The fixation cross then reappeared for 400-600ms, followed by the social feedback

cue for 1000 ms, represented as a face (male or female, 50% each), displaying an expression either of happiness or of disgust. The participants were told that when the face expressed a happy emotion, their response corresponded to that given by the majority of former participants, whereas an expression of disgust indicated that their response differed from the majority. In actual fact, the expression was assigned randomly for each trial. In order to maximise credibility, probes composed of distinct colours (easily identifiable by participants) were always followed by a social cue indicating endorsement (i.e., a happy face).

After feedback, a fixation cross re-appeared for 400-600ms, followed by the same probe again for 800ms. A second judgement was then required, followed by a self-confidence rating, in the same manner as the first (see Figure 15). A blank screen (2000ms) appeared at the end of this sequence, marking the end the trial. A total of 160 trials were presented in each of the three conditions (ambiguous endorsed, ambiguous disputed, distinct endorsed).

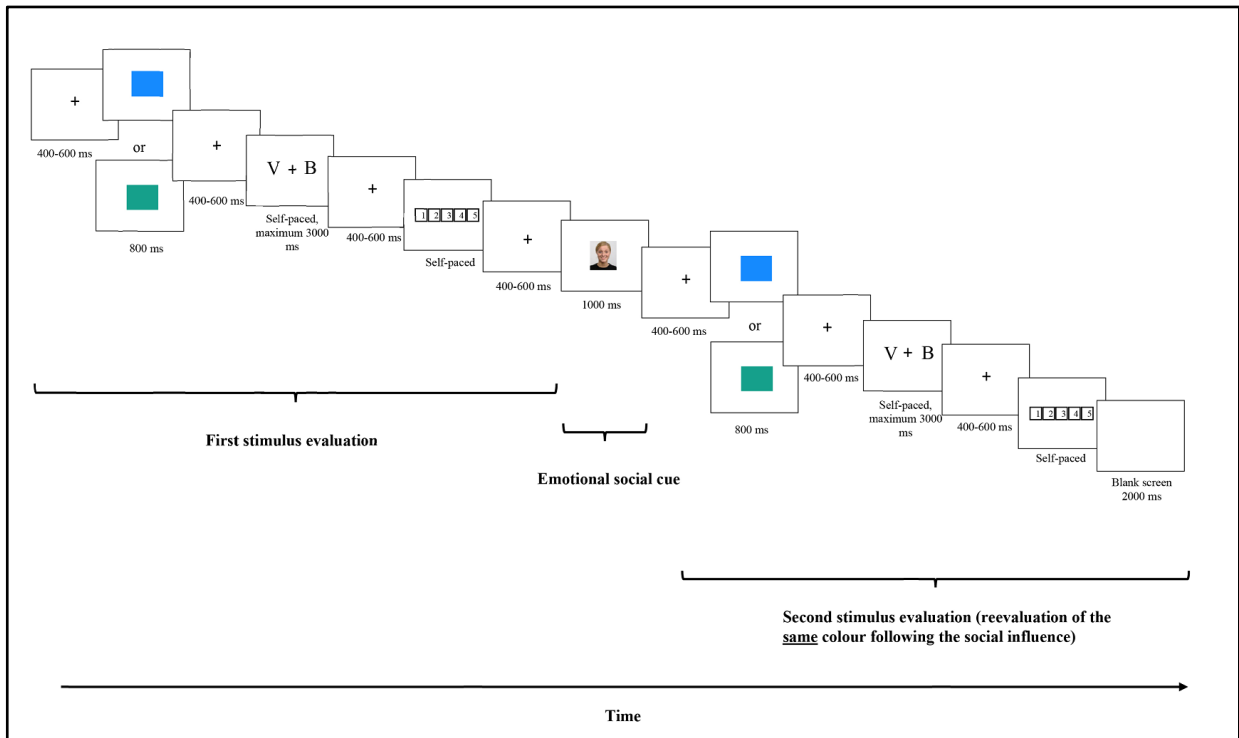


Figure 15. Example of an experimental trial. A distinct blue (top) and distinct green square (bottom) is illustrated, but only one probe was presented in each given trial. Here, the social cue is a happy face, thus indicating endorsement.

After the EEG experiment, participants were asked to evaluate the credibility of the social cue by indicating their level of belief on a 3-point scale (1: never believed in it; 2: believed in it sometimes; 3: always believed in it).

The study was accepted by the local ethics committee (University of Geneva) and was performed in agreement with the Declaration of Helsinki.

3.1.2.3. EEG ACQUISITION

EEG was recorded using a 128-channels Biosemi Active-Two system (Amsterdam, Netherlands) with AG/AgCl electrodes positioned according to the extended 10-20 system. We used four additional flat electrodes, which were placed on the outer canthi of the eyes and above and under the right eye, in order to capture the eye movements and blinks. Each active

electrode is represented with an impedance value, which we tried to keep below 20 k Ω for each participant. The EEG was continuously recorded with a sampling rate of 1024 Hz. Data was re-referenced off-line against the average reference.

3.1.2.4. EEG PROCESSING

Standard processing of EEG data was done offline using the software Brain Vision Analyzer V.2 (Brain Products, Gilching, Germany). The data was downsampled to 512 Hz. For the coloured square stimuli, epochs were computed from 200 ms prior to 800 ms after stimulus onset. Bad electrodes were removed and interpolated using a spherical spline (5.6% of the electrodes were interpolated in this way). A baseline correction was applied using the 200 ms prestimulus period. ERPs were obtained by averaging the trials for each condition, on the data that was filtered with a low-cutoff at 0.1 Hz and a high-cutoff at 30 Hz. Ocular correction was performed on the EEG using the implemented standard algorithm (Gratton, Coles & Donchin, 1983), in order to correct for eye movements and blinks. Trials with other artefacts were removed using a semi-automatic procedure following each stimulus presentation (amplitude allowed: -100 μ V to +100 μ V). Accordingly, the mean number of segments retained per condition was 130 ± 22 trials (out of 160) for the ambiguous endorsed condition, 130 ± 22 trials (out of 160) for the ambiguous disputed condition and 127 ± 24 trials (out of 160) for the distinct endorsed condition. A total of 19% of the trials were removed.

3.1.2.5. BEHAVIOURAL ANALYSIS

Trials in which participants revised their judgement after social feedback were counted as “revisions”. The mean number of revisions was calculated according to the ambiguity of the probe and the emotion of the social cue.

Statistical analyses of behavioural results were performed using repeated-measures ANOVAs. To examine the effect of the social cue on perceptual judgement, we carried out an ANOVA

for repeated-measures, using the number of revisions as the dependent variable and “condition” (ambiguous endorsed vs ambiguous disputed vs distinct endorsed) as the within-subject factors.

3.1.2.6. ELECTROPHYSIOLOGICAL RECORDINGS AND ANALYSIS

ERPs were computed for the distinct and ambiguous probes in the initial and post-cue presentations. Additional analyses were performed on the ERPs of the happy (endorsement) and disgusted faces (dispute) and are reported in the Supplemental material.

Early stages of processing were investigated by examining the P1 and N1 components in the different conditions, i.e., following the onset of the initial probe and following the onset of the post-cue probe. Peaks were determined using a semi-automatic peak detection method. The time windows of investigation were determined on the basis of the peaks observed in the grand averages across all conditions using a collapsed localizer (Luck, 2014). In this manner, P1 was measured over electrodes A14, A15, A16, A27, A28, A29 in the time window from 70ms to 180ms, and N1 was obtained from electrodes A9, A10, A11, B6, B7, and B8 in the time window from 160ms to 240ms (see Figure 16 for electrode positions).

The EEG data were analysed using separate repeated-measures ANOVAs that aimed to identify the effect of social feedback on the early P1 and N1 components of the probes. For this, 2 (presentation: initial vs. post-cue) X 2 (laterality: left vs. right) repeated-measures ANOVAs were performed on the mean latencies and amplitudes obtained over the electrodes within the regions of interest. In order to maintain credibility, our design deliberately excluded the condition in which distinct colours were “disputed” by the social group. Consequently, 3 conditions were presented: distinct stimuli that were endorsed by the alleged social group, ambiguous stimuli that were endorsed and ambiguous stimuli that were disputed. Separate ANOVAs were performed for each of the 3 conditions.

An effect of social cue was expected for the ambiguous disputed condition.

For clarity, only relevant comparisons are reported in the Results.

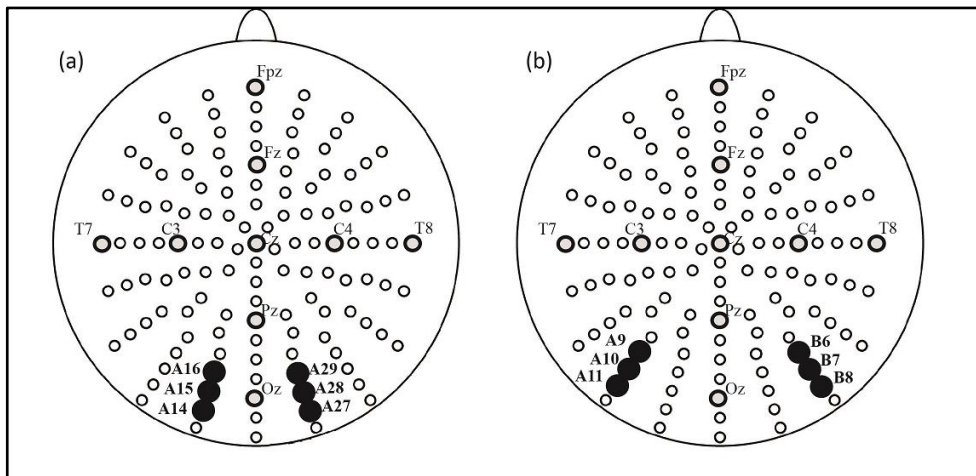


Figure 16. Electrodes retained for analysis. All channels are represented as open circles situated on a view of the scalp seen from above (nose on top, left side on the left). Electrodes used for analysis are indicated with full black circles. (a) the P1 component included electrodes A14, A15, A16 over the left and A27, A28, A29 over the right occipital regions (b) the N1 component included electrodes A9, A10, A11 on the left and B6, B7, B8 on the right.

3.1.3. RESULTS

Among the twenty-two subjects, one participant was excluded due to high number of artefacts. The following analyses (behavioural and EEG) were carried out on twenty-one subjects (nine men and twelve women).

3.1.3.1. BEHAVIOURAL RESULTS

An ANOVA was performed on the number of revisions, using condition (ambiguous endorsed, ambiguous disputed and distinct endorsed) as a within-subject factor, which revealed a significant main effect of condition $F(2, 40)=20.6, p < .00001$. Post-hoc comparisons carried out using Tukey tests revealed a significantly greater number of revisions for ambiguous disputed (26.3%) compared to ambiguous endorsed (4.7%) and distinct

endorsed probes (1.4%) ($p < 10^{-4}$ for ambiguous disputed vs ambiguous endorsed; $p < 10^{-5}$ for ambiguous disputed vs distinct endorsed). The number of revisions did not differ significantly between ambiguous endorsed and distinct endorsed conditions ($p > .05$) (Fig. 17).

Results of the self-report questionnaire revealed that 70% of the participants always believed in the social cue, while 19% stated that they believed in it occasionally and 11% reported that they did not. Importantly, participants who reported not to have believed the social cue, still produced changes after their initial response to match the social feedback. Subjects reporting disbelief in the social feedback revised on average of 6% of their judgments, compared to 9% for those who claimed an occasional belief and 12% for those who reported a full belief in the social feedback.

In summary, the behavioural results showed that the majority of participants considered the social feedback to be credible, and when challenged in their judgement regarding ambiguous probes, generated a significantly greater number of revisions than when these probes were endorsed.

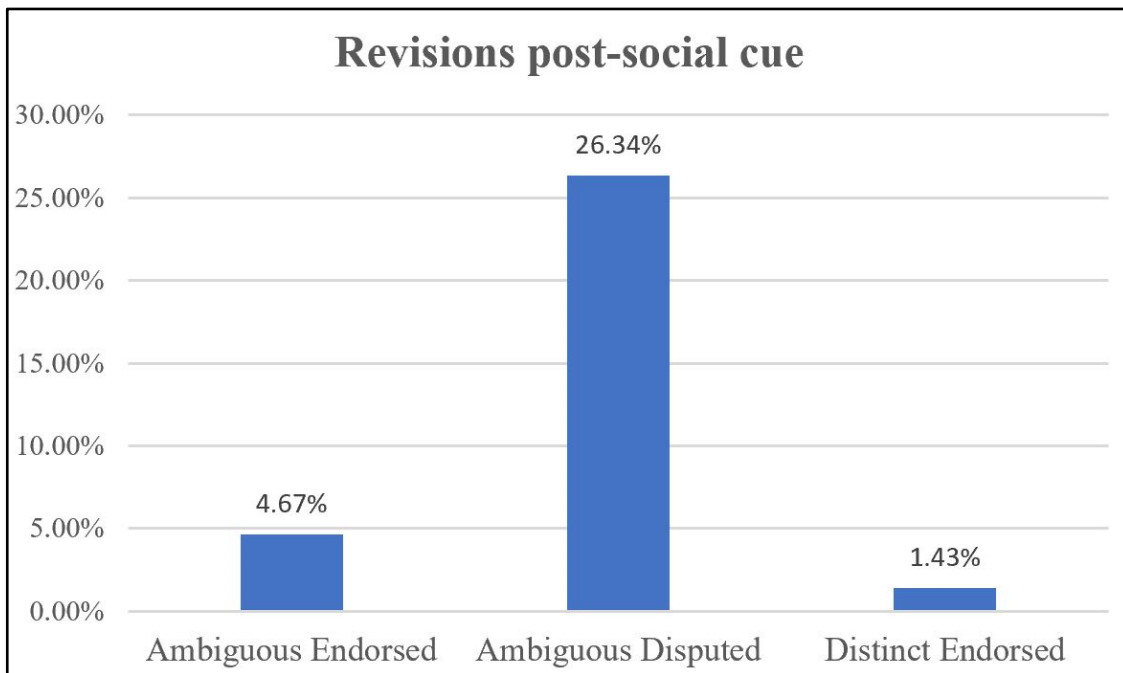


Figure 17. Behavioural results. Percentage of revisions (i.e., reversal of perceptual judgements) made by participants in the three experimental conditions (ambiguous stimuli that were subsequently endorsed, ambiguous stimuli that were subsequently disputed, and distinct stimuli that were subsequently endorsed).

3.1.3.2. ELECTROPHYSIOLOGICAL RESULTS

ERPs

P1 amplitude: A 2 (presentation: initial vs. post-cue) X 2 (laterality: left vs. right) ANOVA performed on the P1 amplitudes for the ambiguous disputed condition showed a main effect of presentation ($F(1, 20)=6.71, p=.018$) arising from the fact that the P1 was greater for the post-cue presentations of the ambiguous probes ($6.84 \pm 2.56\mu\text{V}$) compared to the initial presentation ($6.34 \pm 2.55\mu\text{V}$) (Fig. 20). No such effect was not found in the ANOVA for the distinct endorsed probes ($F(1, 20)= 0.01, p=.92$) (Fig. 18). The same ANOVA performed on the P1 amplitudes of the ambiguous endorsed probes showed a significant interaction between

presentation and laterality ($F(1, 20)=7.42$, $p=.0.013$), due to a difference in amplitude over the right hemisphere leads between initial and post-cue presentations (Fig.19).

P1 latency: The 2 (presentation) X 2 (laterality) ANOVAs performed for each of the 3 conditions showed significant main effects of presentation. In the 3 ANOVAs, P1 was found to peak significantly later than for post-cue stimuli compared to the initial presentation. Table 1 shows the effects on the P1 mean latencies for each of the three conditions and Table 2 summarises the results of the 3 ANOVAs.

SOCIAL CUE: AMBIGUITY AND CUE VALENCE EFFECTS					
	P1 Amplitude		P1 Latency		
	F(1, 20)	p-value	F(1, 20)	p-value	
Social endorsing cue: distinct vs ambiguous initial probes	0.607	0.445	6.023	0.023 *	
Social endorsing vs disputed cue: ambiguous initial probes	0.452	0.509	1.745	0.201	
	N170 Amplitude		N170 Latency		
	F(1, 20)	p-value	F(1, 20)	p-value	
Social endorsing cue: distinct vs ambiguous initial probes	24.355	< 10⁻⁴*	0.280	0.602	
Social endorsing vs disputed cue: ambiguous initial probes	0.049	0.827	9.202	0.007 *	

Table 1. F and p values for the statistical comparison of the P1 (top row) and N170 (bottom row) amplitudes (left column) and latencies (right column) in response to the colour stimuli before and after presentation of social feedback. The results are shown for each of the 3 experimental conditions (ambiguous endorsed, ambiguous disputed and distinct endorsed).

N1 amplitude: The 2 (presentation) X 2 (laterality) ANOVAs performed on the N1 amplitudes in each of the 3 conditions revealed a significant main effect of presentation (ambiguous endorsed: $F(1, 20)=20.36$, $p=.0002$; ambiguous disputed: $F(1, 20)=31.77$, $p=.00002$, and distinct endorsed: $F(1, 20)=48.14$, $p<.00001$) (Fig.18, 19, 20). The mean N1 amplitudes for probes presented after the social cue (see Table 2 for values) were significantly less negative than upon initial presentation (ambiguous = $-2.32 \mu V$, distinct = $-2.65 \mu V$).

PROBES: INITIAL vs POST-CUE				
	P1 Amplitude		P1 Latency	
	F(1, 20)	p-value	F(1, 20)	p-value
Initial and endorsed post-cue distinct probes presentation	0.011	0.919	9.031	0.007 *
Initial and endorsed post-cue ambiguous probes presentation	0.980	0.334	4.698	0.042 *
Initial and disputed post-cue ambiguous probes presentation	6.705	0.018 *	6.692	0.018 *
	N1 Amplitude		N1 Latency	
	F(1, 20)	p-value	F(1, 20)	p-value
Initial and endorsed post-cue distinct probes presentation	48.141	< 10⁻⁵ *	2.023	0.170
Initial and endorsed post-cue ambiguous probes presentation	20.357	< 10⁻³ *	0.017	0.896
Initial and disputed post-cue ambiguous probes presentation	31.766	< 10⁻⁴ *	0.137	0.715

Table 2. F and p values for the statistical comparison of the P1 (top row) and N1 (bottom row) amplitudes (left column) and latencies (right column) in response to the colour stimuli before and after presentation of social feedback. The results are shown for each of the 3 experimental conditions (ambiguous endorsed, ambiguous disputed and distinct endorsed).

N1 latency: No significant effects of latency were observed for the N1 latencies (Table 2).

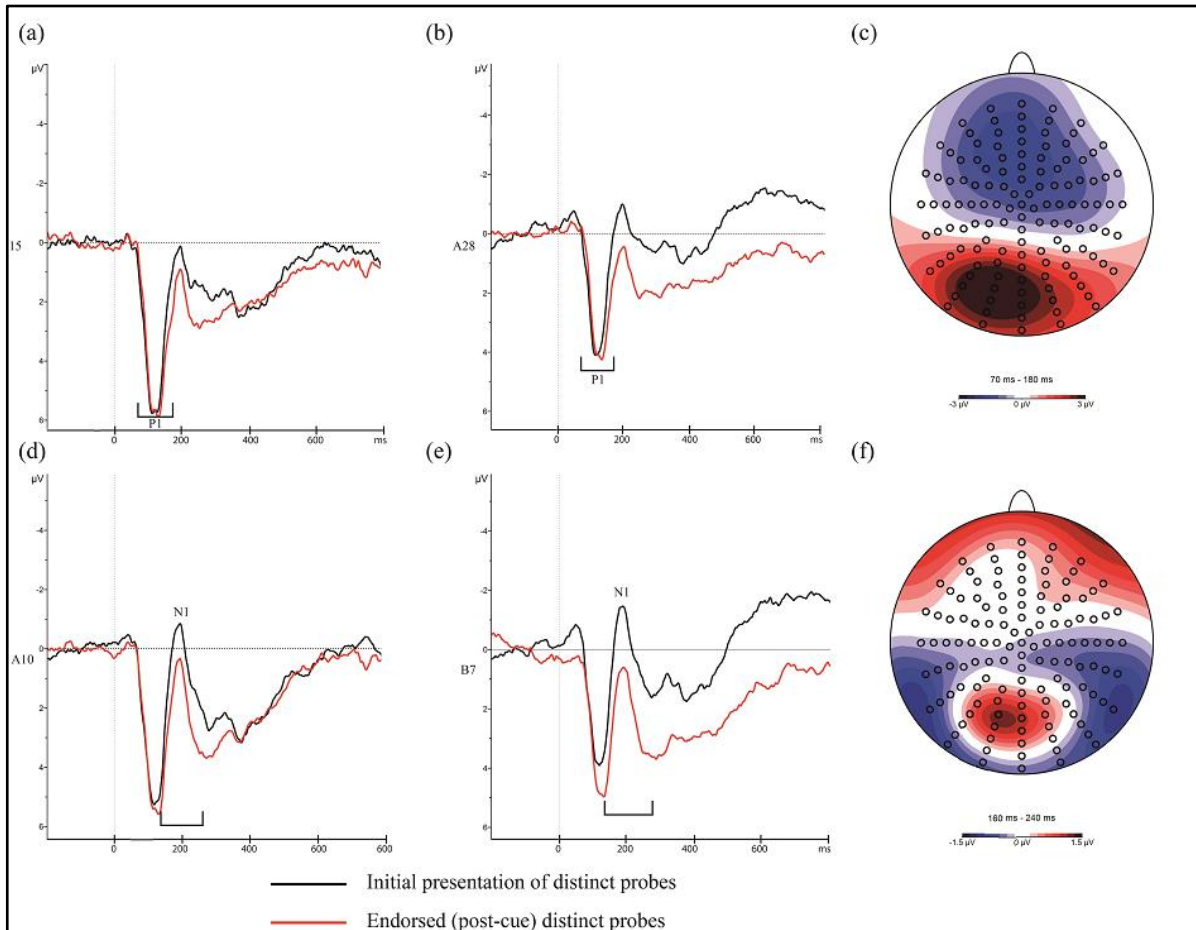


Figure 18. ERPs for distinct probes presented before (black trace) and after (red trace) social endorsement (i.e., presentation of a happy face). Traces are shown for two occipital electrodes (one left and one right) used to compute P1 (a, b) and N1 (d, e). (c) Topographical voltage map illustrating the P1 (time period between 70-180ms indicated with a black bracket in a and b). (f) Topographical voltage map illustrating N1 (time period between 160-240ms indicated with a black bracket in d and e).

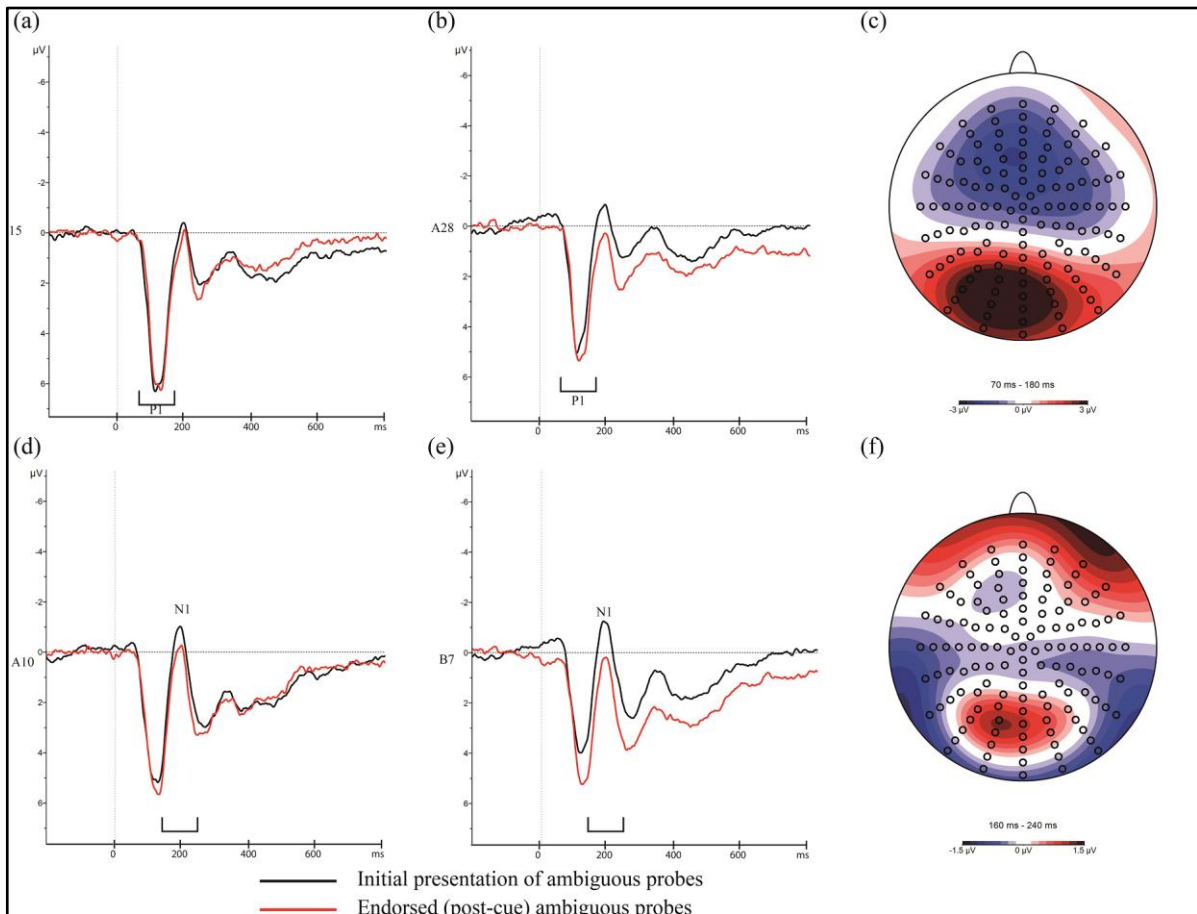


Figure 19. ERPs for ambiguous probes presented before (black trace) and after (red trace) social endorsement (i.e., presentation of a happy face). Traces are shown for two occipital electrodes (one left and one right) used to compute P1 (a, b) and N1 (d, e). (c) Topographical voltage map illustrating the P1 (time period between 70-180ms indicated with a black bracket in a and b). (f) Topographical voltage map illustrating N1 (time period between 160-240ms indicated with a black bracket in d and e).

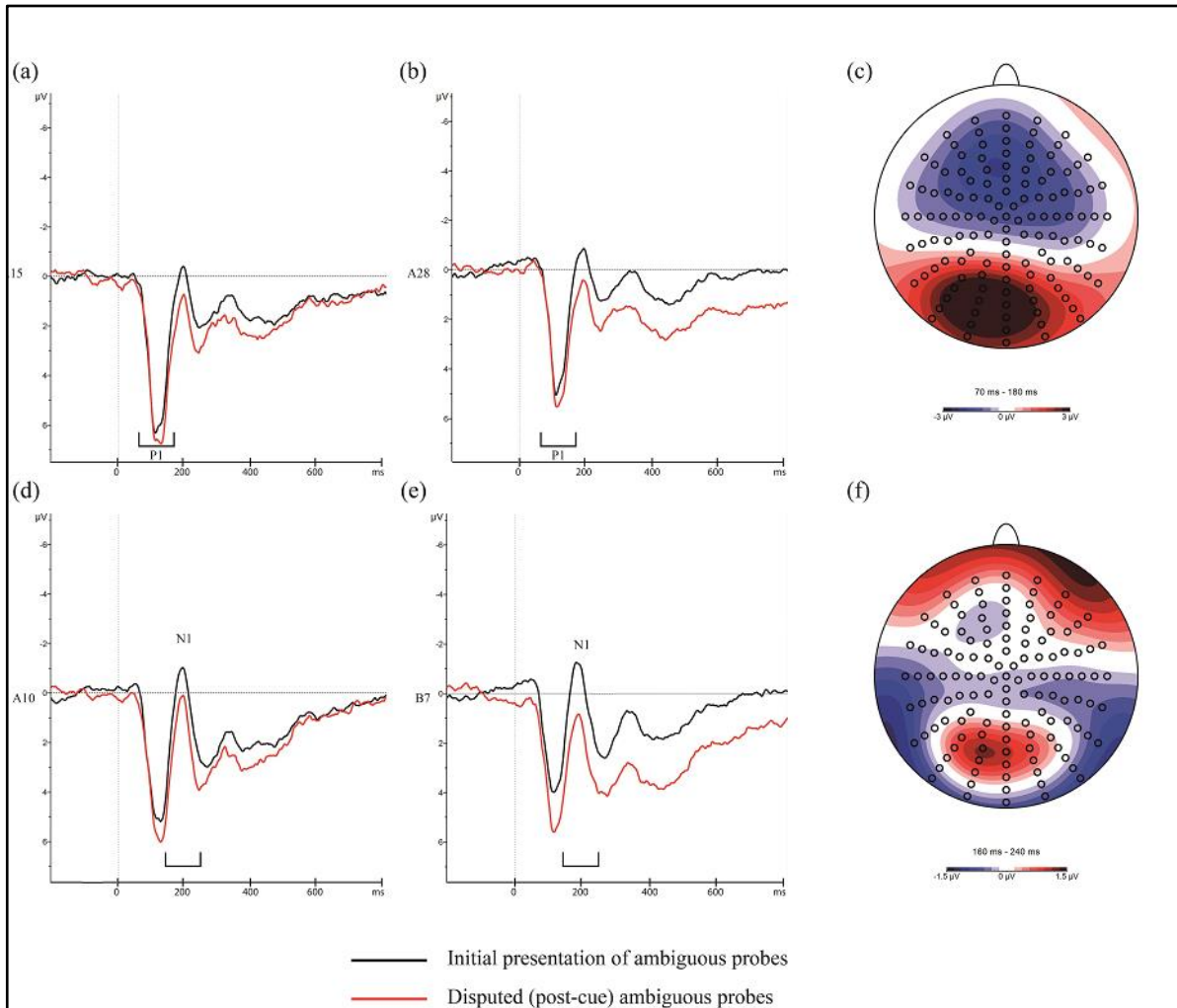


Figure 20. ERPs for ambiguous probes presented before (black trace) and after (red trace) social disagreement (i.e., presentation of a disgusted face). Traces are shown for two occipital electrodes (one left and one right) used to compute P1 (a, b) and N1 (d, e). (c) Topographical voltage map illustrating the P1 (time period between 70-180ms indicated with a black bracket in a and b). (f) Topographical voltage map illustrating N1 (time period between 160-240ms indicated with a black bracket in d and e).

3.1.4. DISCUSSION

The aim of the present study was to explore the effect of social feedback on perceptual processes, and in particular to determine the temporal period on which such feedback impacts.

This was produced by asking participants to categorise distinct or ambiguous colour stimuli before and after alleged social feedback that confirmed or disputed the participants' responses.

As expected, when faced with ambiguous stimuli, participants revised their judgments more often following social disagreement than following endorsement of their judgments (a negligible amount of revisions were made after endorsement of distinct hues). Confirming the validity of the feedback provided, when questioned after the procedure, the majority of the participants claimed to have believed the authenticity of the feedback.

ERPs measured in response to the ambiguous and distinct colour probes before and after social feedback revealed a number of differences arising very early on (within the first 120ms) as well as later in time (beyond 190ms), suggesting that social cues modulate brain activity during early stages of processing. Interestingly, the ERPs in response to the faces providing social feedback showed modulations that differed according to the ambiguity of the probes, further strengthening the idea that the cues were actively taken into account during the perceptual judgment task (see supplementary material).

Most importantly, an increase in P1 amplitude was found after the participants' judgements of ambiguous stimuli were disputed by the social group, while ambiguous probes that were endorsed only enhanced activity over the right electrodes in this period. Moreover, no effect was seen on distinct stimuli.

These findings suggest that social information modulates early perceptual processes. Indeed, the differences observed in the early electrophysiological response between the initial and post-cue presentations occurred even though the stimuli were identical. This indicates that

feedback cues are able to act directly on the early visual ERPs, impinging on early processes that arise in the visual extrastriate regions (Di Russo, Martinez, Sereno, Pitzalis & Hillyard, 2002). Since this effect cannot be driven by bottom-up by low-level features (as the stimuli are identical), it necessarily arises through top-down activation. One likely mechanism for this could be that top-down processes affects neural gain in the visual system by heightening its sensory capability. This mechanism in fact explains the enhancements observed in early ERP components that arise when spatial attention is directed towards specific locations. Indeed, larger P1 amplitudes have been observed for stimuli presented at attended locations, reflecting a facilitation of early sensory processing (Luck et al., 1990).

Consequently, one may contend that the early modulations in our study derive essentially from a similar heightened sensory processing which could be due to a differential engagement of attentional processes for the ambiguous, challenged stimulus.

Alternatively, this effect could be the consequence of a greater mobilisation of attention linked to the increased relevance of the stimulus. Indeed, P1 modulations have been observed in response to highly relevant stimuli such as photographs of spiders, or to anticipatory spider-containing material in arachnophobics (Michalowski, Melzig, Weike, Stockburger, Schupp & Hamm, 2009; Michalowski, Pané-Farré, Löw, & Hamm, 2015). Moreover, enhanced P1 responses have been found for threatening cues more generally (Bublitzky, Flaisch, Stockburger, Schmälzle, & Schupp, 2010; Bublitzky & Schupp, 2012), and heightened N1 responses have been noted under conditions of anticipation of socially relevant feedback (Schindler, Wegrzyn, Steppacher, & Kissler, 2014).

Notwithstanding the underlying mechanism, the fact remains that an early effect was observed, which was caused by manipulation of alleged social information. It is therefore question whether early attentional processes are sensitive, and can be influenced by, higher-order social processes. This question was addressed in a study by Wykowska and colleagues

(Wykowska, Wiese, Prosser & Müller, 2014). The authors showed that the P1 was enhanced for stimuli appearing at a validly cued location when participants believed that the cue was provided by a human being rather than a machine. In our paradigm, the increased P1 for ambiguous stimuli appearing after, compared to before the social cue therefore appear to reflect the effect of social information exerting a top-down influence on early visuospatial processes.

The current findings corroborate the only existing study to our knowledge, (Trautmann-Lengsfeld & Herrmann, 2013), to have investigated ERPs with a similar hypothesis in mind. However, two major differences exist between the latter investigation and the present study. First, our study included distinct colour probes, which served as a control condition in order to examine the impact of uncertainty under social pressure, whereas in the investigation by Trautmann-Lengsfeld & Herrmann, ambiguity was a constant. Even more importantly, our inclusion of sequential processing which contained both positive and negative feedback for ambiguous probes allowed for direct comparisons of the same stimulus before and after the social cue, thus consolidating the visibility of the cue's effect.

A difference also arose for ambiguous probes after social feedback at the N1 level. This overall amplitude enhancement for post-cue presentations of ambiguous probes was in fact also observed for distinct probes. This general enhancement of the post-cue N1 component for all stimuli could be seen either as effect of stimulus repetition, or as a global effect of social feedback that would be independent of its value (agreement or disagreement) and of the participant's perceptual certainty (apparently ambiguous or distinct stimuli). Previous reports have evidenced changes in N1 for repeated presentations of visual stimuli (Olofsson & Polich, 2007; Groh-Bordin, Busch, Herrmann, & Zimmer, 2007), however these have been described as decreases in amplitude occurring with repetition and thus occur in the opposite direction to our findings. Non-specific effects of repetition therefore seem unlikely. The alternate

possibility may therefore be that the N1 enhancement is associated with heightened attention towards the probes (Luck et al., 1990), and an increase in discriminative processes at the attended location (Hillyard, Vogel & Luck, 1998; Luck & Hillyard, 1995). It is plausible that social feedback, independently of probe ambiguity, led to greater attention at the location of the stimulus (Mangun & Hillyard, 1991; Johannes et al., 1995; Hillyard & Annlo-Vento, 1998; Hopfinger & West, 2006) possibly in relation to some aspect of stimulus categorisation (Oliver, Cristino, Roberts, Pegna & Leek, 2017; Pegna, Darque, Roberts & Leek, 2017). Nevertheless, the presence of the enhanced N1 in all our experimental conditions do not allow us to conclude unequivocally to an effect of social feedback.

3.1.5. CONCLUSION

Taken together, our electrophysiological results support the hypothesis that social feedback can modulate early visual perception in situations of perceptual uncertainty, by acting on the early steps of visual processing that take place around 100ms after stimulus presentation. These effects are modulated according to whether social feedback endorses or disputes the participants' responses. Future studies will be necessary to ascertain the significance of the later ERP modulations that may well be linked to more complex functions such as stimulus monitoring.

3.1.6. SUPPLEMENTARY MATERIAL

The early processing of the “social cue” *per se* was investigated by examining the two earliest components evoked by the face, namely the P1 and N170. Here, we hypothesised that if social feedback was effective in influencing behaviour, the processing of agreement faces should differ according to whether they appeared after ambiguous probes than obvious ones.

ERPs were computed separately for happy faces (indicating endorsement) and disgusted faces (indicating disagreement/dispute), and were further examined separately when they followed a distinct or an ambiguous probe.

Electrophysiological recordings and analysis

As with the P1 and N1 for the probes, the P1 and N170 time-locked to the faces (social cues) were identified on the basis of the grand average across all conditions. In this manner, the time window for the P1 was observed between 70ms and 180ms, and that of the N170 between 120ms and 200ms after face presentation. The maximum positivity (for the P1) and negativity (for the N170) were observed on the occipito-temporal electrodes, which included electrodes D31, A10, A15 on the left and A28, B7, B11 on the right (see Fig. S1).

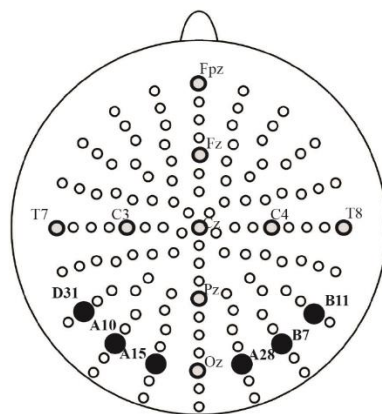


Fig. S1. Electrodes retained for analysis. All channels are represented as open circles situated on a view of the scalp seen from above (nose on top, left side on the left). Electrodes used for analysis of the N170 component are indicated with full black circles. The N170 component included electrodes A15, A10, D31 over the left and A28, B7, B11 over the right occipito-temporal regions.

The P1 and N170 values were then obtained for all participants in response to the facial cue when it indicated social endorsement (happy expression) or when it indicated disagreement (disgusted expression) after a perceptual judgment performed on ambiguous colours. In

addition, happy faces were compared after presentation of distinct colours and ambiguous colours (again, no comparison could be made for disgusted faces after distinct and ambiguous colours, as for the sake of credibility, distinct colours were never followed by disagreement).

After the EEG experiment, participants were asked to evaluate the 20 faces presented during the task (neutral expression) according to three dimensions: attractiveness, intelligence and trust, on a scale ranging from 0 to 5.

Electrophysiological results

ERPs responses to social cue

Given that the P1 and the N170 responses to the social cue could be affected by the ambiguity of the preceding stimulus, we ran two separate repeated measures ANOVAs for each component. The first ANOVA was a 2 (ambiguity: ambiguous or distinct probe preceding the face) X 2 (laterality: left vs right) analysis aimed at comparing if the (happy) faces were processed differently depending on whether they followed an ambiguous probe or a distinct probe. The second ANOVA was a 2 (social cue: endorse vs. dispute) X 2 (laterality: left vs. right) analysis comparing the ERP response to endorsement vs. dispute (i.e. happy vs. disgusted faces) following ambiguous probes. The results are summarized in Table S1.

P1 amplitude: Neither ambiguity ($F(1, 20)=.61, p=.45$), nor social cue ($F(1, 20)=.45, p=.51$) affected P1 amplitude.

P1 latency: The peak P1 latency to happy faces varied significantly according to the ambiguity of the preceding stimuli ($F(1, 20)=6.02, p=.023$), with an earlier response to happy faces when they followed ambiguous probes (116.4 ± 27.22 ms) compared to distinct ones (124.07 ± 31.76 ms) (Fig. S2).

N170 amplitude: The N170 amplitudes for happy faces were affected by the ambiguity of the preceding stimuli ($F(1, 20)=24.36, p=.00008$). The N170 response was significantly enhanced

for happy faces that followed an ambiguous probe ($-3.85 \pm 4.63 \mu\text{V}$) than for those that followed a distinct probe ($-2.16 \pm 4.34\mu\text{V}$) (Fig. S2). No amplitude effect was found for the comparison between happy and disgusted faces following ambiguous probes.

N170 latency: The N170 latency, varied significantly between happy and disgusted expressions that were preceded by ambiguous stimuli ($F(1, 20)=9.202, p=.007$): the N170 to happy faces were significantly earlier ($151.44 \pm 14.75 \text{ ms}$) than those evoked by disgusted faces ($153.74 \pm 17.43 \text{ ms}$) (Fig. S3). No latency effect was found to the social cue in agreement (happy faces) following ambiguous compared to distinct probes.

Table S1 shows the results from the repeated measures ANOVAs for the P1 and N170 components in response to the social cue and as a function of ambiguity of the preceding stimulus and expression of the social cue.

SOCIAL CUE: AMBIGUITY AND CUE VALENCE EFFECTS					
	P1 Amplitude		P1 Latency		
	F(1, 20)	p-value	F(1, 20)	p-value	
Social endorsing cue: distinct vs ambiguous initial probes	0.607	0.445	6.023	0.023 *	
Social endorsing vs disputed cue: ambiguous initial probes	0.452	0.509	1.745	0.201	
	N170 Amplitude		N170 Latency		
	F(1, 20)	p-value	F(1, 20)	p-value	
Social endorsing cue: distinct vs ambiguous initial probes	24.355	< 10⁻⁴ *	0.280	0.602	
Social endorsing vs disputed cue: ambiguous initial probes	0.049	0.827	9.202	0.007 *	

Supplementary Table 1. F and p values for the statistical comparison of the P1 (top row) and N170 (bottom row) amplitudes (left column) and latencies (right column) in response to the social cue. The results are shown for each of the 2 experimental conditions: 1) endorsing cue following distinct vs ambiguous, and 2) endorsing vs disputed cue following ambiguous probes.

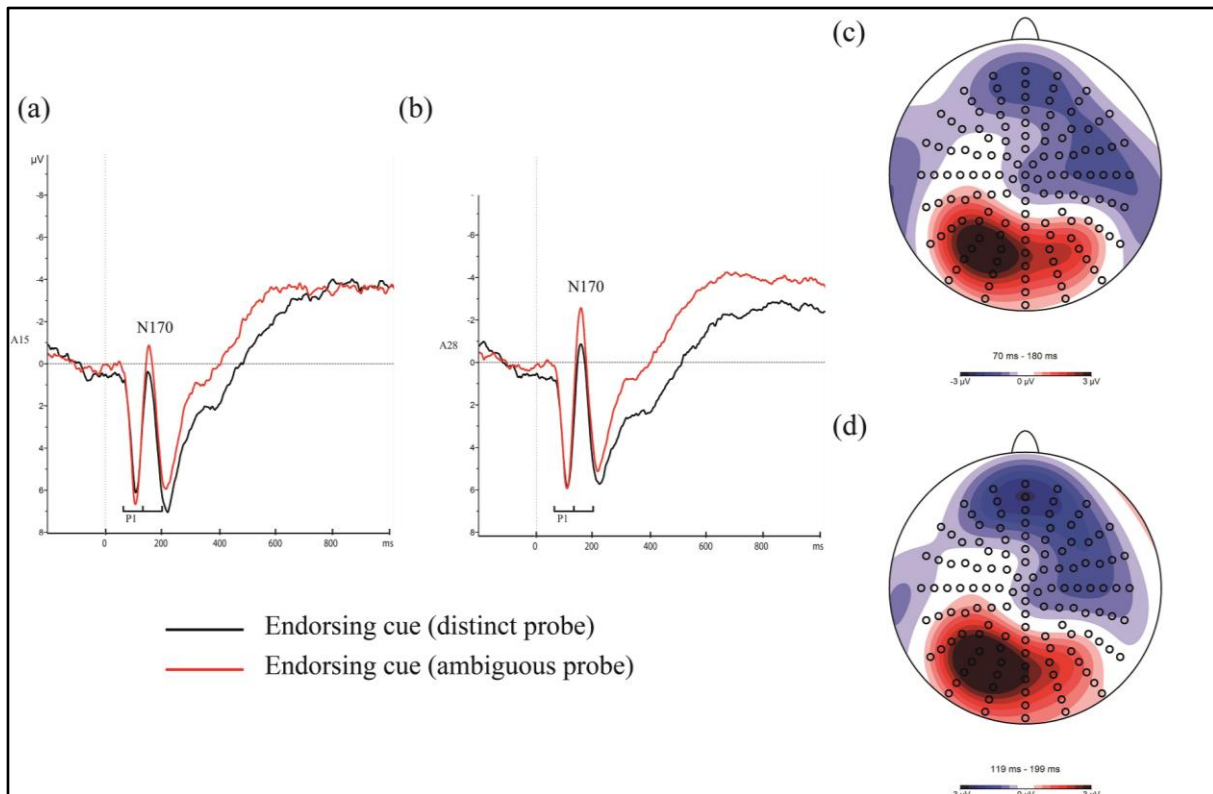


Fig. S2. ERPs for the social cue presentation: ERPs for happy faces presented immediately after ambiguous and distinct stimuli shown over left (a) and right (b) occipito-temporal electrodes. (c) Topographical voltage maps illustrating the P1 (time period between 70-180ms indicated with a black bracket in a and b). (d) Topographical voltage map illustrating N170 (time period between 120-200ms indicated with a black bracket in a and b).

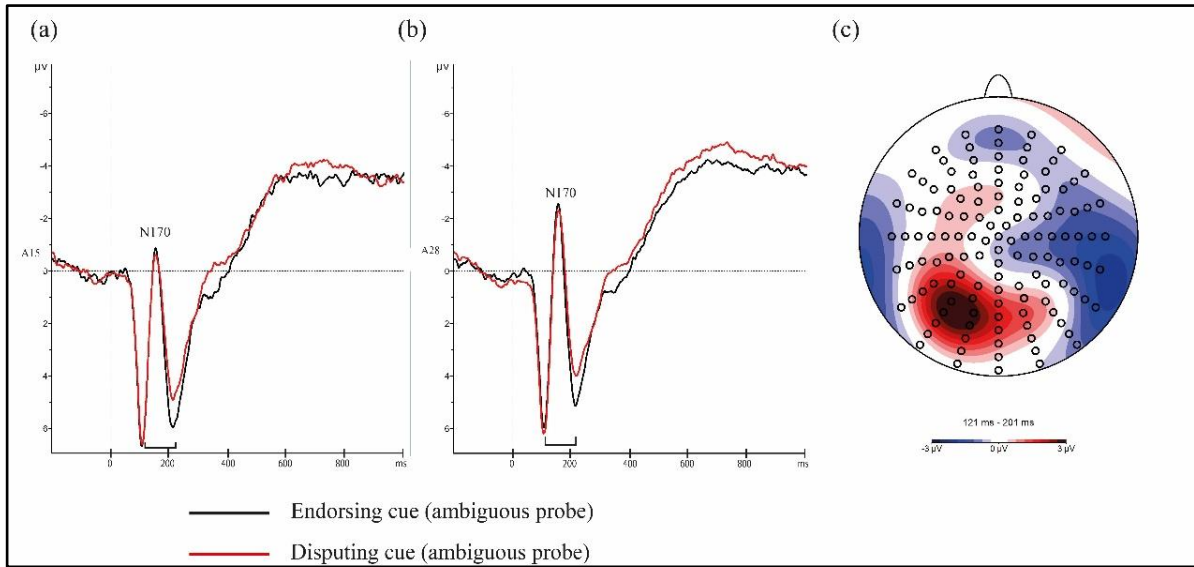


Fig. S3. ERPs for an endorsing social cue (happy face) compared to a disputed social cue (disgusted face) following ambiguous probes illustrating the N170 over left (a) and right (b) temporal electrodes. (c) Topographical voltage map of the N170 (120-200ms) for the happy and disgusted faces, following ambiguous probes.

3.2. STUDY 2: PATTERNS OF ELECTRICAL BRAIN ACTIVATION IN RESPONSE TO SOCIALLY-DISPUTED PERCEPTUAL JUDGMENTS²

Keywords: Uncertainty, social conflict, social feedback, emotional expressions, perception, ambiguity, EEG-ERP, P2, P3, LPP

Abstract

In recent years, neuroscience has begun to investigate brain responses to social stimuli. To date however, the effects of social feedback on attentional and perceptual processes remain unclear. In this study, participants were asked to judge the hues of distinct, or ambiguously coloured stimuli, and to indicate their confidence ratings. Alleged social feedback was then provided, either endorsing or disputing the participants' responses. Participants were then presented the stimulus a second time and given the option to reconsider their decision. Behavioural findings showed that confidence levels decreased both with task difficulty and with conflicting social feedback. ERP data showed greater P2 and N2 amplitudes for ambiguous squares compared to distinct squares upon initial stimulus presentations, compatible with heightened attention. Moreover, a decreased P300 was found for ambiguous stimuli, consistent with an increase in metacognitive activity. After social feedback, an early LPP between 270ms and 370ms continued to distinguish ambiguous from distinct stimuli. More importantly, after 400ms, the LPP distinguished endorsed from disputed stimuli. These results reveal that social feedback, while decreasing effects linked to uncertainty, gives rise to later processes associated with enhanced motivational significance of the stimulus following divergence from social approval.

(2) Reprint of : Zanesco, J., Tipura, E., Clément, F., & Pegna, A. J. (2019). Patterns of electrical brain activation in response to socially-disputed perceptual judgements. *NeuroReport*, 30 (17), 1205-1209.

3.2.1. INTRODUCTION

In everyday life, decisions are often made even though detailed information may be lacking. These decisions are continuously being updated by additional evidence fed back by the environment. One component contributing to decision processes that has been underestimated by cognitive neuroscience is the social information provided by individuals in our surroundings. Indeed, an individual's certainty is not only determined by the degree of ambiguity of the sensory information originating from the stimulus (Selimbeyoglu et al., 2012; Yeung & Summerfield, 2012), but is also influenced by social cues (Eskenazi et al., 2016), which in turn affect perceptual brain processes (Zanesco et al., 2018). This latter point was suggested by Zanesco et al. (2018) who showed that social feedback modified the early event-related (ERP) components in response to ambiguous stimuli already at around 100ms. Such observations raise the question of whether later cognitive processes, indicating more controlled aspects of self-reflection, are influenced by social feedback. Indeed, conflicting and ambiguous information give rise to a subjective feeling of uncertainty (Smithson, 2015), which in turn leads to additional allocation of attentional resources (Dieterich, Endrass & Kathmann, 2016) and conscious control (Shimamura, 2000).

To address this question, an ERP investigation was carried out using a novel procedure (see Zanesco et al., 2018 for details), in which distinct or ambiguous colour stimuli were presented to participants, who were asked to judge their colour and then rate the degree of certainty in their judgment. They were then provided with alleged social feedback that either endorsed or disputed the participants' response. The same stimuli were then shown again and participants were given the option to maintain or revise their decision/ certainty. ERPs were examined for ambiguous and distinct stimuli (initial presentations), and more importantly for endorsed and disputed ambiguous stimuli (post-feedback presentations). We reasoned that, compared to the

initial stimulus presentation, ERPs for stimuli following social feedback would reveal the effects of social information on cognitive processing.

3.2.2. MATERIALS AND METHODS

3.2.2.1. PARTICIPANTS

Twenty paid participants (10 females; mean age = 25 ± 4) were recruited for this study (3 participants were excluded due $>30\%$ errors). All were right-handed, had normal or corrected to-normal vision and had no self-reported psychiatric or neurological disorder.

3.2.2.2. STIMULI AND EXPERIMENTAL PROCEDURE

A fixation cross was presented (400 - 600ms) followed by the probe stimulus (800ms) that was a square stimulus (5.73°) that was either of a distinct blue or green colour (16 stimuli), or of an ambiguous green/blue hue (16 stimuli controlled for isoluminance, ranging from 28.17cd/m² - 30.72 cd/m²). After the stimulus, a response prompt (self-paced) appeared asking the participant to decide whether the stimulus was green or blue. Participants were then asked to rate their level of certainty on a scale from 1 to 5.

They were then presented with a face (1000ms) which they were told reflected the judgement of the majority of previous participants, and which expressed either disgust (disagreement) or joy (endorsement) (Langner et al., 2010). The stimulus sequence was then repeated, in the same order and participants were required to maintain or to revise their decision.

3.2.2.3. EEG ACQUISITION

A 128-channel recording was carried out with a sampling rate of 1024Hz using a Biosemi Active-Two system (Amsterdam, Netherlands) with AG/AgCl electrodes (electrode positions are shown in figs 1 and 2). Eye movements were monitored using 4 additional electrodes. Impedance was kept below 20 k Ω and data was referenced offline against the average reference.

3.2.2.4. EEG PROCESSING

Using Brain Vision Analyzer V.2 (Brain Products, Gilching, Germany), EEG data was downsampled to 512Hz and filtered between 0.1Hz and 30Hz. Bad electrodes were interpolated using a spherical spline (6.6% of the electrodes were interpolated). Eye movements and blinks were corrected (Gratton et al., 1983) and trials containing artefacts were removed (22%). ERPs were computed for distinct and ambiguous stimuli in the initial presentation between -200ms to 800ms using the 200ms prestimulus period for baseline correction. For the post-feedback stimulus presentations ERPs were computed for ambiguous endorsed, ambiguous disputed and distinct endorsed conditions. In order to maintain credibility, our design did not include any social dispute for distinct probes. Following visual inspection, the P2, N2 and P3 amplitudes were retained for statistical investigation of the initial presentation. For the post-feedback presentation, no P3 was observed, by contrast, a late positive potential (LPP) was found to distinguish the experimental conditions. Consequently, the P2, N2 and LPP were analysed for the post-feedback stimulus presentation. When necessary, adjusted p-values were used to control for sphericity.

Initial stimulus presentations

Visual inspection showed differences on the P2, N2 and P3 components. The time windows for analysis were subsequently determined on the basis of the peaks and means observed in the grand averages across all conditions using a collapsed localizer. The P2 peaks (210ms - 260ms) were determined using a semi-automatic peak detection method and were measured over two groups of electrodes on the left and right scalp (Fig. 21). Mean amplitudes were measured for the N2 (220ms - 270ms) over the left, midline and right frontal electrodes (fig. 1). P3 mean amplitudes (350ms - 450ms) were measured over occipito-parietal electrodes on the right, midline and left scalp (Fig. 21).

Post-feedback stimulus presentations

The same electrodes and time windows were used to compute the P2 and N2 components for the post-feedback stimulus presentations. Mean amplitudes for the LPP component were computed over a group of 3 occipito-temporal electrodes (Fig. 22) in two separate time windows (270ms - 370ms and 400ms - 500ms).

3.2.3. RESULTS

3.2.3.1. BEHAVIOURAL RESULTS

Initial presentations: Certainty ratings for distinct stimuli were at 98.55% and at 69.87% for ambiguous stimuli.

Post-feedback presentations: For distinct (endorsed) stimuli, certainty ratings were at 99.22% while for ambiguous stimuli these were at 75.81% for endorsed and 67.07% for disputed stimuli.

ANOVA for repeated-measures was carried out on the confidence ratings of the endorsed stimuli using position (initial/second presentation) and condition (ambiguous/distinct) as factors. The main effects of position ($F(1, 16) = 21.26, p < 10^{-4}$) and condition ($F(1, 16) = 75.3, p < 10^{-6}$) were significant, as well as the interaction between position and condition ($F(1, 16) = 13.3, p < 10^{-3}$). Post-hoc comparisons using Tukey tests revealed that the interaction was driven by a significant increase in confidence ratings between the initial and post-feedback presentations of ambiguous endorsed stimuli ($p < 10^{-4}$), effect that was not observed for distinct stimuli.

A separate 2 (position: initial/second presentation) X 2 (type of feedback: endorsed/disputed) ANOVA was performed on the confidence ratings for ambiguous stimuli alone, examining confidence rating before and after endorsement and dispute. This analysis revealed significant main effects of position ($F(1, 16) = 5.75, p < .05$) and type of feedback ($F(1, 16) = 12.3, p <$

10^{-3}), with endorsement leading to higher confidence ratings than dispute. A significant interaction was also found between position and type of feedback ($F(1, 16) = 12.3, p < 10^{-3}$), which was due to the fact that confidence ratings rose significantly after endorsement compared to the initial rating (Tukey post-hoc; $p < .05$), but decreased after dispute ($p < 10^{-4}$).

Results of the self-report questionnaire revealed that 64.7% of the participants always believed in the social cue, 17.65% stated that they believed in it occasionally and 17.65% (3 subjects) reported that they did not. Participants reporting disbelief in feedback authenticity nevertheless showed confidence ratings of 71% for ambiguous probes following social endorsement, compared to 68.4% prior to social feedback. Their mean confidence level following disagreement was 69.3%. The differences in the sceptical group, reveal that that they were influenced by the valence of the cue in spite of their apparent disbelief.

3.2.3.2. ELECTROPHYSIOLOGICAL RESULTS

Initial stimulus presentation

Posterior P2 amplitude. The ANOVA showed a significant main effect of ambiguity ($F(1,16) = 8.08, p < .05$). The P2 peak was significantly greater for the initial ambiguous probes ($3.8 \pm 2.78 \mu V$), compared to the distinct ones ($3.2 \pm 2.73 \mu V$) (Figure 21, right).

Anterior N2 amplitude. The ANOVA revealed a main effect of ambiguity ($F(1, 16) = 9.52, p < .10^{-3}$). The N2 mean amplitudes were significantly more negative for the presentation of initial ambiguous probes ($-1.52 \pm 2.36 \mu V$) compared to the presentation of initial distinct probes ($-0.83 \pm 2.65 \mu V$) prior social feedback (Figure 21, top).

P3 amplitude. The ANOVA showed a main effect of ambiguity ($F(1, 16) = 12.21, p < .10^{-3}$). The P3 mean amplitude was significantly larger for the presentation of initial distinct probes

($3.7 \pm 2.5 \mu\text{V}$) than for the presentation of initial ambiguous probes ($2.7 \pm 2.2 \mu\text{V}$) prior to social feedback (Figure 21, left).

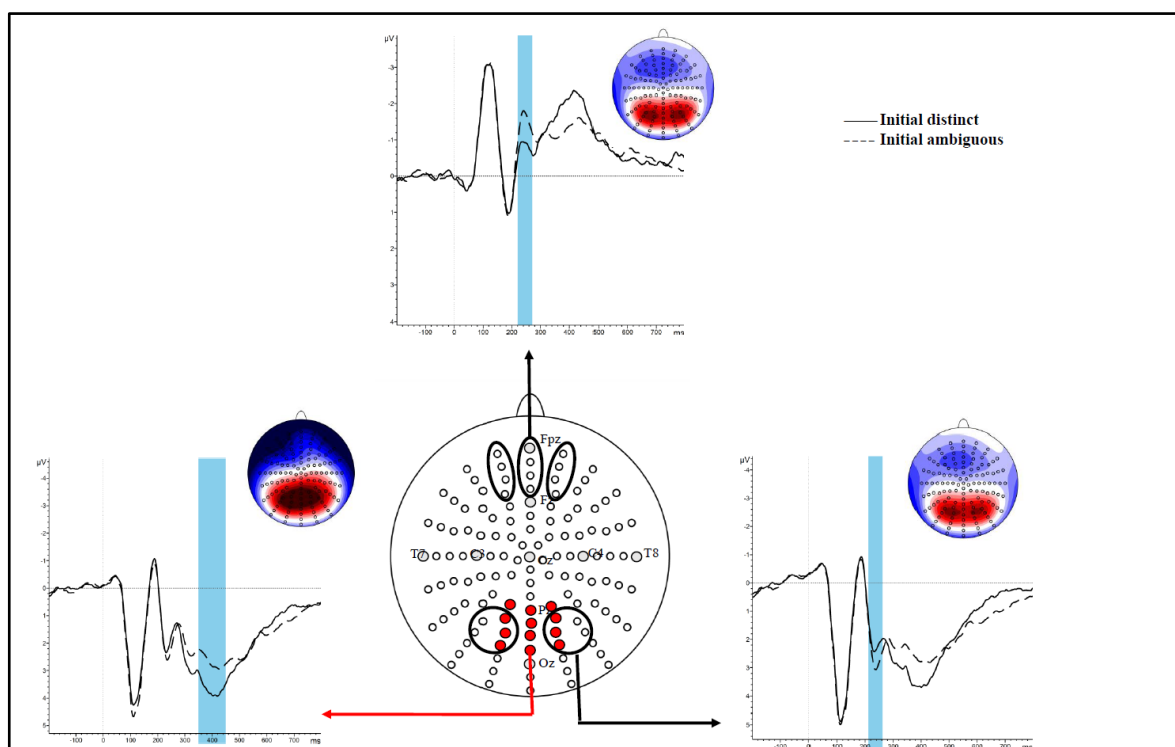


Figure 21: ERPs for ambiguous and distinct probes presented before social feedback. Pooled ERP traces are shown across electrodes used for the computation of the posterior P2 (right) and anterior N2 (top), as well as P3 (left), along with collapsed topographical voltage map illustrating the posterior P2/anterior N2 and the P3 for the two conditions of ambiguity. Central inset shows scalp viewed from above (frontal leads on top, right leads on the right), with electrodes used for P2 and N2 computation circled in black, and electrodes used for P3 computation indicated in red.

Second (post-feedback) stimulus presentation

Posterior P2 amplitude. The ANOVA performed on P2 mean amplitudes after feedback probes revealed no significant differences between the three conditions ($F(1.41, 22.6) = .5$, adj. $p > .05$) (distinct endorsed = $4.05 \pm 2.04 \mu\text{V}$, ambiguous endorsed = $4.00 \pm 1.9 \mu\text{V}$, ambiguous disputed = $4.21 \pm 2.04 \mu\text{V}$).

Anterior N2 amplitude. The same repeated measures ANOVA for post-feedback probes did not reveal any significant effect of social feedback ($F(1.74, 28) = .5$, $p > .05$). There were no significant differences between the presentation of post-endorsed distinct probes (-2.4 ± 1.9

μV), post-endorsed ambiguous probes ($-2.1 \pm 1.44 \mu\text{V}$) and post-disputed ambiguous probes ($-2.2 \pm 1.22 \mu\text{V}$). Only a main effect of laterality was observed ($F(2, 32) = 7.64, p < 10^{-3}$).

LPP. The ANOVA carried for the 270ms - 370ms window revealed main effects of condition ($F(1.89, 29.5) = 9.4, p < 10^{-4}$) and laterality ($F(1.81, 28.9) = 7.8, p < 10^{-3}$). Post-hoc comparisons using Tukey tests showed that the early posterior positivity mean amplitude was significantly larger for distinct endorsed probes ($2.3 \pm 1.9 \mu\text{V}$), compared to both ambiguous conditions (ambiguous endorsed = $1.4 \pm 1.7 \mu\text{V}, p < 10^{-5}$; ambiguous disputed = $1.8 \pm 1.6 \mu\text{V}, p < 10^{-5}$). The mean amplitudes were significantly larger over the right and left hemisphere leads (right: $2.4 \pm 1.7 \mu\text{V}$; left: $2.03 \pm 1.9 \mu\text{V}$) compared to the midline ones ($1.08 \pm 1.7 \mu\text{V}$).

The ANOVA for the later LPP window (400ms - 500ms), showed a main effect of condition ($F(1.32, 21.05) = 4.6, p < .05$), with post-hoc Tukey tests showing that mean amplitudes were significantly greater for ambiguous disputed probes ($2.38 \pm 1.5 \mu\text{V}$) than the two endorsed conditions, while these latter two did not differ significantly (distinct endorsed: $1.71 \pm 1.5 \mu\text{V}; p < .05$; ambiguous endorsed: $1.65 \pm 1.5 \mu\text{V}; p < .05$) (Fig. 22).

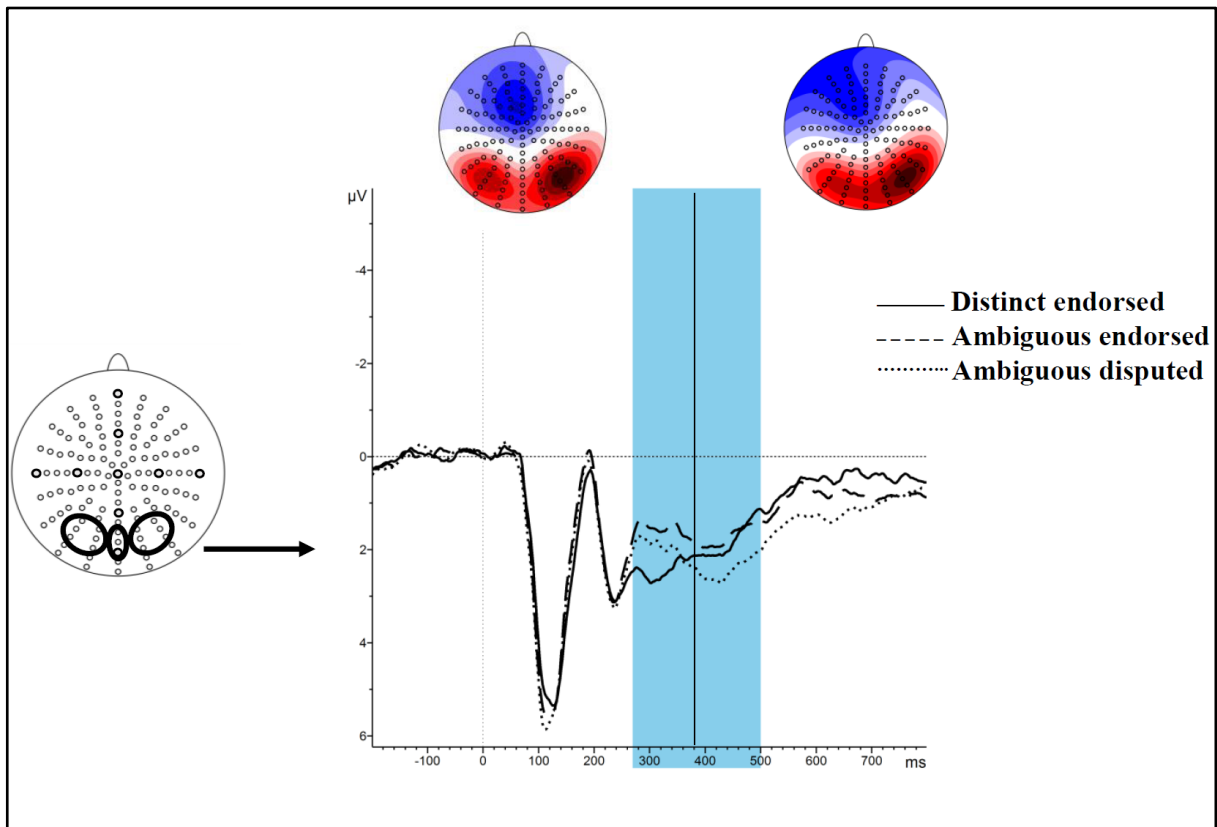


Figure 22: ERPs for stimuli presented after social feedback. Traces obtained from the pooled electrodes indicated in the inset are illustrated for distinct endorsed, ambiguous endorsed and ambiguous disputed stimuli. The two periods of investigation (270ms- 370ms and 400ms- 500ms) are separated by a black line between 370 and 400ms.

3.2.4. DISCUSSION

The behavioural results in this study showed that participants believed in the authenticity of the social feedback and modified their responses accordingly.

The ERPs obtained for the initial presentation of the ambiguous stimuli showed an enhanced posterior P2/anterior N2 amplitude starting at around 200ms. These increases in P2/N2 amplitudes are in line with other findings in the literature that have demonstrated similar responses under conditions of uncertainty (Gole et al., 2012; Wang, Sun, Li & Meng, 2018). The P3 component was greater for distinct stimuli. The P3 has been interpreted as reflecting different functions. One suggestion is that it represents attentional engagement (Polich, 2007).

Indeed, it has been noted that under more demanding task conditions, the P3 amplitude is decreased, contrary to less demanding situations (Kok, 2001; Olofsson & Polich, 2007). In our investigation, the increased difficulty for ambiguous stimuli may have necessitated greater attentional engagement leading to a decreased P3 component. Alternatively, a more recent interpretation has been advanced suggesting that the P3 may be a marker of neural activity which could be linked to metacognition. The term metacognition denotes the explicit representations an agent has of their cognitive processes and can be more broadly defined as cognition about cognition (Shea et al., 2014). This self-reflective ability is thought to increase in the face of uncertainty. Recent investigations have examined the relation between the P3 and the participants' certainty with regards to the stimulus (Desender et al., 2016). Using target detection tasks, it has been observed that as sensory evidence builds up with increasing evidence, participants' accuracy increases, and the P3 builds up more rapidly, peaking earlier and with a greater amplitude (Kelly & O'Connell, 2013; Murphy et al., 2015; Twomey et al., 2015). This has led to the suggestion that the P3 may act as a "decision variable" reflecting the accumulation of sensory information that culminates with the participant' decision (Kelly et al., 2013). This finding could also account for our observations, in which more distinct colours would have led to a rapid build-up of sensory evidence allowing an unequivocal response, which was lacking for ambiguous colours.

Although P2/N2 and P3 differences were found prior to feedback, the ERPs observed after social feedback differed quite clearly. Indeed, the enhanced P2 / N2 responses for ambiguous stimuli were no longer observed and no P3 topography was found. This appears to suggest that when viewing the stimulus a second time, the subsequent attentional engagement (or build-up of sensory information) did not occur. Instead, an LPP after approximately 350ms differentiated disputed and endorsed stimuli.

Different interpretations could be advanced for this LPP. Firstly, it could be speculated that social feedback modulated the emotional value of the stimulus. Indeed, emotionally-valenced stimuli have been found to activate a similar late component. Ito et al. (Ito, Larsen, Smith & Cacioppo, 1998) reported a late centro-parietal positivity for emotional stimuli that was more marked for negative images, when these were set in a context of neutral images. The finding was replicated by Huang & Luo (Huang & Luo, 2006) for negative images in a valence judgment task. Others have reported a similar component for both positively and negatively-valenced stimuli (e.g. Hajcak et al., 2010; Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Schupp, Cuthbert, Bradley, Cacioppo, Ito & Lang, 2000; Dolcos & Cabeza, 2002). In this context, the LPP may be an indication of an emotional appraisal of the stimuli due to their “incorrect” classification by the participant. Alternately, their emotional value may have led to changes in attentional engagement.

3.2.5. CONCLUSION

Within the current context, it might therefore be argued that social disagreement enhances stimulus reprocessing due to what we would term a social epistemic discrepancy, created by the divergence between the participants’ judgment and the dominating social opinion. This appears to modify the emotional value of the stimulus and to bring about later processes causing the ambiguous stimulus to gain a different emotional value.

3.3. STUDY 3: AM I REALLY SEEING WHAT'S AROUND ME ? AN ERP STUDY ON SOCIAL ANXIETY UNDER SPEECH INDUCTION, UNCERTAINTY AND SOCIAL FEEDBACK³

Keywords: *Social anxiety, Uncertainty, Ambiguity, Early Attention, Social feedback, ERPs*

Abstract

Cognitive models of social anxiety propose that socially anxious individuals engage in early excessive self-focusing attention when entering a social situation manifested by hypervigilance towards threatening social stimuli. However, it remains unclear whether their fear to socially threatening information unfolds during the social context or rather before the social-evaluative event, impacting on early visual and attentional processes to external stimuli. To address this question, the present study used a novel paradigm in which participants were assigned to a socially anxious group or control group on the basis of their score at the Liebowitz Social Anxiety Scale. Before the experimental procedure, speech anxiety was induced to all participants who believed they would be making a presentation in front of an audience of three psychologists at the end of the experiment. During the recording of event-related-potentials, participants were asked to judge the hues of distinct, or ambiguously coloured stimuli, and to indicate their confidence ratings. Alleged social feedback was then provided, either endorsing or disputing the participant's responses. Participants were then presented the stimulus a second time and given the option to reconsider their decision. Behaviourally, results indicated that confidence levels were decreased for all participants following disputed feedback, whereas revised judgments were increased post-disputed feedback. This pattern was strengthened among socially anxious individuals. ERP data showed greater occipital P1 amplitudes for ambiguous probes

compared to distinct ones upon initial stimulus presentations, and this, for both groups, compatible with heightened sensory facilitation to ambiguous information. However, P1 amplitudes for all conditions were reduced among socially anxious individuals, suggesting a reduction in sensory facilitation of visual information among the latter. Moreover, a decreased frontal N1 was also found for both initial and post-feedback conditions among socially anxious subjects compared to controls. This component also distinguished disputed conditions from endorsed ones, in both groups of participants. During the presentation of social feedback, P1 was not modulated by the level of social anxiousness. However, the N170 amplitudes were increased for faces following ambiguous probes and were earlier to faces indicating agreement compared to disagreement, without distinguishing socially anxious subjects from healthy ones. The findings provide evidence for the role of anticipation of social situations among socially anxious individuals manifested by a reduction in early attention to external stimuli due to excessive self-focusing.

(3) Reprint of: Zanesco, J. (2019). Am I really seeing what's around me? An ERP study on social anxiety under speech induction, uncertainty and social feedback (*under review*)

3.3.1. INTRODUCTION

Social anxiety disorder (SAD) is one of the most common psychiatric disorders with a prevalence rate 12 to 15% among the general population and with only 10 to 20% of individuals asking for therapeutic counselling (Fumark, Tillfors, Everz, Marteinsdottir, Gefvert & Fredrikson, 1999). According to the most prominent cognitive models of social anxiety (Clark & Wells, 1995; Williams et al., 1998; Mogg & Bradley, 1988; Matthews & Mackintosh, 1998; Eysenck et al., 2007; Bar-Haim et al., 2007), the disorder is characterised by heightened self-focused attention when anticipating or entering a social situation and impaired attentional disengagement from threatening social stimuli (Taylor, Cross & Amir, 2016). In a social situation, attention may be internally oriented (thoughts, emotions, behaviours) or externally oriented (environment, ongoing tasks...). In the case of social anxiety, attention is oriented internally giving rise to enhanced awareness of anxiety symptoms contributing to the fear of failing and thus to the maintenance of the disorder.

A wealth of behavioural research has assessed the attentional biases by measuring reaction times and eye movement data in experimental tasks with emotional face expressions such as the modified dot probe task (MacLeod, Mathews & Tata, 1986), the modified Stroop task (Stroop, 1935), visual search tasks (Öhman, Flykt & Esteves, 2001) and spatial cueing tasks (Posner, 1980) (for a review see Cisler & Koster, 2010). Overall, these studies do not accord on the components and mechanisms of attentional processing biases toward threat. It still remains unclear whether it is about excessive attention to threat (Gamble & Rapee, 2010; Boll, Bartholomaeus, Peter, Lupke & Gamer, 2016; Holas, Krejtz, Cyprianska & Nezlek, 2014), difficulty to disengage attention from threat (Amir, Elias, Klumpp & Przeworski, 2003, Moriya & Tanno, 2011), attentional avoidance from threat (e.g. MacLeod et al., 1986; Moukheiber, Rautureau, Perez-Diaz, Soussignan, Dubal, Jouvent & Pelissolo, 2010), impaired inhibition control and shifting functions (Eysenck & Derakshan, 2011; Taylor et al., 2016) or

even a lack of biases in social anxiety considering the positive attentional bias in the non-anxious population towards positive stimuli (Schofield, Inhoff & Coles, 2013). Some studies showed that the SAD is associated to both hypervigilance and attentional avoidance (Chen, Thomas, Clarke, Hickie & Guastella, 2015). It seems though that the investigation of the stages of information processing is key to understand the integration of attentional and mediating mechanisms at work in social anxious individuals. Taken together, this body of research shows that there are two stages of processing, an automatic preconscious stage followed by a strategic processing stage (Shiffrin & Schneider, 1977). The excessive attention to threatening social stimuli is observed shortly after stimulus presentation. This early hypervigilance for faces occurring at around 150 ms (Gamble & Rapee, 2010; Boll et al., 2016) is followed by a delayed disengagement at around 300 ms after the presentation of angry faces (Moriya & Tanno, 2011). Subsequently, social anxious individuals will avoid the threat in a strategic controlled manner. These last two stages can be modulated by executive control capacities (shifting and inhibition) as well as through emotional regulation strategies in order to avoid avoidance (Cisler & Koster, 2010).

Some recent studies have explored these attentional components using eye-tracking measures and reported discordant results. For example, Moukheiber et al. (2010) observed a lower number of fixations and dwell time in the eye area for the different basic emotions, making eye avoidance a behavioural phenotype in SAD. Other studies using eye measures (Gamble & Rapee, 2010; Holas et al., 2014; Boll et al., 2016) observed hypervigilance in early stages at around 150 ms, manifested by a greater proportion of fixations towards emotional faces or faster initial orienting towards negative face emotions.

The discrepancy between results in behavioural and eye tracking studies may be due to the fact that behavioural tasks are not adequate to explore the temporal dynamics in socially anxious individuals, whereas eye movement measures lack sensitivity to unconscious shifts in

attention (Felmingham, Stewart, Kemp & Carr, 2016). Thus, electrocortical measures such as event-related potential (ERPs), thanks to their high temporal resolution, can inform on the temporal unfolding of neural activation in response to socially threatening stimuli. Several ERP studies have explored early attentional processes during the presentation of emotional expressions in highly socially anxious and social phobic individuals (for a review see: Harrewijn, Schmidt, Westenberg, Tang & Van der Molen, 2017). Overall, results indicate that P1, an early positive wave peaking around 100 ms after stimulus presentation (Luck, 2014), is increased in response to emotional faces in socially anxious individuals, suggesting enhanced sensory processing to socially threatening stimuli (e.g. Peschard et al., 2013; Rossignol et al., 2012, 2013; Mueller et al., 2009; Morel et al., 2014). Results on the N170, a face sensitive negative potential peaking between 130 and 200 ms, revealed no differences in N170 amplitudes between socially anxious individuals and healthy controls (e.g. Morel et al., 2014; Tsuji & Shimada, 2017, Li, Yu, Ye, Chen, Xie, Zhu & Wang, 2017). However, these studies did not examine the effect of social feedback, via emotional expressions indicating agreement or disagreement, on early perceptual processes during the presentation of ambiguous stimuli. In a previous study, Zanesco et al. (2018) investigated these early brain modulations under social pressure and showed that stimulus ambiguity and social feedback influenced early ERP components as well as later metacognitive processes (Zanesco et al., 2019). Thus, the temporal aspects of brain activation to ambiguous visual stimuli, before and after social feedback, in the social anxious population, remain largely unknown.

The present study focused on the early cognitive processes at play in situations of uncertainty caused by stimulus ambiguity, when conflicting social feedback was provided. Uncertainty has been shown to be an important transdiagnostic variable in SAD (Oglesby et al., 2016) as socially anxious individuals tend to interpret ambiguous information as more threatening than non-socially anxious individuals (Constans et al., 1999). To address this question, an ERP

investigation was carried out using a novel paradigm (see Zanesco et al., 2018 for details), in which distinct or ambiguous colour stimuli were presented to participants, who were asked to judge the colour and rate the degree of certainty in their judgment. They were then provided with an alleged social feedback that either endorsed or disputed the participants' response. The same stimuli were then shown again and participants were given the option to maintain or revise their decision and confidence rate. Furthermore, the present study induced social anxiety to all participants by making them believe they would be presenting their subjective experience in front of three psychologists at the end of the experiment.

Since ambiguous situations and disagreement from the social majority increase uncertainty about the response in the general population (Cialdini & Golstein, 2004), we hypothesised that highly socially anxious individuals would revise their judgment more often than healthy controls after a disputing social feedback compared to an endorsed one. Additionally, socially anxious subjects would present lower levels of confidence for ambiguous compared to distinct stimuli, but higher levels of confidence following an endorsing social cue compared to a disputed cue.

From an electrophysiological point of view, we focused on the visual P1 and N1 components locked to the presentation of the probe stimuli (coloured squares), before and after social feedback. The occipital P1 component has been interpreted to reflect facilitation of early sensory processing for stimuli presented in a location where attention is focused, whereas the anterior N1 represents the orienting of attention to a task-relevant stimulus (Luck et al., 1990). It was expected that initial ambiguous stimuli would produce greater P1/N1 amplitudes than initial distinct ones. After the social feedback, it was predicted that ambiguous stimuli following a social feedback in disagreement would generate enhanced P1/N1 amplitudes compared to the endorsed conditions. The effects on P1 and N1 were expected to be larger for the social anxious group compared to controls. Moreover, and based on the literature, P1

locked to the social feedback, was expected to be greater for faces indicating disagreement compared to agreement as this component is thought to reflect rapid emotional processing based on elementary visual information (Vuilleumier & Poutois, 2007). Concerning the N170, which reflects the structural encoding of faces, only one study, using a modified Stroop task, revealed an increased N170 amplitude for angry faces in socially anxious individuals compared to patients with social spider phobia and healthy controls (Kolassa & Miltner, 2006). This study used entire pictures of faces. However, most other studies, using schematic or cropped faces, did not observe any influence of social anxiety on N170 modulations (e.g. Peschard et al., 2013; Rossignol et al., 2012). In the present study, we used entire faces with direct gaze. Thus, the use of more ecological stimuli may lead to N170 differences in amplitude or latency between socially anxious subjects and healthy subjects as well as between disputed and endorsed social cues.

3.3.2. MATERIALS AND METHODS

3.3.2.1. PARTICIPANTS

Twenty-five paid participants were recruited for this study. Three participants were excluded due to high number of artifacts. The final sample was therefore composed of 22 participants (16 females and 6 males; mean age = 23.3 ± 2.9). All were right-handed, had normal or corrected to-normal vision. Twelve subjects had no self-reported psychiatric or neurological disorder, while ten participants reported having social anxiety and were recruited on this basis. Participants were allocated to either the control group (12 subjects; 7 women) or the experimental social anxious group (10 subjects; 9 women) upon completion of the French version (Yao, Note, Fanget, Albuissou, Bouvard, Jalenques & Cottraux, 1999) of the Liebowitz Social Anxiety Scale (LSAS) (Liebowitz, 1987; see annex 1). The LSAS is a 24-item scale scored on a 0 to 3 Likert scale assessing two key dimensions of social anxiety across a variety of situations. The first dimension refers to the level of fear or anxiousness in a

particular situation. The second dimension refers to how often the situation is avoided. Scores range from 0 to 144 points, and the cut off is situated at 56 points representing moderate anxiety. Scores above 80 are associated with severe social anxiety and scores above 95 points, with very severe social anxiety. Thus, subjects scoring at or above 56 constituted the social anxious group and subjects scoring below the cut-off made up the control group. The French version of the LSAS has been shown to present a high empirical and concurrent validity (r -Pearson between 0.49 and 0.69) and it differentiates socially anxious subjects from non-clinical ones (Yao et al., 1999). None of the participants were diagnosed with social anxiety and none were students in psychology. They were paid 50 Swiss francs for their participation. The study was approved by the local ethics committee (University of Geneva) and was performed in agreement with the Declaration of Helsinki.

3.3.2.2. STIMULI AND EXPERIMENTAL PROCEDURE

The procedure and stimuli have been described elsewhere (Zanesco et al., 2018). Briefly, a fixation cross was presented (400 - 600ms) followed by the probe stimulus (700ms) that was a square stimulus (5.73°) that was either of a distinct blue or green colour (16 stimuli), or of an ambiguous green/blue hue (16 stimuli controlled for isoluminance, ranging from 28.17cd/m² - 30.72 cd/m²). After the stimulus, a response prompt (self-paced) appeared asking the participant to decide whether the stimulus was green or blue. Participants were then asked to rate their level of certainty in their response on a scale from 1 to 5.

They were then presented with a face (1000ms) which they were told reflected the judgement of the majority of previous participants, and which expressed either disgust (disagreement) or joy (endorsement). The stimulus sequence was then repeated, in the same order and participants were required to maintain or to revise their decision. The faces used for social feedback were 10 male and 10 female identities expressing happiness or disgust, taken from the Radboud Faces Database (Langner et al., 2010).

Prior to the recording, social anxiety was induced by telling participants that at the end of the task, three psychologists would ask them to give their subjective feeling during the experiment. Furthermore, participants were asked to complete the French version of the Liebowitz Social Anxiety Scale (LSAS) (Liebowitz, 1987).

3.3.2.3. EEG ACQUISITION

EEG was recorded using a 64-channel Biosemi Active-Two system (Amsterdam, Netherlands) with AG/AgCl electrodes positioned according to the extended 10-20 system. Four additional flat electrodes, which were placed on the outer canthi of the eyes and above and under the right eye, in order to capture the eye movements and blinks. Each active electrode is represented with an impedance value, which was kept below 20 k Ω for each participant. The EEG was continuously recorded with a sampling rate of 1024 Hz. Data was re-referenced off-line against the average reference (electrode positions are shown in Fig. 23).

3.2.2.4. EEG PROCESSING

Standard processing of EEG data was done offline using the software Brain Vision Analyzer V.2 (Brain Products, Gilching, Germany). The data was downsampled to 512Hz and filtered between 0.1Hz and 30Hz. Bad electrodes were interpolated using a spherical spline (1.4% of the electrodes were interpolated). Eye movements and blinks were corrected (Gratton et al., 1983) and trials containing artefacts were removed (14%).

3.3.2.5. BEHAVIOURAL ANALYSIS

Behaviourally, mean confidence ratings were compared for each participant separately for initial and post-feedback presentations and for each condition. Additionally, fluctuations in confidence ratings between initial and post-feedback probes were also examined. Finally, trials in which participants revised their judgement after social feedback were counted as

“revisions”. Mean number of revisions was calculated according to the ambiguity of the probe and the valence of the social cue.

Statistical analysis of mean confidence rates was performed using two repeated measures ANOVA. For the initial presentation of stimuli, a 2x2 ANOVA was carried out using the mean confidence rate as the dependent variable, the group (control / social anxious) as the between-subject factor and the condition (initial ambiguous / initial distinct) as the within subject factor. To examine the effect of social feedback on subjective confidence, a 2x3 ANOVA was carried out using mean confidence rate as the dependent variable, the group (control /social anxious) as the between-subject factor and the condition (ambiguous endorsed/ distinct endorsed/ ambiguous disputed) as within-subject factor. To examine the increase or decrease in confidence rate between initial and post-feedback probes, we used a 2x3 repeated measures ANOVA, with the percentage of fluctuation as the dependent variable, the group (control / social anxious) as the between-subject factor and the condition (ambiguous endorsed/ distinct endorsed/ ambiguous disputed) as the within-subject factor.

The number of revisions for each group was investigated using an ANOVA with the mean number of revisions as dependent variable, the group (control /social anxious) as the between-subject factor and the condition (ambiguous endorsed/ distinct endorsed/ ambiguous disputed) as the within-subject factor.

3.3.2.6. ELECTROPHYSIOLOGICAL RECORDINGS AND ANALYSIS

ERPs were computed for distinct and ambiguous stimuli in the initial presentation between 200ms to 700ms using the 200ms prestimulus period for baseline correction. For the post-feedback stimulus presentations, ERPs were computed for ambiguous endorsed, ambiguous disputed and distinct endorsed conditions. For the social feedback presentation, ERPs were computed for faces expressing agreement (happy expressions) and disagreement (disgust

expressions). The latter, following ambiguous stimuli and the former following ambiguous or distinct stimuli. In order to maintain credibility, our design did not include any social dispute for distinct probes. Following visual inspection, the P1, N1 amplitudes were retained for statistical investigation for the initial and post-feedback presentations. For the social feedback presentation, we retained the P1 and the N170 components. When necessary, adjusted p-values were used to control for sphericity.

Initial stimulus presentations

Visual inspection showed differences on the posterior P1, and on the anterior N1 components. The time windows for analysis were subsequently determined on the basis of the peaks and means observed in the grand averages across all conditions using a collapsed localizer. The P1 peaks (80ms - 140ms) were determined using a semi-automatic peak detection method and were measured over electrodes on the left (O1), right (O2) and midline (Oz) scalp (Fig. 23). Peaks for the anterior N1 (60-150ms) were measured over the left (F1, FC1), midline (Fz, FCz) and right (F2, FC2) frontal electrodes (Fig. 23). These early stages of processing were investigated for each component, with a repeated measures ANOVA using difficulty (initial distinct / initial ambiguous) and laterality (left/ midline/ right) as within-subject factors, and the group (control /social anxious) as the between-subject factor.

Post-feedback stimulus presentations

The same electrodes and time windows were used to compute the peak amplitudes on the P1 and N1 components for the post-feedback probe presentations (Fig. 24). The repeated measures ANOVA was carried out using the group (control/ social anxious) as between-subject factor and the three conditions (distinct endorsed / ambiguous endorsed/ ambiguous disputed) and laterality (left / midline / right) as within subject-factors.

Social feedback presentations

ERPs were computed separately for happy faces (indicating agreement / endorsement) and disgusted faces (indicating disagreement/ dispute) and were further examined separately when they followed a distinct or an ambiguous probe. The P1 and N170 time-locked to the social feedback were identified on the basis of the grand average across all condition. In this manner, the time window for the P1 peak amplitude was observed between 60ms and 130ms and measured over posterior left (PO7, O1), midline (Oz) and right (PO8, O2) electrodes. The N170 peak and latency values were observed on temporo-parietal sites (left: P7, P9 and right: P8, P10) between 120 ms and 180 ms (Fig. 25).

3.3.3. RESULTS

3.3.3.1. BEHAVIOURAL RESULTS

The one-way ANOVA performed on the score of social anxiety revealed, as expected, a significantly higher scoring within the social anxious group (83 ± 18.7) compared to the control group (33.83 ± 12.62), ($F(1,20) = 53.84$, $p < 10^{-7}$).

Results of the self-report questionnaire revealed that 32% (7 subjects) of participants always believed in the social feedback, 55% (12 subjects) stated that they believed in it occasionally, while 14% reported not believing in the social feedback. The latter, nevertheless, revised on average 8% of their judgments following the social feedback, compared to 7% for those stating believing occasionally or reporting always believing in the social feedback. Globally, the average percentage credibility reached 72% for the control group and 73% for the social anxious group. A one-way ANOVA did not reveal any significant differences between both groups in terms of credibility in the social cue ($F(1, 20) = .013$, $p > .05$).

The number of revisions was significantly higher in the social anxious group (34.7 ± 18.5) relative to the control group (19.3 ± 8.3), ($F(1, 20) = 6.68$, $p < .05$). The ANOVA performed

on the mean number of revisions revealed a significant main effect of group, ($F(1,20) = 6.7, p < .05$), of condition, ($F(1.1, 22.1) = 29.7, p < 10^{-5}$), as well as an interaction between group and condition, ($F(1.1, 22.1) = 5.9, p < 10^{-3}$). For the main effect of group, mean revisions after feedback were significantly higher in the social anxious group (11.6) compared to the control group (6.4). For the main effect of condition, post-hoc comparisons revealed that the mean number of revisions was significantly higher following a disputed feedback (20.9) compared to both endorsed conditions (ambiguous endorsed: 5.2; distinct endorsed: 0.9) ($p < 10^{-4}$). For the interaction between group and condition, post-hoc comparisons using Tukey tests revealed that the mean number of revisions was significantly higher for disputed ambiguous probes in the social anxious group (28.9) compared to the control group (12.9) ($p < 10^{-3}$).

The ANOVA performed on the mean confidence ratings for the initial probes revealed a main effect of condition, ($F(1, 20) = 149.2, p < 10^{-7}$). Mean confidence ratings were significantly higher for initial distinct probes (95.3%) compared to initial ambiguous probes (73.5%), and this for both groups. After the social feedback, the ANOVA showed a main effect of condition, ($F(1.98, 39.5) = 65.5, p < 10^{-6}$). Post-hoc comparisons using Tukey tests revealed that the significant differences were between all three conditions (distinct endorsed: 96.5%, ambiguous endorsed: 80.7%, ambiguous disputed: 71.8%), (ambiguous endorsed vs ambiguous disputed: $p < 10^{-3}$; ambiguous endorsed and ambiguous disputed vs distinct endorsed: $p < 10^{-4}$), with the lowest mean confidence rate for ambiguous disputed.

Finally, an ANOVA for repeated measures was carried out on the percentage fluctuation between initial and post-feedback confidence ratings. This analysis revealed a main effect of condition, ($F(1.27, 25.5) = 13.06; p < 10^{-5}$). Post-hoc comparison using Tukey tests revealed a significantly increase in confidence rate from initial to post-feedback probes after ambiguous endorsed probes (+10.14%) compared to distinct endorsed (+1.4%) and to ambiguous disputed probes (-2.3%).

In summary, the behavioural results showed that most participants considered the social feedback to be credible, adjusting their subjective confidence ratings accordingly. The level of confidence was higher for distinct probes compared to ambiguous ones and higher for ambiguous endorsed probes compared to ambiguous disputed probes. Although this pattern was similar for both groups, socially anxious individuals showed a higher tendency to increase their confidence rates after endorsed social cues compared to controls, as well as to decrease their confidence ratings after disputed social feedback in comparison to controls.

3.3.3.2. ELECTROPHYSIOLOGICAL RESULTS

Initial stimulus presentation

Posterior P1 amplitude. The repeated measures ANOVA showed a significant main effect of group ($F(1, 20) = 4.5, p < .05$), of condition ($F(1, 20) = 13.9, p < .10^{-3}$), and an interaction between condition and laterality, ($F(1.9, 39.8) = 4.7, p < .05$). The P1 peak amplitude was significantly greater for the control group ($7.4 \pm 2.6 \mu V$) than for the social anxious group ($5.2 \pm 2.8 \mu V$). For the main effect of condition, the P1 was significantly larger for the initial ambiguous probes ($6.85 \pm 2.8 \mu V$), compared to the presentation of initial distinct probes ($5.9 \pm 2.9 \mu V$) (Fig. 23). For the interaction, post-hoc comparisons using Tukey tests revealed larger P1 amplitudes for ambiguous probes compared to distinct ones over the midline scalp (ambiguous: $7.3 \mu V$; distinct: $5.9 \mu V$), compared to the right (ambiguous: $6.3 \mu V$; distinct: $5.6 \mu V$), and left (ambiguous: $6.7 \mu V$; distinct: $5.8 \mu V$) ($p < .10^{-4}$) hemisphere leads. However, there were no significant differences in laterality for distinct probes.

Anterior N1 amplitude. The ANOVA performed on N1 peak amplitudes revealed a main effect of group, ($F(1, 20) = 7.6, p < .05$), and laterality, ($F(1.8, 36.5) = 3.3, p < .05$). The N1 peak amplitudes were significantly more negative for the control group ($-3.43 \pm 0.8 \mu V$) than

for the social anxious group ($-2.34 \pm 1.1 \mu\text{V}$) (Fig. 23). For the main effect of laterality, N1 was found to be significantly larger over midline hemisphere leads ($-2.96 \mu\text{V}$) compared to left hemisphere leads ($-2.77 \mu\text{V}$) ($p < .05$).

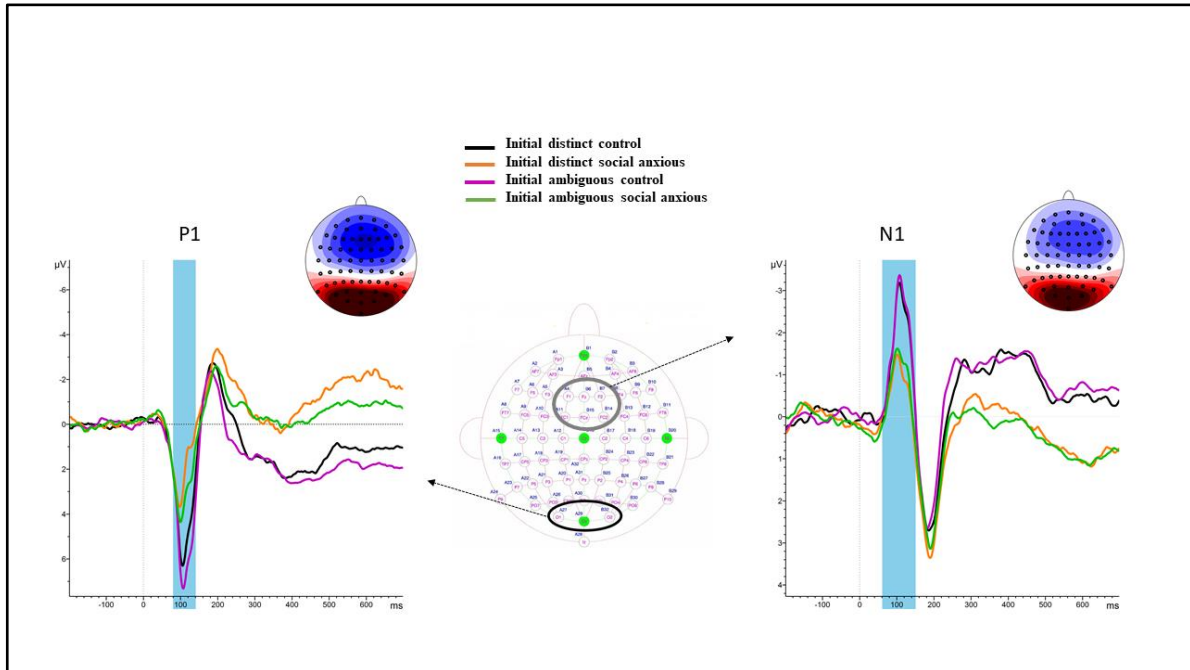


Figure 23. ERPs for ambiguous and distinct probes presented before social feedback. Pooled ERP traces are shown across electrodes used for the computation of the posterior P1 (right) and anterior N1 (left), along with collapsed topographical voltage map illustrating the posterior P1 and anterior N1 for the two conditions of ambiguity and for the two groups (control vs social anxious). Central inset shows scalp viewed from above (frontal leads on top, right leads on the right), with electrodes used for P1 and N1 computation circled in black and grey, respectively.

Second (post-feedback) stimulus presentation

Posterior P1 amplitude. The ANOVA performed on P1 peak amplitudes post-feedback probes revealed significant main effects of group, ($F(1, 20) = 6.6, p < .05$), and condition, ($F(2, 40) = 17.8, p < 10^{-6}$). P1 amplitudes were significantly larger for the control group ($7.7 \pm 2.3 \mu\text{V}$) than for the social anxious group ($4.9 \pm 3.2 \mu\text{V}$) for all three conditions (distinct endorsed, ambiguous endorsed and ambiguous disputed). For the main effect of condition, post-hoc

comparisons using Tukey tests revealed a larger P1 for ambiguous conditions (ambiguous endorsed: $6.6 \pm 3.07 \mu\text{V}$; ambiguous disputed: $6.9 \pm 3.2 \mu\text{V}$) compared to distinct endorsed ($5.7 \pm 2.9 \mu\text{V}$) ($p < 10^{-4}$) (Fig. 24).

Anterior N1 amplitude. The same repeated measures ANOVA for post-feedback probes carried for the 60 ms – 150 ms time window, showed main effects of group, ($F(1, 20) = 11.05$, $p < 10^{-3}$), condition, ($F(2, 40) = 3.6$, $p < .05$), and laterality, ($F(1.3, 26.3) = 7.2$, $p < 10^{-3}$). For the main effect of group, the anterior N1 was significantly more negative for the control group ($-3.9 \pm 1.2 \mu\text{V}$) than for the social anxious group ($-2.3 \pm 1.3 \mu\text{V}$). For the main effect of condition, post-hoc comparisons using Tukey tests revealed that the early anterior negativity peak amplitude was significantly larger for ambiguous disputed ($-3.4 \pm 1.6 \mu\text{V}$) compared to both endorsed conditions (ambiguous endorsed: $-3.01 \pm 1.3 \mu\text{V}$; distinct endorsed: $-3.03 \pm 1.4 \mu\text{V}$) ($p < .05$) (Fig. 24). Additionally, the mean peak N1 amplitudes were significantly larger over midline hemisphere leads ($-3.23 \mu\text{V}$) compared to left ones ($-2.94 \mu\text{V}$) ($p < 10^{-3}$).

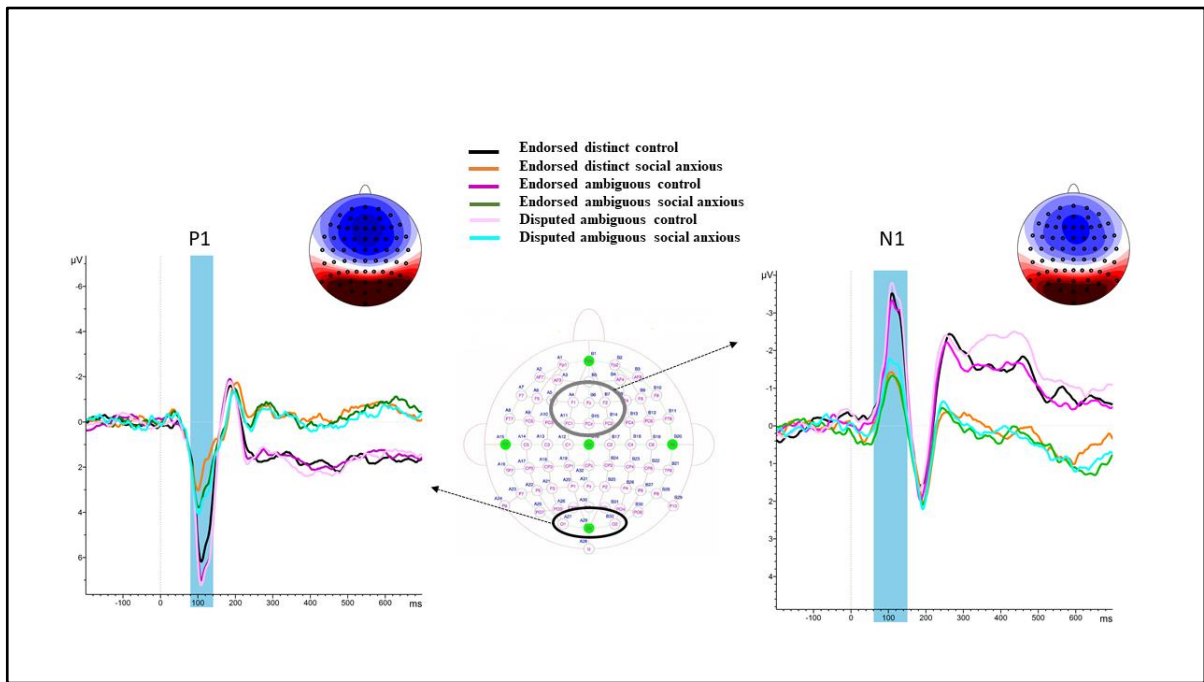


Figure 24: ERPs for stimuli presented after social feedback. Pooled ERP traces are shown across electrodes used for the computation of the posterior P1 (left) and anterior N1 (right), along with collapsed topographical voltage map illustrating the posterior P1 and anterior N1 for the three conditions (distinct endorsed, ambiguous endorsed, ambiguous disputed) and for the two groups (control vs social anxious). Central inset shows scalp viewed from above (frontal leads on top, right leads on the right), with electrodes used for P1 and N1 computation circled in black and grey, respectively.

Social feedback presentation.

Posterior P1 amplitude. The ANOVA carried out on the occipital P1 time-locked to the faces (social cues) in the 60-130 ms time window, revealed a main effect of laterality, ($F(2, 40) = 7.3, p < 10^{-3}$). Post-hoc comparisons using Tukey tests showed that P1 peak amplitudes were significantly larger over the right (8.14 μV), and left (7.9 μV) hemisphere leads compared to midline ones (5.83 μV) (Fig. 25).

N170 amplitude and latency. The 2 (group: control/social anxious) x 3 (condition: ambiguous endorsed/ distinct endorsed/ ambiguous disputed) x 2 (laterality: left/right) ANOVA performed on the N170 peak amplitudes in the 120-180 ms time window, revealed main

effects of condition, ($F(1.5, 29.3) = 6.3, p < .05$), laterality, ($F(1, 20) = 6.6, p < .05$), and an interaction between condition, laterality and group, ($F(1.9, 37.7) = 3.4, p < .05$). Post-hoc comparisons showed that N170 amplitudes were significantly larger for both ambiguous conditions (ambiguous endorsed: $-5.6 \pm 5.6 \mu\text{V}$; ambiguous disputed: $-5.9 \pm 5.7 \mu\text{V}$) compared to distinct endorsed ($-4.7 \pm 5.5 \mu\text{V}$) (ambiguous endorsed vs distinct endorsed: $p < .05$) (ambiguous disputed vs distinct endorsed: $p < 10^{-3}$) (Fig. 25). The N170 amplitude was significantly larger over the right hemisphere ($-6.6 \mu\text{V}$) than over the left one ($-4.3 \mu\text{V}$). Whereas these differences in laterality were observed for the three conditions in the control group, they were absent in the ambiguous endorsed condition for the social anxious group.

Interestingly, the ANOVA performed on the N170 latency also revealed a main effect of condition, ($F(1.3, 25.5) = 11.2, p < 10^{-3}$). Post-hoc comparison showed a significantly earlier N170 for both endorsed conditions (ambiguous endorsed: $147.8 \pm 11.3 \text{ ms}$, distinct endorsed: $147.7 \pm 10.7 \text{ ms}$) compared to the disputed one ($151.9 \pm 14.01 \text{ ms}$), thus discriminating disagreement from agreement ($p < 10^{-4}$) (Fig.25).

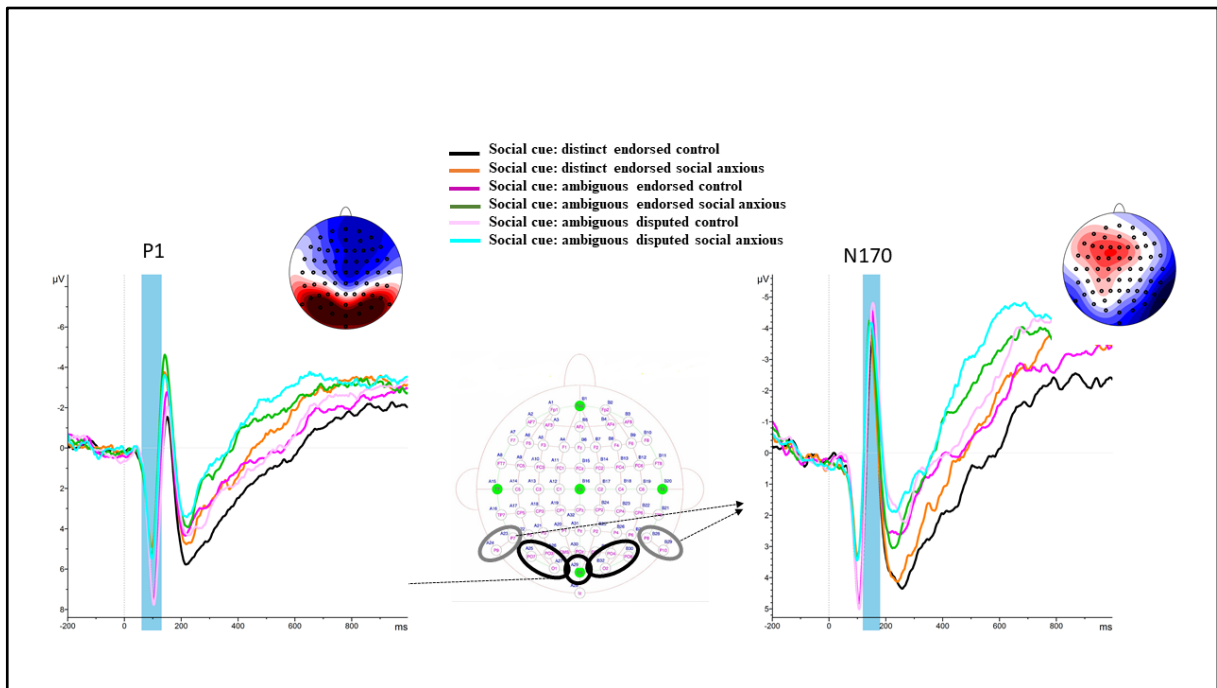


Figure 25: ERPs for social feedback. ERPs for endorsing cues post-ambiguous and post-distinct probes and for disputed cues post-ambiguous probes compared to an endorsing cue post-distinct probes Pooled ERP traces are shown across electrodes used for the computation of the posterior P1 (left) and N170 (right), along with collapsed topographical voltage map illustrating the posterior P1 and N170 for the three conditions and for the two groups (control vs social anxious). Central inset shows scalp viewed from above (frontal leads on top, right leads on the right), with electrodes used for P1 and N170 computation circled in black and grey, respectively.

3.3.4. DISCUSSION

The purpose of the present study was to explore the effect of perceptual uncertainty and social influence on early attentional processes in a socially anxious population compared to healthy controls. In particular, the focus was on the neural responses to ambiguous stimuli other than face expressions.

Behaviourally, and as expected, results showed that all participants, when faced with ambiguous stimuli, revised their judgements more often following social disagreement than following social endorsement. Importantly, the number of revisions after disputing feedback

was higher in the social anxious group, confirming the stronger influence of disputing social feedback on social anxious individuals. Additionally, all participants presented lower confidence ratings for initial ambiguous probes compared to initial distinct probes. After the social feedback, mean confidence ratings were lower for ambiguous disputed probes. However, socially anxious individuals showed a tendency to increase their confidence ratings compared to controls when the social feedback endorsed their response, and to further decrease their subjective confidence level after disputed social feedback in comparison to controls, suggesting that social anxious subjects were more sensitive to social approval than healthy subjects. The behavioural results indicate increased uncertainty in socially anxious subjects (e.g. Harrewijn, Van der Mlen, Van Vliet, Tissier & Westenberg, 2018) and are in line with cognitive-behavioural studies (e.g. Cisler & Koster, 2010) showing that socially anxious individuals fear social rejection and are less tolerant to uncertainty than healthy subjects (Rapee & Heimberg, 1997; Rossignol et al., 2013; Nelson et al., 2015).

At the electrophysiological level, ERPs measured in response to ambiguous probes revealed enhanced P1 for both groups, starting at around 80 ms. The P1 was larger for initial ambiguous as well as for post-feedback ambiguous probes, compared to distinct probes. This increase in P1 for ambiguous stimuli is in line with findings demonstrating the influence of uncertainty produced by perceptual instability of the visual probes (e.g. Dyson, 2011; Klink et al., 2012; Reuman, Jacoby, Fabricant, Herring & Abramowitz, 2015) and corroborates the behavioural data indicating lower confidence rates for ambiguous probes compared to distinct ones. The more ambiguous the visual information, the stronger the brain will respond to it (Zeki, 2006). Most importantly, even though the pattern was the same for both groups, P1 amplitudes were enhanced for controls compared to socially anxious individuals suggesting less sensory facilitation among the latter. This result contradicts most of the studies exploring ERP in the social anxious population which indicate an enhanced sensory facilitation in socially anxious

individuals as a manifestation of hypervigilance and excessive attention to potential threatening information (for a review see: Harrewijn et al., 2018). It could be argued that probes, even when ambiguous, are less threatening than facial expressions. Nevertheless, this hypothesis does not explain why controls showed an increased P1. Additionally, Peschard et al. (2013), demonstrated an increased P1 in socially anxious subjects in response to coloured rectangles in a modified Stroop task, suggesting that increased P1 amplitudes may reflect a more generic response rather than an early allocation of attention to faces. An alternate interpretation for the decreased P1 for all conditions in the social anxious group could be the anticipation of the social task creating excessive internal attention and self-focus, thus, impairing processing of external stimuli (Clark & Wells, 1995; Deiters et al., 2013; Sluis et al., 2017). In the present study, all participants were led to believe they would be giving an oral description/presentation at the end of the experiment in front of three psychologists. Indeed, it has been noted that the induction of speech anxiety in socially anxious subjects creates greater self-focus and task interference (Judah, Grant & Carlisle, 2016). For example, Mellings & Alden (2000) observed that high socially anxious individuals recalled less environmental features than non-anxious individuals. Thus, these results are in line with Clark & Wells 's (1995) cognitive model for social anxiety which predicts internally oriented attentional resources accompanied by attentional reduction to external social threats.

The anterior N1 response before social feedback did also distinguish socially anxious subjects from control ones. Here again, the N1 was reduced for the former, suggesting that the initial probes were less attended by socially anxious individuals compared to controls (Luck et al., 1990). After the social feedback, N1 amplitudes were enlarged for both groups for ambiguous probes following disputed feedback, suggesting an endogenous attentional role of the N1 when a relevant discrimination is necessary to perform the task (Hopfinger & West, 2006). This was supported by the current study's findings, which showed an enhanced N1 for ambiguous

probes following expressions of disgust compared to expressions of happiness in both groups of subjects. Moreover, findings in this study evidenced a decrease in N1 amplitudes for the three conditions among socially anxious individuals compared to controls, thus supporting [Clark & Wells \(1995\)](#) cognitive model which proposes a reduction in attention to external stimuli due to excessive self-focusing in the socially anxious population. Only one recent study ([Harrewijn et al., 2018](#)), using a social judgment paradigm, observed an increased frontal N1 after disputed feedback and interpreted this result as a general pessimism bias in socially anxious individuals and a possible candidate endophenotype of SAD. The current results corroborate N1's sensitivity to negative feedback but not its specificity to SAD as healthy subjects also showed defensive motivation when their response did not match the majority.

Although the aim of the current study was to investigate the effects of social anxiety on external non-social ambiguous stimuli within a social context, we also looked at the neural responses to social feedback, as ERPs have been widely used to examine processing of emotional faces in social anxiety. P1 amplitudes were not modulated by feedback valence. The effect was observed later when examining the face sensitivity N170. Findings showed greater N170 amplitudes for faces following ambiguous probes compared to distinct ones but earlier N170 response to both endorsed conditions (ambiguous and distinct endorsed) compared to the disputed condition. Nevertheless, these effects were similar for both groups of subjects. Thus, the findings are in line with most studies on socially anxious individuals, showing no influence of social anxiety on N170 amplitudes ([for a review, see Harrewijn et al., 2017](#)). Instead, these results suggest a bias in the general population towards the encoding of faces expressing agreement. As a consequence, it seems reasonable to conclude that the structural analysis of faces in socially anxious subjects is not altered ([e.g. Peschard et al., 2013](#)).

The present study had some limitations that should be taken into consideration. First, the sample of socially anxious individuals was mainly constituted by female subjects. Thus, future studies should investigate these effects of anticipation on external stimuli in a male population. Second, the number of participants per group was low, thus reducing the statistical power of certain effects. Third, in this study, all participants were told they would be doing a speech at the end of the experiment. It would be interesting to add two groups, socially anxious and non-socially anxious without inducing speech anxiety. Additionally, future studies examining later components of executive control may help to better understand individual differences in socially anxious individuals, as mechanism of inhibition, mental flexibility and emotional regulation, interact with threat anticipation and with visual processing of external cues.

From a clinical point of view, this investigation may provide further insight into the mechanisms and consequences of anticipatory processing in social anxiety and how they interact with impaired attention to external stimuli within a social context. Specifically, rather than focusing treatments on behavioural exposure of the anxiogenic social situation, treatments may want to consider the effects of imagery and interpretation of future social situations. Thus, clinical interventions should target negative imagery in anticipation of social events as well as unpleasant memory representations of social interactions and concentrate on imagery with rescripting techniques (Arntz, 2012) that focus on changing these unpleasant memories.

3.3.5. CONCLUSION

In conclusion, the present study provides behaviour and electrophysiological evidence for the role of anticipation of social situations among socially anxious individuals manifested by lower confidence ratings, higher number of revisions and a reduction in occipital and frontal networks which are thought to mediate early attention to external stimuli due to excessive self-

focusing and self-consciousness. Moreover, findings provide further insight into the clinical implications of cognitive- behavioural therapy among socially anxious individuals.

4. GENERAL CONCLUSION

The purpose of the experimental part of this thesis was to identify neural responses of ambiguous stimuli processing and its modulation by social feedback (agreement/happy faces vs disagreement/disgust faces). For this, we recorded EEG while examining the effects of social influence while participants performed a visual discrimination task. The ambiguity of the stimuli was used to induce uncertainty whereas distinct stimuli were used to induce certainty.

In the first study, we focalised on early visual responses by analysing two ERP components, the P1 and the N1 over posterior sites. Behaviourally, the number of revised judgments (after social feedback) was significantly higher for ambiguous stimuli compared to distinct ones. Moreover, when stimuli were ambiguous, the number of revisions was significantly greater following disputed social feedback compared to endorsed social feedback. Electrophysiologically, results indicated an earlier P1 and N1 for ambiguous probes compared to distinct probes, before and after social feedback, suggesting heightened sensory processing and selective attention to stimuli inducing uncertainty. The P1 amplitude was also enhanced for ambiguous probes compared to distinct ones, although the effect was marginally significant. More specifically, the P1 was enhanced for disputed ambiguous probes compared to initial ambiguous probes, even though the stimuli were identical. Interestingly, this effect was only observed on the right hemisphere leads for ambiguous endorsed probes and was not found for distinct stimuli. These findings suggest that social feedback modulates early perceptual processes in visual extrastriate regions corroborating the fact that top-down processes interact with bottom-up processes, when stimuli become relevant to the task (e.g. [Hopfinger & West, 2006](#); [Luck et al., 1990](#); [Hermann & Knight, 2001](#)).

In the second study, we focalised on later cognitive processes by exploring three ERP components, the posterior P2, the anterior N2 and the occipito-parietal P3. Since the P3 topography was not found for the post-cue probes, we analysed two-time windows of the late

posterior positivity (LPP) following social feedback. Behaviourally, we looked at mean subjective confidence ratings before and after social feedback. Results showed higher certainty levels for distinct probes and lower confidence ratings for ambiguous disputed probes compared to both endorsed conditions, confirming the effect of the social manipulation (e.g. Cialdini & Goldstein, 2004; McGarty, Turner, Oakes & Haslam, 1993). From an electrophysiological point of view, before social feedback, enhanced P2/N2 amplitudes were observed for ambiguous probes compared to distinct probes, whereas the P3 amplitude was larger for initial distinct stimuli compared to initial ambiguous stimuli. These findings corroborate that uncertainty modulates selective attention starting at 200 ms (e.g. Lin, Xiang, Liang, Zhao, Yin & Jin, 2017), whereas the enhanced P3 amplitude for distinct probes suggests that, at later stages of processing, the feeling of certainty induced by the accumulation of sensory evidence increases participants' allocation of attentional resources (e.g. Kelly & O'Connell, 2013), making the P3 component a likely correlate of metacognition (e.g. Desender et al., 2016). The conscious effect of the social feedback was found for the LPP response at around 400 ms, when disputed ambiguous probes triggered a larger sustained positivity, in line with the emotional appraisal of the face expressions (e.g. Ito & al., 1998).

In the last study, we were interested in replicating the effects of ambiguity and social conflict on early perceptual processes in healthy and socially anxious individuals (e.g. Peschard et al., 2013). For this, we used the same experimental paradigm but we added a stressor (speech induction) in order to explore the effects of anticipation in a socially anxious population compared to non-socially anxious participants. Again, behavioural results indicated that confidence ratings were lower for ambiguous probes and even lower when the social cue was in disagreement. This was observed for both groups, although the pattern was enhanced in socially anxious individuals, as expected. Interestingly, confidence ratings for ambiguous probes following agreement were increased in the social anxious group compared to healthy subjects, suggesting higher sensitivity

to agreement in uncertain situation across the former. Electrophysiologically, findings were replicated for the early visual P1 component in both groups. Indeed, the P1 was enhanced for ambiguous probes compared to distinct ones, before and after the social feedback and for both groups. However, socially anxious individuals showed a decreased P1 for all conditions suggesting that anticipation of the social context decreased sensory facilitation of stimuli in the social environment. The effect of the social feedback was also replicated with the anterior N1, as this component was enhanced for ambiguous disputed probes in both groups. The N1 pattern was again diminished for all conditions in socially anxious individuals, thus supporting [Clarks & Wells \(1995\)](#) cognitive model for social anxiety, which posits a reduction in attention to external stimuli due to excessive self-focusing. Finally, we looked at the face-sensitivity N170 component, as most studies investigating socially anxious attentional biases focalised on the response locked to faces. In line, with these studies, we did not find any social anxious modulation for this ERP, corroborating that the early structural analysis of faces is not altered in this disorder (e.g. [Harrewijn et al., 2017](#)).

Although the three studies demonstrate that social feedback had an influence on early perception, the question remains whether this social feedback made up of emotional facial expressions indicating agreement (expressions of happiness) or disagreement (expressions of disgust), can truly be called social influence. It could be that the emotional valence of the faces modulated perceptual processes instead of the social group pressure itself. However, several important aspects reduce the probability of this interpretation. First, participants were told that the feedback was made up of responses of the majority of a sample population of women and men tested beforehand. Second, both probes in each trial, before and after feedback, were identical. Third, participants were asked at the end of the procedure if they believed in the social feedback. Fourth, effects of emotion arise later on, at around 400ms and fifth, behavioural results showed that participants altered their response and confidence levels following disputed feedback. Thus, we

can conclude that the social cue was experienced by participants as a social pressure from a social majority. Nevertheless, it would be interesting in a future study to add a condition where social feedback is given by a robot in agreement or disagreement.

Taken together, the behavioural results in the three studies showed that participants were challenged in their judgements when facing uncertainty induced by stimulus ambiguity and were further influenced when the social feedback was in disagreement. The decreased average confidence ratings for ambiguous stimuli and disputed social feedback indicated that uncertainty and social conflict had a strong effect on their subjective feeling of certainty, and this effect was enhanced in socially anxious individuals compared to healthy subjects. From an electrophysiological point of view, the findings demonstrate that endogenous attention can have a top-down effect on early automatic exogenous attention and on early visual perception when stimuli are relevant to the task and when social pressure provokes uncertainty. Moreover, human beings seem to be sensitive to the amount of stimulus sensory evidence increasing the feeling of accuracy allowing metacognitive experiences to take place. These effects of uncertainty and social influence are enhanced in socially anxious individuals, demonstrating their vulnerability to potentially threatening information in the environment.

Findings contribute to the understanding of human attitudes and neural correlates in conflict social situations by demonstrating how early unconscious perception and controlled conscious processes unfold in our daily life as we are constantly facing uncertainty and social pressure.

Moreover, results across socially anxious subjects have clinical implications in terms of therapeutic work, demonstrating the importance of anticipation of the social context in this populations.

5. REFERENCES

- Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology*, 12(2), 169-177.
- Amoruso, L., Gelormini, C., Aboitiz, F. A., González, A., Manes, F., Cardona, J., & Ibanez, A. (2013). N400 ERPs for actions: building meaning in context. *Frontiers in Human Neuroscience*, 7, 57.
- Amir, N., Elias, J., Klumpp, H., & Przeworski, A. (2003). Attentional bias to threat in social phobia: Facilitated processing of threat or difficulty disengaging attention from threat?. *Behaviour Research and Therapy*, 41(11), 1325-1335.
- Arbuckle, T. Y., & Cuddy, L. L. (1969). Discrimination of item strength at time of presentation. *Journal of Experimental Psychology*, 81(1), 126-131.
- Arntz, A. (2012). Imagery rescripting as a therapeutic technique: Review of clinical trials, basic studies, and research agenda. *Journal of Experimental Psychopathology*, 3(2), 189-208.
- Asch, S.E. (1951). Effects of group pressure upon the modification and distortion of judgments. In H. Guetzkow (Ed.), *Groups, leadership and men; research in human relations* (pp. 177-190). Oxford, England: Carnegie Press.
- Ashley, V., Vuilleumier, P., & Swick, D. (2004). Time course and specificity of event-related potentials to emotional expressions. *Neuroreport*, 15(1), 211-216.
- Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, 55(5), 485-496.
- Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & Van Ijzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychological Bulletin*, 133(1), 1-24.
- Batty, M., & Taylor, M. J. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research*, 17(3), 613-620.
- Bartra, O., McGuire, J. T., & Kable, J. W. (2013). The valuation system: a coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value. *Neuroimage*, 76, 412-427.

- Beard, C., & Amir, N. (2008). A multi-session interpretation modification program: Changes in interpretation and social anxiety symptoms. *Behaviour Research and Therapy*, *46*(10), 1135-1141.
- Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*, *8*(6), 551-565.
- Berger, H. (1929). Über das Elektrenkephalogramm des Menschen. *European Archives of Psychiatry and Clinical Neuroscience*, *87*(1), 527-570.
- Berggren, N., & Derakshan, N. (2013). Attentional control deficits in trait anxiety: Why you see them and why you don't. *Biological Psychology*, *92*(3), 440-446.
- Berns, G., Capra, C. M., Moore, S., & Noussair, C. (2009). Neural mechanisms of social influence in consumer decisions. *Organizational Behavior and Human Decision Processes*, *110*(2), 152-159.
- Berns, G. S., Chappelow, J., Zink, C. F., Pagnoni, G., Martin-Skurski, M. E., & Richards, J. (2005). Neurobiological correlates of social conformity and independence during mental rotation. *Biological Psychiatry*, *58*(3), 245-253.
- Bisley, J. W., & Goldberg, M. E. (2003). Neuronal activity in the lateral intraparietal area and spatial attention. *Science*, *299*(5603), 81-86.
- Boll, S., Bartholomaeus, M., Peter, U., Lupke, U., & Gamer, M. (2016). Attentional mechanisms of social perception are biased in social phobia. *Journal of Anxiety Disorders*, *40*, 83-93.
- Bötzel, K., Schulze, S., & Stodieck, S. R. (1995). Scalp topography and analysis of intracranial sources of face-evoked potentials. *Experimental Brain Research*, *104*(1), 135-143.
- Breen, N., Caine, D., & Coltheart, M. (2000). Models of face recognition and delusional misidentification: A critical review. *Cognitive Neuropsychology*, *17*(1-3), 55-71.
- Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(3), 305-327.
- Bublitzky, F., Fleisch, T., Stockburger, J., Schmälzle, R., & Schupp, H. T. (2010). The interaction of anticipatory anxiety and emotional picture processing: An event-related brain potential study. *Psychophysiology*, *47*, 687-696.

- Bublitzky, F., & Schupp, H. T. (2012). Pictures cueing threat: Brain dynamics in viewing explicitly instructed danger cues. *Social Cognitive and Affective Neuroscience*, 7, 611-622.
- Calder, A. J., Keane, J., Manes, F., Antoun, N., & Young, A. W. (2000). Impaired recognition and experience of disgust following brain injury. *Nature Neuroscience*, 3(11), 1077-1078
- Campbell-Meiklejohn, D. K., Bach, D. R., Roepstorff, A., Dolan, R. J., & Frith, C. D. (2010). How the opinion of others affects our valuation of objects. *Current Biology*, 20(13), 1165-1170.
- Carretié, L., Hinojosa, J. A., Martín-Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: neural correlates. *Human Brain Mapping*, 22(4), 290-299.
- Chen, N. T. M., Thomas, L. M., Clarke, P. J. F., Hickie, I. B., & Guastella, A. J. (2015). Hyperscanning and avoidance in social anxiety disorder: the visual scanpath during public speaking. *Psychiatry Research*, 225(3), 667-672.
- Chen, J., Wu, Y., Tong, G., Guan, X., & Zhou, X. (2012). ERP correlates of social conformity in a line judgment task. *BMC Neuroscience*, 13-43.
- Cialdini, R. B., & Goldstein, N. J. (2004). Social influence: Compliance and conformity. *Annual Review of Psychology*, 55, 591-621.
- Cisler, J. M., & Koster, E. H. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, 30(2), 203-216.
- Clark, D. M., & Wells, A. (1995). A cognitive model of social phobia. In R. Heimberg, M. Liebowitz, D. A. Hope, & F. R. Schneier (Eds.), *Social Phobia: Diagnosis, assessment and treatment* (pp. 69-93). New York: Guilford Press.
- Constans, J. I., Penn, D. L., Ihen, G. H., & Hope, D. A. (1999). Interpretive biases for ambiguous stimuli in social anxiety. *Behaviour Research and Therapy*, 37(7), 643-651.
- Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience*, 3(3), 292-297.
- 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(2), 95-111.

- Daffner, K. R., Scinto, L. F., Calvo, V., Faust, R., Mesulam, M. M., West, W. C., & Holcomb, P. J. (2000). The influence of stimulus deviance on electrophysiologic and behavioral responses to novel events. *Journal of Cognitive Neuroscience*, *12*(3), 393-406.
- Damasio, A. R., Damasio, H., & Van Hoesen, G. W. (1982). Prosopagnosia: anatomic basis and behavioral mechanisms. *Neurology*, *32*(4), 331-331.
- Dehaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science*, *5*(5), 303-305.
- Deiters, D. D., Stevens, S., Hermann, C., & Gerlach, A. L. (2013). Internal and external attention in speech anxiety. *Journal of Behavior Therapy and Experimental Psychiatry*, *44*(2), 143-149.
- Del Cul, A., Dehaene, S., Reyes, P., Bravo, E., & Slachevsky, A. (2009). Causal role of prefrontal cortex in the threshold for access to consciousness. *Brain*, *132*(9), 2531-2540.
- Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. *European Psychologist*, *14*(2), 168-176.
- Desender, K., Van Opstal, F., Hughes, G., & Van den Bussche, E. (2016). The temporal dynamics of metacognition: Dissociating task-related activity from later metacognitive processes. *Neuropsychologia*, *82*, 54-64.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*(1), 193-222.
- Dieterich, R., Endrass, T., & Kathmann, N. (2016). Uncertainty is associated with increased selective attention and sustained stimulus processing. *Cognitive, Affective, & Behavioral Neuroscience*, *16*(3), 447-456.
- Di Russo, F., Martinez, A., Sereno, M.I., Pitzalis, S., & Hillyard, S.A. (2002). Cortical sources of the early components of the visual evoked potential. *Human Brain Mapping*, *15*(2), 95-111.
- Dolcos, F., & Cabeza, R. (2002). Event-related potentials of emotional memory: encoding pleasant, unpleasant, and neutral pictures. *Cognitive, Affective, & Behavioral Neuroscience*, *2*(3), 252-263.
- Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, *11*, 357-374.

- Dyson, B. (2011). The advantage of ambiguity? Enhanced neural responses to multi-stable percepts correlate with the degree of perceived instability. *Frontiers in Human Neuroscience*, 5(73), 1-12.
- Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology*, 111(4), 694-705.
- El Zein, M., Gamond, L., Conty, L., & Grèzes, J. (2015). Selective attention effects on early integration of social signals: same timing, modulated neural sources. *NeuroImage*, 106, 182-188.
- Engell, A. D., & Haxby, J. V. (2007). Facial expression and gaze-direction in human superior temporal sulcus. *Neuropsychologia*, 45(14), 3234-3241.
- Eskenazi, T., Montalan, B., Jacquot, A., Proust, J., Grèzes, J., & Conty, L. (2016). Social influence on metacognitive evaluations: The power of nonverbal cues. *The Quarterly Journal of Experimental Psychology*, 69(11), 2233-2247.
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion*, 7(2), 336-353.
- Eysenck, M. W., & Derakshan, N. (2011). New perspectives in attentional control theory. *Personality and Individual Differences*, 50(7), 955-960.
- Felleman, D. J., & Van Essen, D. E. (1991). Distributed hierarchical processing in the primate cerebral cortex. *Cerebral Cortex*, 1(1), 1-47.
- Felmingham, K. L., Stewart, L. F., Kemp, A. H., & Carr, A. R. (2016). The impact of high trait social anxiety on neural processing of facial emotion expressions in females. *Biological Psychology*, 117, 179-186.
- Fiser, J., Berkes, P., Orbán, G., & Lengyel, M. (2010). Statistically optimal perception and learning: from behavior to neural representations. *Trends in Cognitive Sciences*, 14(3), 119-130.
- Fleming, S. M., & Dolan, R. J. (2012). The neural basis of metacognitive ability. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 367(1594), 1338-1349.
- Fleming, S. M., Dolan, R. J., & Frith, C. D. (2012). Metacognition: computation, biology and function. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 2280-1286.

- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 1030-1044.
- Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*(1), 152-170.
- Frith, C. D. (2012). The role of metacognition in human social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1599), 2213-2223.
- Furmark, T., Tillfors, M., Everz, P. O., Marteinsdottir, I., Gefvert, O., & Fredrikson, M. (1999). Social phobia in the general population: prevalence and sociodemographic profile. *Social Psychiatry and Psychiatric Epidemiology*, *34*(8), 416-424.
- Galvan, A., Hare, T. A., Davidson, M., Spicer, J., Glover, G., & Casey, B. J. (2005). The role of ventral frontostriatal circuitry in reward-based learning in humans. *Journal of Neuroscience*, *25*(38), 8650-8656.
- Gamble, A. L., & Rapee, R. M. (2010). The time-course of attention to emotional faces in social phobia. *Journal of Behavior Therapy and Experimental Psychiatry*, *41*(1), 39-44.
- Garvert, M. M., Friston, K. J., Dolan, R. J., & Garrido, M. I. (2014). Subcortical amygdala pathways enable rapid face processing. *Neuroimage*, *102*, 309-316.
- Gole, M., Schäfer, A., & Schienle, A. (2012). Event-related potentials during exposure to aversion and its anticipation: the moderating effect of intolerance of uncertainty. *Neuroscience Letters*, *507*(2), 112-117.
- Goodwin, A. H., & Sher, K. J. (1992). Deficits in set-shifting ability in nonclinical compulsive checkers. *Journal of Psychopathology and Behavioral Assessment*, *14*(1), 81-92.
- Gosling, A., & Eimer, M. (2011). An event-related brain potential study of explicit face recognition. *Neuropsychologia*, *49*(9), 2736-2745.
- Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 468-484.
- Groh-Bordin, C., Busch, N.A., Herrmann, C.S., & Zimmer, H.D. (2007). Event-related potential repetition effects at encoding predict memory performance at test. *Neuroreport*, *18*(18), 1905-1909.

- Gruendler, T. O., Ullsperger, M., & Huster, R. J. (2011). Event-related potential correlates of performance-monitoring in a lateralized time-estimation task. *PloS one*, 6(10). Doi.org/10.1371/journal.pone.0025591.
- Hajcak, G., Holroyd, C. B., Moser, J. S., & Simons, R. F. (2005). Brain potentials associated with expected and unexpected good and bad outcomes. *Psychophysiology*, 42(2), 161-170.
- Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-related potentials, emotion, and emotion regulation: an integrative review. *Developmental Neuropsychology*, 35(2), 129-155.
- Harrewijn, A., Schmidt, L. A., Westenberg, P. M., Tang, A., & van der Molen, M. J. (2017). Electrocortical measures of information processing biases in social anxiety disorder: A review. *Biological Psychology*, 129, 324-348.
- Harrewijn, A., van der Molen, M. J., van Vliet, I. M., Tissier, R. L., & Westenberg, P. M. (2018). Behavioral and EEG responses to social evaluation: A two-generation family study on social anxiety. *NeuroImage: Clinical*, 17, 549-562.
- Hart, J. T. (1965). Memory and the feeling-of-knowing experience. *Journal of Educational Psychology*, 56(4), 208-216.
- Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, 4(6), 223-233.
- Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2002). Human neural systems for face recognition and social communication. *Biological Psychiatry*, 51(1), 59-67.
- Henson, R.N.A., & Rugg M.D. (2003). Neural response suppression, haemodynamic repetition effects, and behavioural priming. *Neuropsychologia*, 41(3), 263-270.
- Herrmann, C. S., & Knight, R. T. (2001). Mechanisms of human attention: event-related potentials and oscillations. *Neuroscience & Biobehavioral Reviews*, 25(6), 465-476.
- Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, 95(3), 781-787.
- Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 353(1373), 1257-1270.

- Hoffman, E. A., & Haxby, J. V. (2000). Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature Neuroscience*, 3(1), 80-85.
- Holas, P., Krejtz, I., Cyprianska, M., & Nezlek, J. B. (2014). Orienting and maintenance of attention to threatening facial expressions in anxiety—An eye movement study. *Psychiatry Research*, 220(1-2), 362-369.
- Holmes, A., Vuilleumier, P., & Eimer, M. (2003). The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials. *Cognitive Brain Research*, 16(2), 174-184.
- 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), 679-709.
- Hopfinger, J. B., & Mangun, G. R. (1998). Reflexive attention modulates processing of visual stimuli in human extrastriate cortex. *Psychological Science*, 9(6), 441-447.
- Hopfinger, J. B., & West, V. M. (2006). Interactions between endogenous and exogenous attention on cortical visual processing. *NeuroImage*, 31(2), 774-789.
- Huang, Y. X., & Luo, Y. J. (2006). Temporal course of emotional negativity bias: an ERP study. *Neuroscience Letters*, 398(1-2), 91-96.
- Hubel, D. H., & Wiesel, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *The Journal of Physiology*, 160(1), 106-154.
- Humphreys, G. W., & Riddoch, M. J. (1987). The fractionation of visual agnosia. In G.W. Humphreys & M.J. Riddoch (Eds.). *Visual object processing: a cognitive neuropsychological approach* (p. 281-306). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc.
- Johannes, S., Münte, T. F., Heinze, H. J., & Mangun, G. R. (1995). Luminance and spatial attention effects on early visual processing. *Cognitive Brain Research*, 2(3), 189-205.
- Judah, M. R., Grant, D. M., & Carlisle, N. B. (2016). The effects of self-focus on attentional biases in social anxiety: An ERP study. *Cognitive, Affective, & Behavioral Neuroscience*, 16(3), 393-405.

- Ibáñez, A., Gleichgerrcht, E., Hurtado, E., González, R., Haye, A., & Manes, F. F. (2010). Early neural markers of implicit attitudes: N170 modulated by intergroup and evaluative contexts in IAT. *Frontiers in Human Neuroscience*, *4*(188), 1-14.
- Ishai, A. (2008). Let's face it: it's a cortical network. *Neuroimage*, *40*(2), 415-419.
- Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. *Psychophysiology*, *17*(3), 259-273.
- 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*(4), 887-900.
- Izuma, K., Matsumoto, M., Murayama, K., Samejima, K., Sadato, N., & Matsumoto, K. (2010). Neural correlates of cognitive dissonance and choice-induced preference change. *Proceedings of the National Academy of Sciences*, *107*(51), 22014-22019.
- Izuma, K. (2013). The neural basis of social influence and attitude change. *Current Opinion in Neurobiology*, *23*(3), 456-462.
- Johannes, S., Münte, T. F., Heinze, H. J., & Mangun, G. R. (1995). Luminance and spatial attention effects on early visual processing. *Cognitive Brain Research*, *2*(3), 189-205.
- 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.
- Kim, B. R., Liss, A., Rao, M., Singer, Z., & Compton, R. J. (2012). Social deviance activates the brain's error-monitoring system. *Cognitive, Affective, & Behavioral Neuroscience*, *12*(1), 65-73.
- Klink, P. C., van Wezel, R. J. A., & van Ee, R. (2012). United we sense, divided we fail: context-driven perception of ambiguous visual stimuli. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1591), 932-941.
- Kolassa, I. T., & Miltner, W. H. (2006). Psychophysiological correlates of face processing in social phobia. *Brain Research*, *1118*(1), 130-141.
- Klucharev, V., Hytönen, K., Rijpkema, M., Smidts, A., & Fernández, G. (2009). Reinforcement learning signal predicts social conformity. *Neuron*, *61*(1), 140-151.

- Knutson, B., & Cooper, J. C. (2005). Functional magnetic resonance imaging of reward prediction. *Current Opinion in Neurology*, *18*(4), 411-417.
- Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*(3), 557-577.
- Kolb, B., & Whishaw, I. Q. (2009). *Fundamentals of Human Neuropsychology*. Macmillan.
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*(4427), 203-205.
- Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. *Science*, *197*(4305), 792-795.
- Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H., Hawk, S. T., & Van Knippenberg, A. D. (2010). Presentation and validation of the Radboud Faces Database. *Cognition and Emotion*, *24*(8), 1377-1388.
- Larson, M. J., Clayson, P. E., & Clawson, A. (2014). Making sense of all the conflict: a theoretical review and critique of conflict-related ERPs. *International Journal of Psychophysiology*, *93*(3), 283-297.
- LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, *23*(1), 155-184.
- Li, D., Yu, F., Ye, R., Chen, X., Xie, X., Zhu, C., & Wang, K. (2017). How does gaze direction affect facial processing in social anxiety? - An ERP study. *Psychiatry Research*, *251*, 155-161.
- Liebowitz, M. R. (1987). Social Phobia. *Mod Probl Pharmacopsychiatry*, *22*, 141-173.
- Lin, H., Xiang, J., Li, S., Liang, J., Zhao, D., Yin, D., & Jin, H. (2017). Cued uncertainty modulates later recognition of emotional pictures: An ERP study. *International Journal of Psychophysiology*, *116*, 68-76.
- Long, Y., Jiang, X., & Zhou, X. (2012). To believe or not to believe: trust choice modulates brain responses in outcome evaluation. *Neuroscience*, *200*, 50-58.
- Luck, S. J., Heinze, H. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index focused attention within bilateral stimulus arrays. II. Functional dissociation

of P1 and N1 components. *Electroencephalography and Clinical Neurophysiology*, 75(6), 528-542.

Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, 31(3), 291-308.

Luck, S.J., & Hillyard, S.A. (1995). The role of attention in feature detection and conjunction discrimination: An electrophysiological analysis. *International Journal of Neuroscience*, 80(1-4), 281-297.

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

Lysaker, P. H., Leonhardt, B. L., Pijnenborg, M., van Donkersgoed, R., de Jong, S., & Dimaggio, G. (2014). Metacognition in schizophrenia spectrum disorders: methods of assessment and associations with neurocognition, symptoms, cognitive style and function. *Isr J Psychiatry Relat Sci*, 51(1), 54-61.

MacLeod, C., & Donnellan, A. M. (1993). Individual differences in anxiety and the restriction of working memory capacity. *Personality and Individual Differences*, 15(2), 163-173.

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, 95(1), 15-20.

Mangun, G.R., & Hillyard, S.A. (1991). Modulations of sensory-evoked brain potentials indicated changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology Human Perception & Performance*, 17(4), 1057-1074.

Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*, Henry Holt and Co. Inc., New York, NY, 2(4.2).

Mars, R. B., Coles, M. G., Grol, M. J., Holroyd, C. B., Nieuwenhuis, S., Hulstijn, W., & Toni, I. (2005). Neural dynamics of error processing in medial frontal cortex. *Neuroimage*, 28(4), 1007-1013.

Mathews, A., & Mackintosh, B. (1998). A cognitive model of selective processing in anxiety. *Cognitive Therapy and Research*, 22(6), 539-560.

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, 95(1), 15-20.

- McCurdy, L.Y., Maniscalco, B., Metcalfe, J., Liu, K.Y., de Lange, F.P., & Lau, H. (2013). Anatomical Coupling between Distinct Metacognitive Systems for Memory and Visual Perception. *The Journal of Neuroscience*, *33*(5), 1897-1906.
- McGarty, C., Turner, J. C., Oakes, P. J., & Haslam, S. A. (1993). The creation of uncertainty in the influence process: The roles of stimulus information and disagreement with similar others. *European Journal of Social Psychology*, *23*(1), 17-38.
- Meadows, J. C. (1974). Disturbed perception of colours associated with localized cerebral lesions. *Brain*, *97*(1), 615-632.
- Mellings, T. M., & Alden, L. E. (2000). Cognitive processes in social anxiety: The effects of self-focus, rumination and anticipatory processing. *Behaviour Research and Therapy*, *38*(3), 243-257.
- Michalowski, J.M., Melzig, C.A., Weike, A.I., Stockburger, J., Schupp, H.T., & Hamm, A.O. (2009). Brain dynamics in spider-phobic individuals exposed to phobia-relevant and other emotional stimuli. *Emotion*, *9*(3), 306-315.
- Michalowski, J.M., Pané-Farré, C.A., Löw, A., & Hamm, A.O. (2015). Brain dynamics of visual attention during anticipation and encoding of threat- and safe-cues in spider-phobic individuals. *Social Cognitive and Affective Neuroscience*, *10*(9), 1177–1186.
- Michel, C. M., Murray, M. M., Lantz, G., Gonzalez, S., Spinelli, L., & de Peralta, R. G. (2004). EEG source imaging. *Clinical Neurophysiology*, *115*(10), 2195-2222.
- Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: two cortical pathways. *Trends in Neurosciences*, *6*, 414-417.
- Mogg, K., & Bradley, B. P. (1998). A cognitive-motivational analysis of anxiety. *Behaviour Research and Therapy*, *36*(9), 809-848.
- Morel, S., George, N., Foucher, A., Chammat, M., & Dubal, S. (2014). ERP evidence for an early emotional bias towards happy faces in trait anxiety. *Biological Psychology*, *99*, 183-192.
- Moretto, G., Walsh, E., & Haggard, P. (2011). Experience of agency and sense of responsibility. *Consciousness and Cognition*, *20*(4), 1847-1854.

- Moriya, J., & Tanno, Y. (2011). The time course of attentional disengagement from angry faces in social anxiety. *Journal of Behavior Therapy and Experimental Psychiatry*, 42(1), 122-128.
- Moscovici, S., Lage, E., & Naffrechoux, M. (1969). Influence of a Consistent Minority on the Responses of a Majority in a Color Perception Task. *Sociometry*, 32(4), 365-380.
- Moukheiber, A., Rautureau, G., Perez-Diaz, F., Soussignan, R., Dubal, S., Jouvent, R., & Pelissolo, A. (2010). Gaze avoidance in social phobia: objective measure and correlates. *Behaviour Research and Therapy*, 48(2), 147-151.
- Mueller, E. M., Hofmann, S. G., Santesso, D. L., Meuret, A. E., Bitran, S., & Pizzagalli, D. A. (2009). Electrophysiological evidence of attentional biases in social anxiety disorder. *Psychological Medicine*, 39(7), 1141-1152.
- Murphy, P. R., Robertson, I. H., Harty, S., & O'Connell, R. G. (2015). Neural evidence accumulation persists after choice to inform metacognitive judgments. *Elife*. doi: 10.7554/eLife.11946
- Nelson, B. D., Hodges, A., Hajcak, G., & Shankman, S. A. (2015). Anxiety sensitivity and the anticipation of predictable and unpredictable threat: Evidence from the startle response and event-related potentials. *Journal of Anxiety Disorders*, 33, 62-71.
- Oglesby, M. E., Raines, A. M., Short, N. A., Capron, D. W., & Schmidt, N. B. (2016). Interpretation bias for uncertain threat: A replication and extension. *Journal of Behavior Therapy and Experimental Psychiatry*, 51, 35-42.
- Öhman, A. (2005). The role of the amygdala in human fear: automatic detection of threat. *Psychoneuroendocrinology*, 30(10), 953-958.
- Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology*, 130(3), 466-478.
- Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113.
- Oliver, Z. J., Cristino, F., Roberts, M. V., Pegna, A. J., & Leek, E. C. (2018). Stereo viewing modulates three-dimensional shape processing during object recognition: A high-density ERP study. *Journal of Experimental Psychology: Human Perception and Performance*, 44(4), 518-534.

- Olofsson, J. K., & Polich, J. (2007). Affective visual event-related potentials: arousal, repetition, and time-on-task. *Biological Psychology*, 75(1), 101-108.
- Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: an integrative review of ERP findings. *Biological Psychology*, 77(3), 247-265.
- Pacheco-Unguetti, A. P., Acosta, A., Callejas, A., & Lupiáñez, J. (2010). Attention and anxiety: Different attentional functioning under state and trait anxiety. *Psychological Science*, 21(2), 298-304.
- Palmer, E. C., David, A. S., & Fleming, S. M. (2014). Effects of age on metacognitive efficiency. *Consciousness and Cognition*, 28, 151-160.
- Pegna, A.J., Darque, A., Roberts, M.V., & Leek, E.C. (2017) Effects of stereoscopic disparity on early ERP components during classification of three-dimensional objects. *Quarterly Journal of Experimental Psychology*, 71(6), 1419-1430.
- Peschard, V., Philippot, P., Joassin, F., & Rossignol, M. (2013). The impact of the stimulus features and task instructions on facial processing in social anxiety: an ERP investigation. *Biological Psychology*, 93(1), 88-96.
- Phillips, M. L., Young, A. W., Senior, C., Brammer, M., Andrew, C., Calder, A. J., ... & Gray, J. A. (1997). A specific neural substrate for perceiving facial expressions of disgust. *Nature*, 389(6650), 495-498.
- Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology*, 9(4), 456-479.
- Polich, J. (2004). Clinical application of the P300 event-related brain potential. *Physical Medicine and Rehabilitation Clinics*, 15(1), 133-161.
- Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128-2148.
- Polich, J. (2012). Neuropsychology of P300. In S. J. Luck & E. S. Kappenman (Eds.), *Oxford library of psychology. The Oxford handbook of event-related potential components* (pp. 159-188). New York, NY, US: Oxford University Press.
- Polich, J., & Bondurant, T. (1997). P300 sequence effects, probability, and interstimulus interval. *Physiology & Behavior*, 61(6), 843-849.

- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32(1), 3-25.
- Poy, R., del Carmen Eixarch, M., & Avila, C. (2004). On the relationship between attention and personality: Covert visual orienting of attention in anxiety and impulsivity. *Personality and Individual Differences*, 36(6), 1471-1481.
- Proust, J. (2013). *The philosophy of metacognition: Mental agency and self-awareness*. OUP Oxford.
- Proust, J. (2014). Précis of the philosophy of metacognition. *Philosophy and Phenomenological Research*, 89(3), 703-709.
- Rapee, R. M., & Heimberg, R. G. (1997). A cognitive-behavioral model of anxiety in social phobia. *Behaviour Research and Therapy*, 35(8), 741-756.
- Ratner, K. G., & Amodio, D. M. (2013). Seeing “us vs. them”: Minimal group effects on the neural encoding of faces. *Journal of Experimental Social Psychology*, 49(2), 298-301.
- Reuman, L., Jacoby, R. J., Fabricant, L. E., Herring, B., & Abramowitz, J. S. (2015). Uncertainty as an anxiety cue at high and low levels of threat. *Journal of Behavior Therapy and Experimental Psychiatry*, 47, 111-119.
- Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science*, 306(5695), 443-447.
- Ron, O., Oren, E., & Dar, R. (2016). The doubt-certainty continuum in psychopathology, lay thinking, and science. *Journal of Behavior Therapy and Experimental Psychiatry*, 53, 68-74.
- Rossignol, M., Philippot, P., Bissot, C., Rigoulot, S., & Campanella, S. (2012). Electrophysiological correlates of enhanced perceptual processes and attentional capture by emotional faces in social anxiety. *Brain Research*, 1460, 50-62.
- Rossignol, M., Campanella, S., Bissot, C., & Philippot, P. (2013). Fear of negative evaluation and attentional bias for facial expressions: An event-related study. *Brain and Cognition*, 82(3), 344-352.
- Rouault, M., McWilliams, A., Allen, M. G., & Fleming, S. M. (2018). Human metacognition across domains: insights from individual differences and neuroimaging. *Personality Neuroscience*, 1.

- Rozin, P., Lowery, L., & Ebert, R. (1994). Varieties of disgust faces and the structure of disgust. *Journal of Personality and Social Psychology*, *66*(5), 870-881.
- Sacks, O., & Wasserman, R. L. (1987). The painter who became colour blind. *New York Review of Books*, *34*(18), 25-33.
- Schnyer, D. M., Nicholls, L., & Verfaellie, M. (2005). The role of VMPC in metamemorial judgments of content retrievability. *Journal of Cognitive Neuroscience*, *17*(5), 832-846.
- Schenk, T., Ellison, A., Rice, N., & Milner, A. D. (2005). The role of V5/MT in the control of catching movements: an rTMS study. *Neuropsychologia*, *43*(2), 189-198.
- Schindler, S., Wegrzyn, M., Steppacher, I., & Kissler, J. (2014). It's all in your head—how anticipating evaluation affects the processing of emotional trait adjectives. *Frontiers in Psychology*, *5*(1292), 1-11.
- Schofield, C. A., Inhoff, A. W., & Coles, M. E. (2013). Time-course of attention biases in social phobia. *Journal of Anxiety Disorders*, *27*(7), 661-669.
- Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: the late positive potential is modulated by motivational relevance. *Psychophysiology*, *37*(2), 257-261.
- Schweinberger, S. R., Pickering, E. C., Jentsch, I., Burton, A. M., & Kaufmann, J. M. (2002). Event-related brain potential evidence for a response of inferior temporal cortex to familiar face repetitions. *Cognitive Brain Research*, *14*(3), 398-409.
- Selimbeyoglu, A., Keskin-Ergen, Y., & Demiralp, T. (2012). What if you are not sure? Electroencephalographic correlates of subjective confidence level about a decision. *Clinical Neurophysiology*, *123*(6), 1158-1167.
- Shea, N., Boldt, A., Bang, D., Yeung, N., Heyes, C., & Frith, C. D. (2014). Supra-personal cognitive control and metacognition. *Trends in Cognitive Sciences*, *18*(4), 186-193.
- Shestakova, A., Rieskamp, J., Tugin, S., Ossadtchi, A., Krutitskaya, J., & Klucharev, V. (2012). Electrophysiological precursors of social conformity. *Social Cognitive and Affective Neuroscience*, *8*(7), 756-763.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127-190.

- Shimamura, A. P. (2000). Toward a cognitive neuroscience of metacognition. *Consciousness and Cognition*, 9, 313-323.
- Sluis, R. A., Boschen, M. J., Neumann, D. L., & Murphy, K. (2017). Anticipatory processing in social anxiety: Investigation using attentional control theory. *Journal of Behavior Therapy and Experimental Psychiatry*, 57, 172-179.
- Smithson, M. (2015). Probability judgments under ambiguity and conflict. *Frontiers in Psychology*, 6, 674. Doi: 10.3389/fpsyg.2015.00674
- Song, C., Kanai, R., Fleming, S. M., Weil, R. S., Schwarzkopf, D. S., & Rees, G. (2011). Relating inter-individual differences in metacognitive performance on different perceptual tasks. *Consciousness and Cognition*, 20(4), 1787-1792.
- Stallen, M., Smidts, A., & Sanfey, A. (2013). Peer influence: neural mechanisms underlying in-group conformity. *Frontiers in human neuroscience*, 7, 50.
Doi.org/10.3389/fnhum.2013.00050
- Stapel, D.A., & Koomen, W. (1997). Social categorization and perceptual judgment of size: When perception is social. *Journal of Personality and Social Psychology*, 73(6), 1177-1190.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643-662.
- Szechtman, H., & Woody, E. (2004). Obsessive-compulsive disorder as a disturbance of security motivation. *Psychological review*, 111(1), 111-127.
- Taylor, C. T., Cross, K., & Amir, N. (2016). Attentional control moderates the relationship between social anxiety symptoms and attentional disengagement from threatening information. *Journal of Behavior Therapy and Experimental Psychiatry*, 50, 68-76.
- Theeuwes, J. (1994). Endogenous and exogenous control of visual selection. *Perception*, 23(4), 429-440.
- Trautmann-Lengsfeld, S. A., & Herrmann, C. S. (2013). EEG reveals an early influence of social conformity on visual processing in group pressure situations. *Social Neuroscience*, 8(1), 75-89.
- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12(1), 97-136.

- Tsuji, Y., & Shimada, S. (2017). Socially anxious tendencies affect neural processing of gaze perception. *Brain and Cognition*, *118*, 63-70.
- Twomey, D. M., Murphy, P. R., Kelly, S. P., & O'Connell, R. G. (2015). The classic P300 encodes a build-to-threshold decision variable. *European Journal of Neuroscience*, *42*(1), 1636-1643.
- Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, *37*(2), 190-203.
- Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174-194.
- Walsh, M. M., & Anderson, J. R. (2012). Learning from experience: event-related potential correlates of reward processing, neural adaptation, and behavioral choice. *Neuroscience & Biobehavioral Reviews*, *36*(8), 1870-1884.
- Wang, L., Sun, H., Li, L., & Meng, L. (2018). Hey, what is your choice? uncertainty and inconsistency enhance subjective anticipation of upcoming information in a social context. *Experimental Brain Research*, *236*(10), 2797-2810.
- Weinberg, A., Ferri, J., & Hajcak, G. (2013). Interactions between attention and emotion. *Handbook of Cognition and Emotion*, 35-54.
- Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development*, *72*(3), 655-684.
- Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin*, *120*(1), 3-24.
- Williams, J. M. G., Watts, F. N., MacLeod, C., & Mathews, A. (1988). *Cognitive psychology and emotional disorders*. John Wiley & Sons.
- Wu, X., & Zhi, Q. (2016). Impact of shared economy on urban sustainability: From the perspective of social, economic, and environmental sustainability. *Energy Procedia*, *104*, 191-196.
- Wykowska, A., Wiese, E., Prosser, A., & Müller, H. (2014). Beliefs about the minds of Others Influence How We Process Sensory Information. *Plos One*, *9*(4), 1-11.

- Yao, S. N., Note, I., Fanget, F., Albuisson, E., Bouvard, M., Jalenques, I., & Cottraux, J. (1999). L'anxiété sociale chez les phobiques sociaux : validation de l'échelle d'anxiété sociale de Liebowitz (version française). *L'encéphale*, 25, 429-435.
- Yeung, N., & Summerfield, C. (2012). Metacognition in human decision-making: confidence and error monitoring. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 367(1594), 1310-1321.
- Yoshida, W., & Ishii, S. (2006). Resolution of uncertainty in prefrontal cortex. *Neuron*, 50(5), 781-789.
- Zaki, J., Schirmer, J., & Mitchell, J. P. (2011). Social influence modulates the neural computation of value. *Psychological Science*, 22(7), 894-900.
- ZanESCO, J. (2019). Am I really seeing what's around me ? An ERP study on social anxiety under speech induction, uncertainty and social feedback. *Under review*.
- ZanESCO, J., Tipura, E., Posada, A., Clément, F., & Pegna, A. J. (2019). Seeing is believing: Early perceptual brain processes are modified by social feedback. *Social Neuroscience*, 14(5), 519-529.
- ZanESCO, J., Tipura, E., Clément, F., & Pegna, A. J. (2019). Patterns of electrical brain activation in response to socially-disputed perceptual judgments. *NeuroReport*, 30(17), 1205-1209.
- Zeki, S. (2006). "The neurology of ambiguity," in *The Artful Mind*, ed. M. Turner (Oxford: Oxford University Press), 243–270.
- Zhou, Z., Yu, R., & Zhou, X. (2010). To do or not to do? Action enlarges the FRN and P300 effects in outcome evaluation. *Neuropsychologia*, 48(12), 3606-3613.

6. ANNEXES

6.1. Liebowitz questionnaire (French version)

Échelle d'anxiété sociale de Liebowitz

Date:/...../.....

Nom: Prénom: Sexe: Âge:

	ANXIÉTÉ 0 = Aucune 1 = Légère 2 = Moyenne 3 = Sévère	ÉVITEMENT 0 = Jamais 1 = Occasionnel (0-33 %) 2 = Fréquent (33-66 %) 3 = Habituel (67-100 %)
1. Téléphoner en public (P)		
2. Participer au sein d'un petit groupe (P)		
3. Manger dans un lieu public (P)		
4. Boire en compagnie dans un lieu public (P)		
5. Parler à des gens qui détiennent une autorité (S)		
6. Jouer, donner une représentation ou une conférence (P)		
7. Aller à une soirée (S)		
8. Travailler en étant observé (P)		
9. Écrire en étant observé (P)		
10. Contacter par téléphone quelqu'un que vous ne connaissez pas très bien (S)		
11. Parler à des gens que vous ne connaissez pas très bien (S)		
12. Rencontrer des inconnus (S)		
13. Uriner dans les toilettes publiques (P)		
14. Entrer dans une pièce alors que tout le monde est déjà assis (P)		
15. Être le centre d'attention (S)		
16. Prendre la parole à une réunion (P)		
17. Passer un examen (P)		
18. Exprimer son désaccord ou sa désapprobation à des gens que vous ne connaissez pas très bien (S)		
19. Regarder dans les yeux des gens que vous ne connaissez pas très bien (S)		
20. Faire un compte-rendu à un groupe (P)		
21. Essayer de « draguer » quelqu'un (S)		
22. Rapporter des marchandises dans un magasin (S)		
23. Donner une soirée (S)		
24. Résister aux pressions d'un vendeur insistant (S)		
TOTAL	A =	E =
Deux scores : S = Interaction sociale	A.S =	E.S =
P = Performance	A.P =	E.P =

6.2. Debriefing (study 3)

Debriefing

Code participant.....

L'expérience que vous avez réalisée fait partie du domaine des neurosciences sociales. Par conséquent, et afin de vous influencer socialement, nous vous avons transmis un message sur la signification des feedbacks de la source sociale (expression de joie et de dégoût des visages) qui ne représentait pas la réalité. Les expressions de joie et dégoût des visages étaient aléatoires et indépendants de votre réponse au 1^{er} carré de couleur. De plus, nous avons voulu induire de l'anxiété avec la phrase qui se trouvait dans les informations aux participants : « *A la fin de l'expérience, 3 psychologues vous demanderont de vous présenter et décrire votre ressenti durant l'expérience* ». Ce message est un leurre et est donc également faux.

Sur la base de ces nouvelles informations, nous avons besoin de votre confirmation que vous êtes d'accord qu'on utilise vos données à des fins de recherche.

- Oui, j'autorise l'utilisation de mes données à des fins de recherche

- Non, je n'autorise pas l'utilisation de mes données à des fins de recherche