Cognitive and Neural Mechanisms of Social Eye Gaze

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I, Maria Roser Cañigueral Vila, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed:

Date:

Abstract

Social interactions are characterised by exchanges of a variety of social signals to communicate with other people. A key feature in real-life interactions is that we are in the presence of other people who can see us (audience), and we modulate our behaviour to send and receive signals (audience effect). Although social neuroscience research has traditionally examined how we respond to pictures and videos of humans, second-person neuroscience suggests that interactions with pre-recorded versus live people recruit distinct neurocognitive mechanisms. The aim of this thesis was to investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched, particularly focusing on eye gaze, facial displays and prosocial behaviour as social signals. Using a novel ecologically valid paradigm, the first study showed that the opportunity to signal good reputation is a key modulator of eye gaze and prosocial behaviour. Using the same paradigm, the second study found no evidence to support the hypothesis that audience effects are mediated by an increase in self-referential processing. The third study focused on the time-course of eye gaze and facial displays patterns in relation to speech, both in typical and autistic individuals: contrary to what was expected both groups modulated eye gaze and facial displays according to the belief in being watched and speaker/listener role. Finally, the fourth study tested the role of reciprocity in live interactions: sharing information with a partner modulated eye gaze, facial displays, and brain activity in regions related to mentalising and decision-making. I discuss the theoretical implications of these findings and set out a cognitive model of gaze processing in live interactions. Finally, I outline directions for future research in social neuroscience.

Impact Statement

Social interactions are at the core of our organisation and functioning as a society. However, the cognitive and neural mechanisms that allow us to interact and communicate with others remain poorly understood. Departing from traditional experiments that use pictures and videos of people, this thesis investigated how being in a live interaction modulates social behaviours and brain activity. To do so, state-of-the-art methodologies such as wearable eye-trackers (to record eye gaze), face-tracking algorithms (to measure facial displays) and functional near-infrared spectroscopy (to record brain activity) were employed.

This thesis reports four key findings. First, during live interactions we use eye gaze and facial displays in coordination with speech to send signals and communicate with others, and not just to perceive information or express emotions. Second, autistic individuals show no overall differences in eye gaze and facial displays patterns when compared to typical participants. Third, in live interactions we behave in more prosocial ways to maintain our reputation in front of others, although this might depend on the identity of our interacting partners. Lastly, mutual sharing of information with other people engages brain systems linked to evaluating and learning about others.

These findings make a significant contribution to current cognitive models of social interactions by demonstrating that live interactions recruit specific neurocognitive mechanisms that are not engaged in non-interactive situations. At a time when video-calls, virtual avatars and robots are rapidly becoming main characters of our society, it is critical to understand how our brain and behaviour implement different strategies to communicate with different types of interacting partners (e.g. face-to-face, video-feed, avatars). By identifying which behaviours and mechanisms enable successful human communication we can develop more efficient technologies for connecting with others, but also for teaching and clinical purposes. Thus, the findings reported in this thesis have long-term implications for technological, educative and clinical communities.

This thesis also advances our knowledge of social cognition in autism (a neurodevelopmental condition characterised by difficulties in social interactions and communication). Although poor eye contact is generally considered a hallmark of autism, this thesis shows that in live interactions gaze patterns of autistic individuals are generally similar to those of typical people. This finding emphasises the need to revise our current understanding of autism in the light of novel theories and methodologies developed in the context of live interactions. In the long run, this will contribute towards a better understanding of the neurodiversity that makes up our society.

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Table of Contents

Table of Figures

Table of Tables

Chapter 1. Introduction

Part of Chapter 1 was published in a review paper in Frontiers in Psychology:

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1.1. Communication needs an audience

In the midst of the Enlightenment revolution, Diderot coined the term "fourth wall" to refer to the imaginary wall that separates the actors from the audience in a traditional three-walled stage. According to this convention, the audience watches the play on stage through this imaginary wall, but actors perform pretending there is no audience (Bell, 2008). Theatre, and later on cinema, have a long history of "breaking the fourth wall" by directly addressing the audience in various ways. For instance, actors can refer to spectators in their speech, or can look at them (or the camera) directly to establish eye contact (Figure 1-1). Those who have seen *Annie Hall* or *House of Cards* have probably experienced how this raises the funniness or tension of the scene, thus increasing their engagement with the movie. Crucially, "breaking the fourth wall" means that the audience transitions from being a passive (unseen) observer, to an active (seen) participant who needs to respond in some way (Schroeder, 2016).

Contrary to theatre or cinema, the field of social neuroscience has only recently discovered the existence of a "fourth wall" in research studies (Risko, Richardson, & Kingstone, 2016). In typical lab studies, participants' behaviour is recorded while they observe a monitor that displays pictures or videos of other people (see Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012 for a review). Although these traditional approaches allow good experimental control, they are not truly interactive: participants receive some information from the picture or video, but they do not send any information back because the picture cannot receive it. Consequently, the second-person neuroscience approach has proposed that social interactions recruit a range of neurocognitive processes that are different from those recruited when participants just observe pictures or videos (Redcay & Schilbach, 2019; Schilbach et al., 2013). This has revealed the need for a fundamental step forward in social neuroscience research: to fully understand the cognitive mechanisms behind real-life social behaviour, the study of social interactions needs to break the “fourth wall” between the stimulus and the participant (Risko et al., 2016).

a) Screenshot from *Annie Hall*

b) Screenshot from *House of Cards*

Figure 1-1. Examples of “breaking the fourth wall” by directly gazing at the audience. a) Screenshot of the movie Annie Hall (1977). b) Screenshot of the TV series House of Cards (1990).

Critical to real-life social interactions (also referred to as live or face-to-face interactions) is that we are in the presence of other people who can see us (i.e. audience). Past psychology research has thoroughly investigated how we behave differently when we are alone or in the presence of others. Triplett first introduced this idea 120 years ago, when he showed that cyclists were faster when competing against each other than against a clock (Triplett, 1898). To explain this effect, he suggested that the "bodily presence of another" causes changes in the behaviour of participants, which makes them more competitive when racing against others. However, previous research has shown that there is more than one way in which the presence of another person can change our behaviour.

On the one hand, social facilitation refers to a change in behaviour caused by the presence of a conspecific who may or may not be watching us (Zajonc, 1965). This effect is present in humans but also in a wide range of species (e.g. cockroaches, rats and monkeys), suggesting that it relies on a simple mechanism like arousal. Zajonc further claimed that an increase in arousal in the presence of others would facilitate dominant behaviours (i.e. responses that are elicited most quickly by a stimulus). For instance in an easy task the dominant response is usually the correct one, while in a difficult task the dominant response is usually the incorrect one. Zajonc and Sales found that, in the presence of a conspecific, participants performed better on a verbal recognition task with familiar items (easy task), and worse on the same task with unfamiliar items (hard task) (Zajonc & Sales, 1966). This effect has been found in a range of tests on both mental and physical skills (Geen, 1985; Strauss, 2002). Blascovich and colleagues replicated these findings and also showed that, in the presence of others, the cardiovascular system is differently triggered depending on the task: in a difficult task the cardiovascular response fits a threat-like pattern, whereas in an easy task the cardiovascular response fits a challenge-like pattern (Blascovich, Mendes, Hunter, & Salomon, 1999). This suggests that the facilitation of different dominant responses in the presence of others is mediated by different arousal patterns.

On the other hand, the audience effect is a change in behaviour specifically caused by the belief that someone else is watching me. It builds on mechanisms which process the perceptual state of the other, known as perceptual mentalising (Teufel, Fletcher, & Davis, 2010). Perceptual mentalising modulates the processing of social information from the eyes (e.g. gaze direction or duration) in a variety of ways. For example, seeing a live-feed of a person with transparent glasses (who can see) leads to a larger gaze cuing effect than a matched stimulus of a person with opaque glasses (who cannot see) (Nuku & Bekkering, 2008; Teufel, Alexis, Clayton, & Davis, 2010), and similar results are seen in tests of visual perspective taking (Furlanetto, Becchio, Samson, & Apperly, 2016). This demonstrates that even basic social processing is influenced by the knowledge that another person can see something. The audience effect takes this one step further, considering how our social cognition is affected by the knowledge that another person can see us.

It has been proposed that audience effects reflect a communicative function (Hamilton & Lind, 2016): being in front of an audience will lead to changes in our behaviour to send *signals* to this audience. Signals can be defined as “physical events, behaviours or structures to which receivers respond" (Stegmann, 2013), and they are sent with the purpose of having an effect on the receiver. This means that we will usually send signals when we know they can be received (i.e. in the presence of an audience). For instance, when we are with other people our actions become more prosocial to maintain a good public image (Bond, 1982; Izuma, Matsumoto, Camerer, & Adolphs, 2011; Izuma, Saito, & Sadato, 2009). Moreover, in the presence of a stranger we avert our gaze to signal that we do not want to start an interaction (Laidlaw, Foulsham, Kuhn, & Kingstone, 2011), and when watching pleasant videos with a friend we smile more to signal affiliation (Fridlund, 1991).

Thus, in the same way that Alvy Singer (*Annie Hall*) or Francis Urquhart (*House of Cards*) make us feel like we need to answer back when they pretend they can see us, participants in research studies will show communicative behaviours (i.e. send signals) as long as they are in front of an audience who can see them (as happens in real-life interactions). The aim of this thesis was to investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched, particularly focusing on the use of eye gaze, facial displays and prosocial behaviour as social signals. In the following, I review four cognitive theories that explain audience effects on these social behaviours: the dual function of eye gaze, the behavioural ecology view of facial displays, reputation management theory, and the Watching Eyes model. Common to all these theories is that they build on perceptual mentalising processes (i.e. detecting whether another person can see me). Moreover, they are not mutually exclusive. The dual function of gaze, the behavioural ecology view of facial displays and reputation management theory provide plausible accounts of how being watched modulates eye gaze, facial displays and prosocial behaviour to send signals to others. Instead, the Watching Eyes model can help us understand how the presence of an audience triggers these cognitive mechanisms.

1.2. The dual function of eye gaze

In his book *Soziologie* (Simmel, 1908), Georg Simmel already highlighted how our sensory organs are key to perceive others during social interactions. He also stated that, of all senses, “the eye has a uniquely sociological function” since the “interaction of individuals is based upon mutual glances” (Simmel, 1908, 1921). He particularly emphasized that mutual gaze (i.e. eye contact) represents the “most perfect reciprocity” in social interactions, where our eyes both perceive information from others and reveal information about ourselves (Argyle & Cook, 1976; Simmel, 1908, 1921).

The idea that our eyes have a dual function in social interactions – to perceive information from others and to signal information to others – has only been recently introduced in cognitive research (Gobel, Kim, & Richardson, 2015; Risko et al., 2016). In line with Simmel’s early work (Simmel, 1908, 1921), it is thought that the dual function makes our eyes a powerful tool for social interactions. For instance, when we see a pair of eyes we can gather information about what other people are looking at (Frischen, Bayliss, & Tipper, 2007), and how they feel or think (Baron-Cohen, Wheelwright, & Jolliffe, 1997). At the same time, we can use our eyes to strategically cue another’s attention (Kuhn, Tatler, & Cole, 2009). Depending on the duration and direction of our gaze, we are also able to perceive and signal a variety of meanings, such as desire to communicate (Ho, Foulsham, & Kingstone, 2015), threat and dominance (Ellyson, Dovidio, & Fehr, 1981; Emery, 2000), affiliation and attractiveness (Argyle & Dean, 1965; Georgescu et al., 2013), or seeking for approval (Efran, 1968; Efran & Broughton, 1966). Importantly, perceptual mentalising is key to engage the dual function of eye gaze, since our eyes will only perceive *and* signal information when we detect someone is watching us.

Thus, planning eye movements in social interactions requires taking into account the information we can gather from each location, but also the information we will send to others depending on where (and for how long) we direct our gaze. In the following, I describe how the visual system implements the perceiving function of eye gaze, and review studies suggesting that gaze planning also takes into account its signalling functions.

1.2.1. The perceiving function of eye gaze

As Simmel anticipated (Simmel, 1908, 1921), active sensing is a key process in our interaction with the world, since it allows our sensors to be directed to the environment in order to extract relevant information (Yang, Wolpert, & Lengyel, 2016). Gaze behaviour (i.e. deciding where to look) can be considered a form of active sensing in that we choose to move our eyes to specific locations to sample useful information from a visual scene. Since our visual system only gains high-resolution information for items falling in the fovea, the motor system needs to move our eyes to orient the fovea to different locations of interest. Thus, our motor actions shape the quality of the sensory information we sample (Yang et al., 2016).

The active sensing framework provides a mathematical account of how we can sample the world with our eyes to get useful information. Because we can only direct our eyes to one location at a time, each eye movement (i.e. saccade) comes at some opportunity cost. For instance, in Figure 1-2a, looking at the woman and child on the bottom means we might lose the chance to get information about the house in the centre or the woman and child on the left. Similarly, in Figure 1-2b, looking at the landscape on the right means we will lose information about the blue car on the left or the speedometer. Active sensing suggests that saccades are planned to maximise the information we sample depending on the goal of the task at hand.

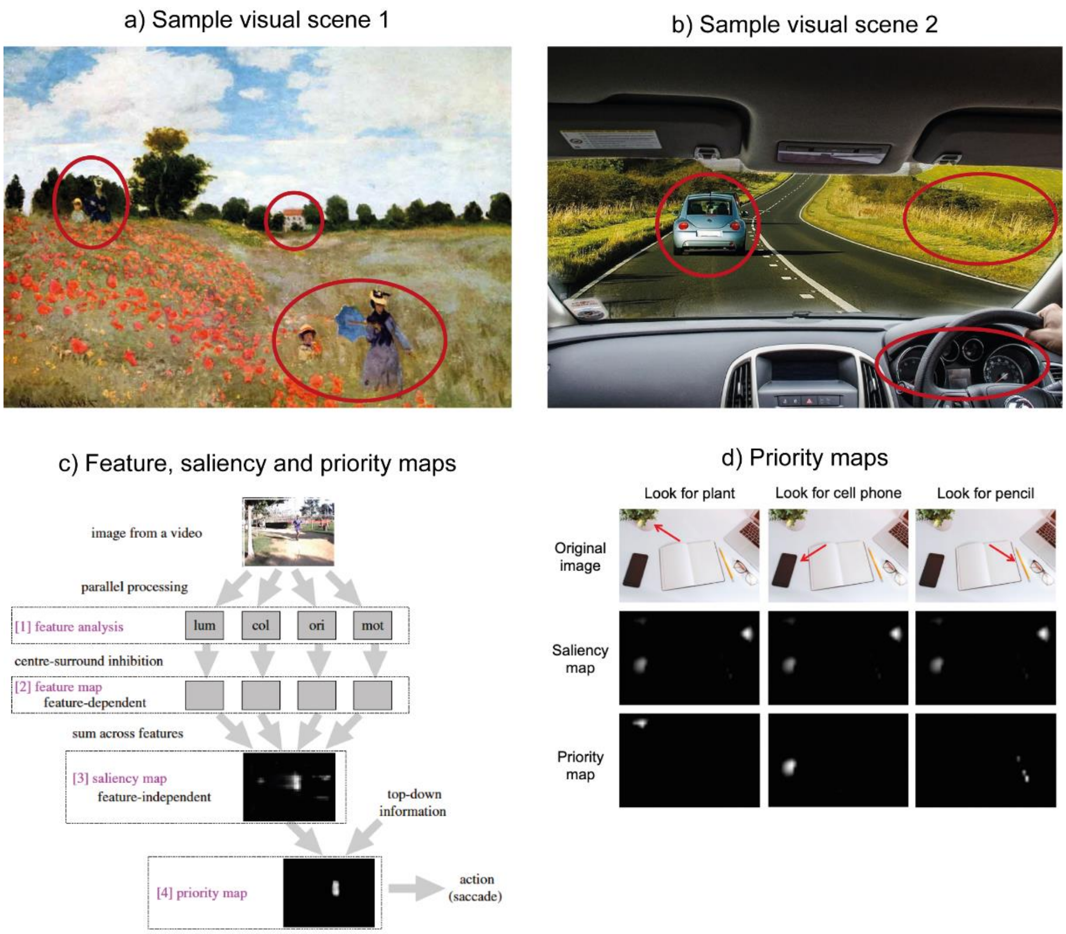

Figure 1-2. The perceiving function of gaze.
a-b) Sample visual scenes with red circles indicating different locations where gaze can be directed. Photographic reproduction of painting Poppies by Claude Monet (a), and image originally published by Max Pixel under the Creative Commons CC0 License (b). c) Feature, saliency and priority maps (original image published by Veale et al. 2017). d) Priority maps for different task goals (original image published by Max Pixel under the Creative Commons CC0 License; maps were generated with SaliencyToolbox for Matlab; Walther & Koch, 2006).

To understand how sampled information is maximised it is useful to consider the concept of saliency maps. A saliency map is “an explicit twodimensional topographical map that encodes stimulus conspicuity, or saliency, at every location in the visual scene" (Itti & Koch, 2001). It results from the combination of different topographical or feature maps, each representing a single visual feature, either static (e.g. colour, orientation, intensity, center-surround difference; Itti & Koch, 2001; Koch & Ullman, 1985) or dynamic (e.g. rotation, expansion, contraction or planar motion; Jeong, Ban, & Lee, 2008; Milanese, Gil, & Pun, 1995). A saliency map is a pre-attentive computation, in the sense that at this stage all locations are competing for representation in the visual cortex (Itti & Koch, 2001). Only the location that is most salient will gain further access in downstream visual areas and guide the next eye movement so as to deploy attention in that specific location (Itti & Koch, 2001; Kastner & Ungerleider, 2000; Koch & Ullman, 1985; Veale, Hafed, & Yoshida, 2017) (see Figure 1-2c[1-3]).

While low-level features (static and dynamic) generate a bottom-up bias on saliency maps, these can also be modelled by a top-down bias emerging from affective features (e.g. preference or dislike for the visual stimuli; Itti et al., 1998; Jeong et al., 2008; Olshausen, Anderson, & Van Essen, 1993; Tsotsos et al., 1995; Veale et al., 2017) (see Figure 1-2c[4]). Affective features are mainly associated with the goal of the task at hand, and are integrated with bottom-up information in associative visual areas (extrastriate cortex) (Veale et al., 2017). For instance, as shown on Figure 1-2d, different search goals will generate different priority maps derived from the same saliency map (see also the pioneering work from Yarbus, 1967). This top-down bias is particularly important in the context of active sensing, since the task goal will modify the reward value of each location in the visual scene and, in turn, determine which information needs to be maximized (Jeong et al., 2008; Yang et al., 2016).

Recent evidence has also found that when participants view social naturalistic scenes they primarily fixate on the faces and eyes of people in the scene (Birmingham, Bischof, & Kingstone, 2009; End & Gamer, 2017; Nasiopoulos, Risko, & Kingstone, 2015; Rubo & Gamer, 2018). Since our eyes have low saliency (Birmingham et al., 2009), low-level features alone cannot fully explain gaze behaviour in social contexts. This suggests that there is an implicit preferential (top-down) bias to attend to others in social scenes (Birmingham et al., 2009; Nasiopoulos et al., 2015), probably because the face and the eyes are a rich source of information for social interactions (Crivelli & Fridlund, 2018; Hamilton, 2016). Indeed, Kendon suggested that, during conversation, eye gaze has a monitoring function (Kendon, 1967): it allows participants to track attentional states and facial displays of the partner to ensure mutual understanding and seek approval from others (Efran, 1968; Efran & Broughton, 1966; Kleinke, 1986)

Active sensing provides a useful framework to understand how eye movements are planned to process non-social stimuli (e.g. objects or landscapes), as well as social stimuli in pictures or videos. In both cases, the saccade planner combines bottom-up and top-down features to maximise information relevant for the task and decide where gaze is next directed (Yang et al., 2016). However, in the case of face-to-face interactions, our gaze not only needs to maximise the information gained but also optimise the information signalled to another person.

1.2.2. The signalling function of eye gaze

Eye gaze is an ostensive communicative signal (Argyle & Cook, 1976; Gobel et al., 2015; Risko et al., 2016). As Watzlavick's axiom "one cannot not communicate" suggests (Watzlawick, Helmick Beavin, & Jackson, 1967), even in a waiting room where two people are not intended to communicate and avoid engaging in eye contact, they are sending a signal that means "I do not want to interact with you" (Foulsham, Walker, & Kingstone, 2011). This means that in face-to-face interactions our eye movements are constantly planned so as to send signals to others, and not just to gain information from the world.

Original studies about the role of eye gaze during communicative encounters date back to the 60s, when Argyle and colleagues (Argyle & Cook, 1976; Argyle & Dean, 1965) put forward the intimacy equilibrium model, which is the first account on the relationship between "looking and liking": they showed that gaze directed at other people serves to control the level of intimacy or affiliation with the partner, and that it compensates with other behaviours (e.g. physical proximity) to achieve an equilibrium level of intimacy (see also Loeb, 1972). At the same time, Kendon proposed that eye gaze has an expressive function (Kendon, 1967), which allows participants to regulate the level of arousal in the interaction. He found that some participants tended to avert their gaze at moments of high emotion, and that the amount of eye contact was inversely related to the frequency of smiling. He suggested that averting gaze at this highly emotional moments could be interpreted as a "cut off" act to express embarrassment and reduce arousal.

With the emergence of sophisticated eye-tacking technology, recent research has implemented more ecologically valid approaches to study gaze behaviour in the real world. These studies show that gaze patterns in computer-based tasks (i.e. when watching pictures or videos) and in the real world have little in common (Foulsham & Kingstone, 2017; Hayward, Voorhies, Morris, Capozzi, & Ristic, 2017). For instance, Laidlaw and colleagues (Laidlaw et al., 2011) found that participants sitting in a waiting room would look more to a confederate in a video-clip than to the same confederate present in the room. In another study, Foulsham and colleagues (Foulsham et al., 2011) showed that participants gaze less to close pedestrians than distant pedestrians. In these contexts, averting gaze from a stranger signals no interest in starting an interaction with a stranger (i.e. civil inattention; Goffman, 1963). Moreover, Gobel and colleagues (2015) found that the ratio of gaze directed to eyes relative to gaze directed to mouth was higher for video-clips of a low rank confederate and lower for video-clips of a high rank confederate, but only when they believed the confederate would later see their gaze recording. These two gaze behaviours, direct and averted gaze, have been associated with signalling of dominance and submission, respectively (Ellyson et al., 1981; Emery, 2000).

A main limitation in these studies is that participants and audience (i.e. stranger or confederate) are not supposed to talk to each other, that is, they do not communicate. This may create a rather unnatural situation for the participant, and findings may not generalise to other social contexts where there are communicative exchanges (e.g. conversation). Indeed, during communicative exchanges both partners need to coordinate a variety of incoming and outgoing signals to enable successful progression of the interaction. This gives rise to temporal dependencies between social signals.

For instance, Kendon identified asymmetrical gaze behaviour between speakers and listeners during conversation (Kendon, 1967): while listeners gaze at speakers most of the time (to signal interest), speakers avert gaze when they begin to talk (to indicate that they want to retain their role) but gaze back to the listener when they are about to end an utterance (to signal that the listener can take the floor) (Cummins, 2012; Duncan & Fiske, 1977; Ho et al., 2015; Kendon, 1967; Sandgren, Andersson, Weijer, Hansson, & Sahlén, 2012). Thus, Kendon proposed that eye gaze has a regulatory function during conversation because it allows individuals to modulate transitions between speaker and listener states (i.e. turn-taking). These findings illustrate how studying fine-grained dynamics social signals can bring new insight into which mechanisms modulate these behaviours in face-to-face interactions.

The discrepancy between findings from computer-based tasks and the real world is also relevant for research on disorders of social interaction, such as autism. For instance, although poor eye contact is one of the most used diagnostic criteria for autism from early infancy (Zwaigenbaum et al., 2005), evidence in autistic adults is mixed (Chita-Tegmark, 2016; Falck-Ytter & Von Hofsten, 2011; Frazier et al., 2017). Some of these inconsistencies may be a consequence of the wide spectrum in autistic individuals, but it has been suggested that they could also be a consequence of the lack of experimental paradigms for studying gaze behaviour in real social interactions (Chevallier et al., 2015; Drysdale, Moore, Furlonger, & Anderson, 2018; Von dem Hagen & Bright, 2017). Moreover, a recent qualitative study highlights that self-declared autistic adolescents and adults struggle with the appropriate use and timing of eye gaze during face-to-face interactions (Trevisan, Roberts, Lin, &

Birmingham, 2017). Thus, to fully understand autistic social cognition it is necessary to examine whether their eye movements are planned to perceive *and* signal information, and whether this is modulated over the course face-to-face interactions.

1.2.3. Summary

Eye gaze is a powerful tool for social interactions (Simmel, 1908, 1921). Our eyes allow us to perceive information form the world but also signal information to others (Gobel et al., 2015; Risko et al., 2016). Past research on visual attention has investigated how eye movements are planned to sample information from the world: low-level features from the stimuli and affective features associated with our preferences or goals are encoded in saliency maps in the visual cortex, but only the location that is most salient will guide our next eye movement (Itti & Koch, 2001; Jeong et al., 2008; Koch & Ullman, 1985; Veale et al., 2017). A special case is that of social scenes, where there is an implicit preferential bias to attend to rich sources of social information such as faces or eyes (Birmingham et al., 2009; Nasiopoulos et al., 2015). More recently, modern eye-tracking technology has allowed researchers to study the signalling function of gaze. These studies show that we direct less gaze towards a real or close stranger than towards a pre-recorded or distant stranger (Foulsham et al., 2011; Laidlaw et al., 2011), suggesting that participants avert gaze to signal no interest in starting an interaction with a stranger. However, it is not known if these findings generalise to communicative exchanges. Equally, there is little evidence on how autistic individuals use eye gaze during face-to-face communication. An overarching aim of this thesis was to study how gaze patterns change between the presence and absence of an audience during communicative exchanges (both in typical and autistic individuals).

1.3. The behavioural ecology view of facial displays

Similar to our eyes, faces are a rich source of information about others. Greeks and Romans already thought that the physical appearance of a person, and particularly the face, revealed inner characteristics of the person (Russell, 1994; Sihvola & Engberg-Pedersen, 1998), and it has been shown that we use various facial features to judge social attributes in others, such as trustworthiness or approachability (Santos & Young, 2011). Although most of past research on face processing has focused on facial displays as expressions of emotional states (Ekman, 1971), the behavioural ecology view has recently proposed that facial displays have a communicative function in social interactions (Crivelli & Fridlund, 2018): just as perceptual mentalising triggers the signalling function of eye gaze, the detection of someone watching will also engage the use of facial displays as social signals. In the following, I briefly review each of these theories.

1.3.1. Facial displays as expressions of emotion

It is generally assumed that faces reflect our emotional states. Shortly after Descartes' description of the human passions (Descartes, 1649), the artist Charles Le Brun depicted a specific facial configuration for each passion (Figure 1-3a). Later on, Duchenne used electrical stimulation to identify which muscles are responsible for different facial displays, and compiled the resulting (and often grotesque) expressions in his book *The Mechanisms of Human Facial Expression* (Duchenne, 1862) (Figure 1-3b). Inspired by these photographs, Darwin claimed that each facial configuration expresses a specific emotion, and that some of these configurations are universal across ages and cultures (Darwin, 1872). A century later, Ekman identified six emotions with common facial displays across cultures (happiness, disgust, surprise, anger, sadness and fear), and suggested that they conform universal prototypes of emotion expression (i.e. basic emotions theory; Ekman, 1971, 1992; Ekman & Friesen, 1971). Consequently, research on perception and production of facial displays has been mainly focused on these six basic emotions (Figure 1-3c).

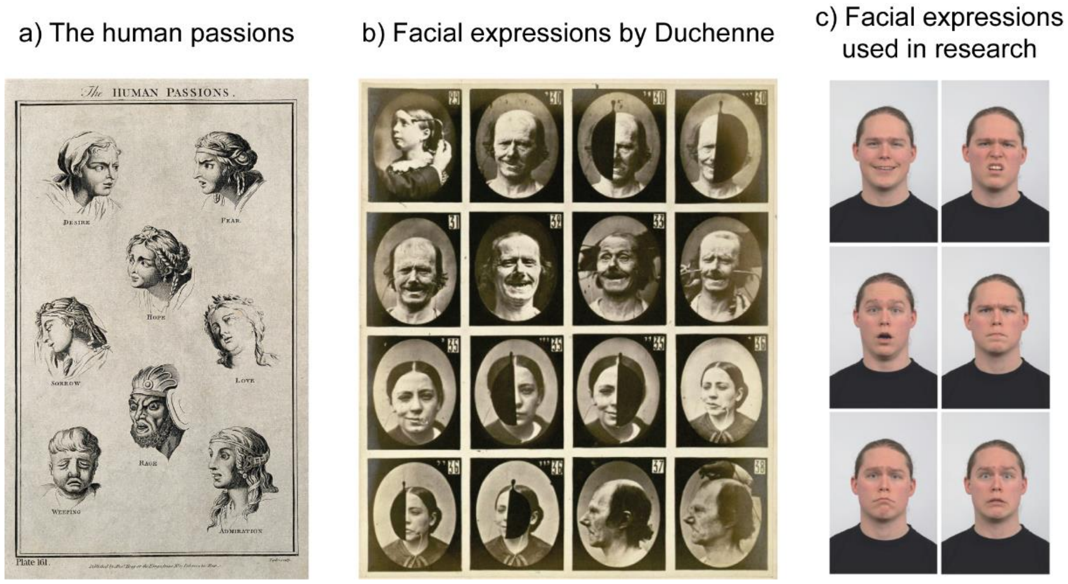

Figure 1-3. Representations of facial displays.
a) Photographic reproduction of an etching by Taylor (after Charles Le Brun) depicting The Human Passions (1788). b) Photographs from Duchenne's book The Mechanisms of Human Facial Expression (1862). c) Facial expressions commonly used in research; from left to right, top to bottom: happiness, disgust, surprise, anger, sadness and fear (original images published in the Radboud Faces Database; Langner et al., 2010).

For instance, research on face perception has traditionally involved categorising or discriminating between facial displays that gradually change from one to another basic emotion. In turn, studies on production of facial displays have relied on pictures, videos or descriptions of events that are expected to evoke one of the basic emotions. These studies have shown that we spontaneously mimic facial expressions of others (Sato & Yoshikawa, 2007), and that blocking mimicry impairs recognition of emotions (Oberman, Winkielman, & Ramachandran, 2007). Moreover, it has been found that the amygdala is key for processing emotion expressions (Blair, Morris, Frith, Perrett, & Dolan, 1999; Sergerie, Chochol, & Armony, 2008; Wang et al., 2017), and that it recruits distinct brain regions for different basic emotions (Diano et al., 2017). Instead, voluntary production of emotional expressions recruits motor areas and the inferior frontal gyrus (Lee, Josephs, Dolan, & Critchley, 2006).

1.3.2. Facial displays as communicative signals

The assumption that facial displays are based on prototypes and that they are primarily used to express emotions has been challenged by the behavioural ecology view of facial displays (Crivelli & Fridlund, 2018). This theory claims that facial displays have a more general communicative function. For instance, it has been found that we make and mimic more facial displays when we are being watched by others, that is, when we know others are able to perceive us (Chovil, 1991b; Fridlund, 1991; J. K. Hietanen, Kylliäinen, & Peltola, 2018). We also use a variety of facial displays alongside speech to complement verbal information, e.g. to emphasize what we say, to mark questions, to provide feedback, or to convey messages that cannot be expressed with words (Chovil, 1991a). Moreover, a recent comparison of studies with adults living in urban areas, adults living in isolated societies, infants, children and congenitally blind individuals has shown that the meaning of a specific facial display is more variable and context-dependent than expected by the basic emotions theory (Barrett, Adolphs, Marsella, Martinez,

& Pollak, 2019; see also Jack, Garrod, Yu, Caldara, & Schyns, 2012). These findings provide evidence that our facial displays communicate a spectrum of meanings instead of just expressing categories of emotions (Crivelli & Fridlund, 2018).

The behavioural ecology view of facial displays brings forward another critical limitation to past studies investigating perception and production of basic emotions: during communicative exchanges with other people, facial displays are *spontaneously* produced, perceived and integrated with other social signals. Thus, while most of previous studies have focused on production and perception of isolated facial configurations (which are often posed), there is little evidence on spontaneous production and perception of facial displays during face-to-face interactions. This thesis aimed to investigate whether the belief in being watched modulates the spontaneous production of facial displays during communicative exchanges, as well as which brain systems are involved during spontaneous production and perception of facial displays.

1.3.3. Summary

Although facial displays have commonly been studied as expressions of emotions (Ekman, 1992), the behavioural ecology view of facial displays proposes that they are also used to communicate a variety of meanings during conversation (Barrett et al., 2019; Crivelli & Fridlund, 2018). However, evidence is scarce on spontaneous production and perception of facial displays during real-life interactions. Thus, this thesis aimed to test whether spontaneous production of facial displays is modulated by the belief in being watched over the course of communicative exchanges, as well as identify which neural correlates are associated with spontaneous production and perception of facial displays.

1.4. Reputation management theory

In previous sections I have reviewed how being watched engages the signalling function of eye gaze and facial displays and, consequently, they become critical signals for successful communication with others. Critically, the detection of other people watching us also implies that these partners will evaluate the signals and information we send to them, and in turn this will shape the impression they have about us. In line with this, previous studies have shown that, when others can see us, we change our behaviour to appear desirable to others (Bradley, Lawrence, & Ferguson, 2018). These changes in behaviour have been previously described in terms of self-presentation theory (Bond, 1982), which claims that people modulate their behaviour in front of others to maintain a good public image and increase their self-esteem. In this section I focus on an updated version of this theory, reputation management theory, which explains how perceiving that someone can see us (and evaluate us) prompts changes in behaviour to manipulate the partner’s beliefs to our advantage.

1.4.1. Reputation management and prosocial behaviour

Reputation is a social construct that emerges from the desire to cultivate good self-impressions in front of others (Silver & Shaw, 2018). It is based on how we think others see us, and it changes over time depending on our actions (Cage, 2015; Izuma, 2012). To maintain or manage reputation, individuals need to think about what others think of them, care about how others see them, and have the desire to foster positive impressions in others (Cage, 2015;

Izuma, 2012). This means that mentalising and social motivation have a central function in reputation management (Cage, 2015; Izuma, 2012; Saito et al., 2010; Tennie, Frith, & Frith, 2010). In line with this, neuroimaging studies have shown that mentalizing and reward brain areas are engaged during different phases of reputation management. For instance, processing what others think of us engages the medial prefrontal cortex, a classical region linked to mentalising (Frith & Frith, 2006; Izuma, Saito, & Sadato, 2010); instead, anticipating positive reputation recruits the ventral striatum, which is linked to reward processing (Izuma et al., 2009, 2010). It has been suggested that reputation management also engages decision-making processes, to strategically modulate our behaviour in a way that it is desirable to others (Izuma, 2012). Moreover, it may also involve social perceptual processes, which allow us to detect signals in the audience that inform us about what they think of us (e.g. gaze direction or facial displays) (Izuma, 2012).

One strategy that people use to maintain good reputation in front of others is to behave in a more prosocial fashion, for instance by helping, sharing, donating or volunteering. Prosocial behaviour is usually defined as a social behaviour that benefits other people rather than the self (Twenge, Ciarocco, Baumeister, DeWall, & Bartels, 2007), and is thought to be key to the development of social groups and communities throughout human evolution (Nowak & Sigmund, 2005). Although some have suggested that prosocial behaviours are mainly motivated by empathy and concerns about the welfare of other people (Decety, Bartal, Uzefovsky, & Knafo-Noam, 2016), others have proposed that they are actually driven by the norm of reciprocity, either direct ("You scratch my back, and I'll scratch yours") or indirect ("I scratch your back and someone else will scratch mine") (Nowak & Sigmund, 2005). Critical to both accounts is the fact that our actions (prosocial or not) can be judged by others. Thus, a recent proposal claims that prosocial behaviour aims to exhibit desirable traits in front of others, which in turn serves to signal our own good reputation to others (Bradley et al., 2018).

A way to test whether prosocial behaviour is used to signal good reputation is by comparing how people behave in the presence or absence of an audience. Tasks like economic games are useful to measure prosocial behaviour in the lab: because they usually have repeated trials, this facilitates reputation building between participants in the game (Bradley et al., 2018; T. Pfeiffer & Nowak, 2006). For instance, Filiz-Ozbay and Ozbay (2014) used the Public Goods game and found that people invest more effort to contribute to public, but not private, goods when someone is observing them. Izuma and colleagues (2011) used the Dictator game (Guala & Mittone, 2010; Kahneman, Knetsch, & Thaler, 1986) as a donation task, where participants receive a sum of money and must decide on repeated trials whether to accept a proposal to share the money with a charity, or reject it and keep all the money (see also Cage, Pellicano, Shah, & Bird, 2013). Results showed that in the presence of a confederate who pretended to monitor the answers, participants decided to accept the proposed sharing more often than when they were alone in the room. These findings clearly illustrate how participants manipulate the beliefs of the observer to maintain their good reputation.

1.4.2. Factors modulating audience effects on prosocial behaviour

A recent meta-analysis has found a number of factors that modulate how strong the audience effect is on prosocial behaviour (Bradley et al., 2018).

For the scope of this thesis, here I will focus on two of these factors: the type of stimuli used to recreate absence and presence of an audience, and the type of task participants perform.

First, Bradley and colleagues (2018) compared how strong the audience effect was depending on the type of audience. They categorised different audiences in four groups: absence of real audience (e.g. picture of eyes), the audience is the experimenter, the audience is another participant performing the task, or the audience is a passive observer (i.e. someone who does not conduct the study or complete the task, such as a confederate). They found that audience effects were stronger when the audience was a passive observer than when there was no real audience or the audience was another participant. This is in line with another meta-analysis showing that artificial audience cues (e.g. pictures of eyes) have no effects on prosocial behaviour (Bateson, Nettle, & Roberts, 2006; Northover, Pedersen, Cohen, & Andrews, 2017), and further suggests that audience effects might be due to the high level of scrutiny experienced when someone is just watching us. However, this finding and previous studies have a main limitation: they compare a situation where participants are alone in the room versus a situation where participants are in the presence of an audience (e.g. Filiz-Ozbay & Ozbay, 2014; Izuma et al., 2011, 2009, 2010). This design is not optimal to strictly test whether prosocial behaviour is used to signal good reputation in front of an audience, since effects could be related to the presence of another person rather than to the mere belief that this person can perceive me: using control and test conditions that are both social would be a more appropriate test for audience effects.

Second, Bradley and colleagues (2018) compared how audience effects are modulated depending on the type of task participants perform. Traditionally, research on prosocial behaviour has used two types of economic tasks: social dilemmas (e.g. Public Goods game) and bargaining games (e.g. Dictator game). A key difference between both is that social dilemmas generate a conflict between short-term self-interests and long-term collective interests, whereas bargaining games involve a trade-off between short-term personal and others' interests (Bradley et al., 2018; Larrick & Blount, 1997; Van Lange, Joireman, Parks, & Van Dijk, 2013). Bradley and colleagues (2018) found that audience effects were stronger in social dilemmas than in bargaining games, suggesting that contribution to collective resources is a stronger motivator for reputation management than short-term individual interests. However, it has been recently noted that economic games have poor external validity when they are compared to field situations (e.g. choose whether to help someone else moving a big box) and self-reports on past prosocial behaviours (Galizzi & Navarro-Martinez, 2019). Thus, it remains to be seen whether the presence of an audience modulates prosocial behaviour in tasks other than economic games.

1.4.3. Summary

A recent proposal suggests that changes in prosocial behaviour when being watched aim to signal good reputation (Bradley et al., 2018). Various studies provide support for this hypothesis: participants behave more prosocially in the presence of an audience than in its absence (Cage et al., 2013; Filiz-Ozbay & Ozbay, 2014; Izuma et al., 2011, 2009). However, these studies have two main limitations: they do not strictly test effects related to the belief that someone can perceive me (i.e. audience effect), and they use tasks that have poor external validity. Therefore, a core aim in this thesis was to use more closely matched experimental conditions to test the hypothesis that prosocial behaviour is used as a social signal. This was tested on a novel task that tried to better reflect prosocial behaviour of participants in their everyday life.

1.5. The Watching Eyes model

The dual function of eye gaze, the behavioural ecology view of facial displays and reputation management theory present plausible explanations of how being watched modulates our behaviour to send signals to others. While all these theories imply that individuals somehow process the perceptual state of the partner (i.e. can the partner see me?), the specific cognitive mechanisms by which the belief in being watched translates into behavioural changes are not yet understood. In this section I review the Watching Eyes model (Conty, George, & Hietanen, 2016) and propose that it can help us understand how being watched triggers changes in behaviour.

Early work on gaze processing proposed various mechanisms how direct gaze modulates our attention and behaviour. For instance, Baron-Cohen (1995) suggested that there is a specialised Eye Direction Detector module in the brain. This module rapidly identifies whether we are the target of someone else's attention by processing the direction of other people's eyes relative to us. The detection of direct gaze will in turn trigger mentalising processes that allow us to interpret the other person's mental states (Baron-Cohen & Cross, 1992; Baron-Cohen et al., 1997). Later, Senju & Johnson (2009) coined the term "eye contact effect" to describe changes in cognitive processing following perception of direct gaze, and introduced the Fast-track Modulator model of gaze processing. This model suggests that detection of direct gaze is implemented by a fast subcortical route involving the pulvinar and amygdala, and is modulated by higher cortical regions that depend on social context and task demands. The Watching Eyes model (Conty et al., 2016) builds up on these models and suggests that eye contact effects are due to the "self-referential power of direct gaze".

Similar to the Fast-track Modulator model by Senju & Johnson (2009), the Watching Eyes model proposes two stages in the processing of direct gaze. In the first stage, direct gaze captures the beholder's attention by a subcortical route. This seems to be an automatic effect of direct gaze (Senju & Hasegawa, 2005), and is thought to be triggered by the detection of low-level visual cues in eye gaze (e.g. luminance distribution in the eye; Kobayashi & Kohshima, 2001; von Grünau & Anston, 1995). Then, the subcortical route engages mentalising brain areas (medial prefrontal cortex and temporo-parietal junction) that process the perceptual state of the observer, that is, the belief that s/he is or is not watching us. In the second stage, if the observer can see us, then direct gaze will elicit self-referential processing, and the sense of self-involvement in the interaction will increase. This will lead to the Watching Eyes effects, causing a change in behaviour in various ways, such as enhancement of self-awareness (Baltazar et al., 2014; Hazem, George, Baltazar, & Conty, 2017; Pönkänen, Peltola, & Hietanen, 2011) or promotion of prosocial behaviours (Izuma et al., 2011, 2009), among others.

Recently, J. O. Hietanen and Hietanen (2017) have directly tested the Watching Eyes model of self-referential processing. To measure self-referential processing they used the foreign-language task, where participants read sentences in a language that they do not understand and need to match underlined words with pronouns in their native language. In this task, more use of first person singular pronouns is thought to be related to more self-referential processing. Participants completed this task but they watched a video-clip of a person with direct or averted gaze before each sentence was presented. Results showed no effect of eye gaze direction on the pronouns used. Then, a second group of participants completed the same task while they watched live faces with direct or averted face. They found that participants in the direct gaze group used more first person singular pronouns than the averted gaze group. These findings provide evidence in favour of the Watching Eyes model: to trigger self-reference it is not enough to see a pair of eyes directly gazing at us – the belief that these pair of eyes can see us is also required.

Nonetheless, it is not yet known whether audience effects are mediated by self-referential processing: does the belief in being watched trigger self-reference in the same way that direct gaze does? Interestingly, a recent study on bodily self-awareness (Hazem et al., 2017) found that participants are more accurate in rating the intensity of a physiological signal when they believe they are in online connection with someone wearing clear sunglasses (eyes are not visible but the observer can see through) rather than someone wearing opaque sunglasses (eyes are not visible and the observer cannot see through). The fact that the mere belief in being watched is enough to increase self-awareness suggests that the "self-referential power" of live direct gaze might be linked to the belief that a pair of eyes can see me. Thus, this thesis aimed to test the hypothesis that audience effects are mediated by self-referential processing.

1.5.1. Summary

The Watching Eyes model (Conty et al., 2016) has proposed that changes in behaviour following eye contact can be explained by an increase in self-referential processing upon the detection of direct gaze. In line with this, it has been shown that, when participants believe the interaction is live, direct gaze increases self-referential processing (compared to averted gaze) (J. O. Hietanen & Hietanen, 2017). However, it remains to be seen whether an increase in self-referential processing can be triggered by the mere belief in being watched. This could provide a mechanism to explain how being watched activates reputation management or the dual function of gaze. This thesis aimed to address this question.

1.6. Reciprocity in social interactions

So far, I have reviewed four cognitive theories that provide plausible mechanisms to understand how the belief in being watched modulates social signals, particularly eye gaze, facial displays and prosocial behaviour. In the studies presented above, aimed at testing audience effects, participants complete a task where they share some information while an audience (e.g. confederate) is or is not watching them, yet the audience does not share any information with participants. This is particularly true in studies looking at reputation management, where audiences usually have a passive role in the task and just observe the participant without providing any feedback or making choices. These situations are far from daily social interactions, where we reciprocally exchange information with each other. In this section, we focus on *reciprocity* as a key component of real-life social interactions that, beyond the belief in being watched, might also modulate how we use social signals.

Reciprocal social interactions require interacting partners "to explicitly take on complementary and alternating roles throughout the course of the interaction" (Redcay & Schilbach, 2019). For instance, during conversation participants alternate between speaker and listener roles, or during economic games participants alternate between investor and trustee roles. Importantly, for an interaction to be reciprocal participants need to be mutually engaged with each other, that is, they need to jointly share information addressed to one another and integrate a variety of incoming social signals (Di Paolo & De Jaegher, 2012; Hasson & Frith, 2016; Redcay & Schilbach, 2019). Mutual sharing of information also provides a common ground for the interaction, upon which subsequent communicative exchanges are built. This means that, for successful progression of reciprocal interactions, participants need to update their knowledge about a partner with new incoming information they learn or receive from social signals.

Previous studies have explored the role of reciprocity during reputation management using iterative economic games, where players need to build models of the other player's intentions to guide their own choices and predict the other's actions. For instance, the medial prefrontal cortex (mPFC) and temporo-parietal junction (TPJ), which are part of the mentalising network, show greater activity when playing against human partners than against a computer (Gallagher, Jack, Roepstorff, & Frith, 2002; Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Tang et al., 2016). Particularly, the TPJ seems to have a key role in tracking information that is relevant to predict others' future choices (Carter, Bowling, Reeck, & Huettel, 2012). Another study found that activity in the caudate, a region involved in reward learning, changed over the course of a trust economic game (King-Casas et al., 2005): while at the start of the game it was engaged *after* the payments of the other player were revealed, towards the end it was engaged *before* the payment was revealed. This suggests that, over time, the caudate incorporated information about previous exchanges in order to compute predictions about future exchanges. These findings are consistent with single-participant studies on reputation management, where brain areas linked to mentalising and reward processing show greater activity when participants need to manage their reputation (Izuma, 2012; Izuma et al., 2009, 2010).

However, there are two main limitations in these studies. First, they happen in neuroimaging environments that are restricted for the study of face-to-face interactions (e.g. functional magnetic resonance imaging, fMRI): this means that participants are isolated inside the scanner and there is no exchange of social signals, which are crucial in shaping the relationship between partners. Instead, new techniques like functional near-infrared spectroscopy (fNIRS) offer the possibility to simultaneously record brain activity of two participants interacting face-to-face. Second, these studies are based on economic games that have poor external validity (Galizzi & Navarro-Martinez, 2019). Thus, it is unknown how reciprocally sharing (non-monetary) information in face-to-face interactions modulates brain activity.

1.6.1. Summary

During reciprocal social interactions we engage in mutual sharing of information with each other (Redcay & Schilbach, 2019). In these situations our behaviour is modulated, not only by the belief in being watched, but also by the integration of social signals with new information we learn about others.

However, previous studies have used neuroimaging methodologies that are restricted for the study of face-to-face interactions. Using fNIRS, this thesis examined how brain activity related to information sharing and social signals (eye gaze and facial displays) are modulated by reciprocal disclosure of biographical information in face-to-face interactions.

1.7. Measuring social interactions

Throughout this chapter I have focused on how “breaking the fourth wall” in social neuroscience research has critical theoretical implications on previous cognitive and neural models of social information processing (Redcay & Schilbach, 2019; Risko et al., 2016; Schilbach et al., 2013). However, it also imposes great methodological challenges when it comes to measuring social interactions, since researchers need to record social behaviours and brain activity in much more flexible environments than a lab booth or the MRI scanner. Thus, second-person neuroscience has come hand in hand with the development of novel techniques that can be used in much more ecologically valid tasks and settings. For the scope of this thesis, in the following I briefly introduce how eye gaze, facial displays and brain activity can be measured in face-to-face interactions.

1.7.1. Measuring eye gaze

The first eye-tracker was built in 1908 by Edmund Huey to record eye movements while reading (Huey, 1908): this system used a contact lense with a hole for the pupil, attached to an aluminium pointer that moved following eye movements. Less intrusive eye-trackers were pioneered by Guy Thomas Buswell in the 1930s, using beams of light that were reflected on the subject’s eyes and recorded on a film (Buswell, 1935, 1938) (Figure 1-4a). At the same time, Fenn & Hursh introduced the electro-oculography (EOG) method, which used electrodes placed around the eye to measure the voltage induced by eye movements (Fenn & Hursh, 1936). Later on, Yarbus introduced his well-known retinal stabilisation technique in the form of a suction cup (Yarbus, 1967). With the advent of computers, eye movement research experienced rapid progress in the 1970s and 1980s, which culminated in the development of non-intrusive, highly accurate and low-cost eye-tracking systems that are used nowadays.

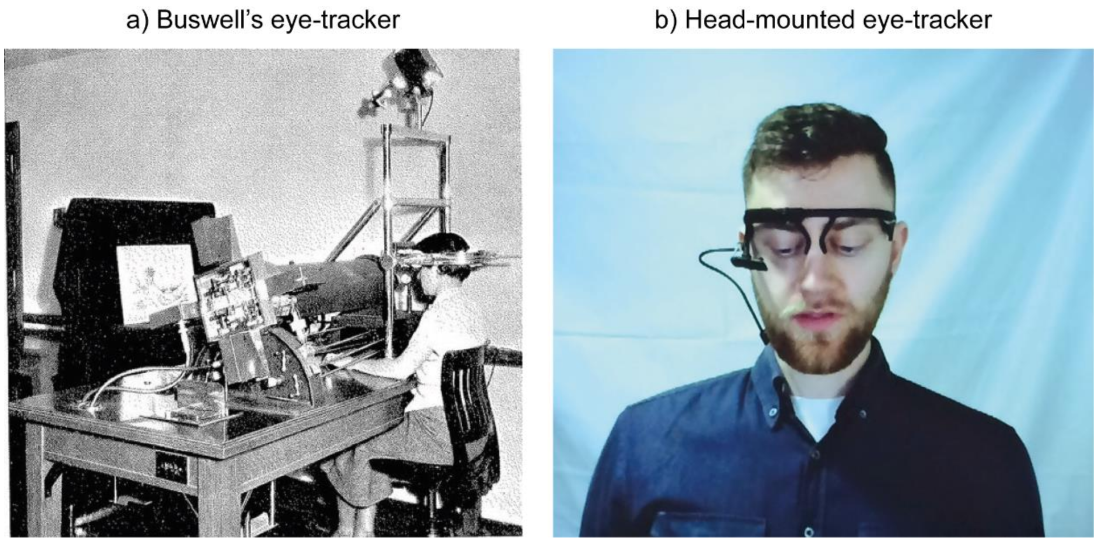

Figure 1-4. Eye-tracking systems.
a) Photograph of Buswell's eye-tracking system based on light beams (1930s). b) Photograph from the study reported in Chapter 4, showing a head-mounted eye-tracking system combining infrared and "world" cameras (Pupil Labs).

Modern eye-tracking systems are of two types. Video-based eye-trackers estimate gaze direction from the images recorded with a video-camera. However, this requires algorithms that can detect the face and eyes of the person being recorded. A more straightforward system is found in eye-trackers that use infrared light (which are the ones used in this thesis). In this system, a source sends infrared light (which is invisible to our eye) to the frontal surface of the eyeball and a detector measures the amount of light that is reflected by the pupil, which will vary depending on the eye's position (Singh & Singh, 2012). In both cases, eye-trackers sample eye movements at rates around 30 or 60 Hz, although some video-based systems can go as high as 1000 Hz. Moreover, while older eye-trackers recorded eye movements in relation to the head, these systems allow researchers to record eye movements in relation to their surroundings (Richardson & Spivey, 2004). For instance, table-based eye-tracking systems usually use a chin-rest to ensure the head is immobilised and accurately measure which location on the screen participants look at. More recently, head-mounted eye-trackers combine eye movement recordings with images from a camera that records the subjects' field of view (Figure 1-4b): this allows individuals to naturally move their head and body while performing a task or interacting with another person, and has been crucial for the study of eye gaze in face-to-face interactions.

Along the emergence of cognitive research, eye movements were studied to learn how people scan and process visual information. With this scope, two main types of eye movements have been identified. First, fixations are periods of time where our eyes are locked to a target, holding the fovea towards that target to process high-resolution information. Fixations are usually around 50-600 ms long, and are thought to reflect interest in, and processing of, that particular target (Rayner, 2009; Yarbus, 1967). Second, saccades are rapid eye movements between fixations, which allow us to scan visual scenes and relocate the point of attention (Liversedge & Findlay, 2000). From these two types of eye movements, there is a wide range of metrics that researchers have used to quantify gaze behaviour (Borys & Plechawska-wójcik, 2017): duration of fixations, number of fixations, time to first fixation, saccade amplitude and saccade velocity are some examples.

Throughout this thesis, the main measure used for eye gaze was the proportion of looking time to a specific target or region of interest (ROI), also known as total dwell time or proportion of fixation time. This measure corresponds to the total amount of time that participants spend looking at a specific ROI relative to the total duration of the task and, similar to duration or number of fixations, it reflects interest and high relevance of the ROI to the task at hand. In the context of this thesis, the proportion of looking time allowed us to measure how the belief in being watched modulates which ROI (e.g. eyes or mouth of a confederate) is most relevant over the course of a structured conversation.

1.7.2. Measuring facial displays

Facial displays are visible facial movements (e.g. changes in distance between facial features, display of wrinkles on the skin) that correspond to the contraction of one or several facial muscles (Barrett et al., 2019). Based on such muscle contractions, two main methods have been developed to quantify the production of facial displays: facial electromyography and the Facial Action Coding System.

Facial electromyography (fEMG) relies on the detection of electrical activity generated by facial muscles when they contract (Tassinary & Cacioppo, 1992), by placing electrodes on the participant's face. Although fEMG provides an objective measure of facial movements, it is limited by the fact that the face can only tolerate simultaneous attachment of few electrodes (Barrett et al., 2019). Thus, most studies using fEMG have focused on two facial displays: frowning (linked to the muscle *corrugator supercilii*) and smiling (linked to the muscle *zygomaticus major*). Moreover, fEMG does not allow participants to freely move their head while performing a task. This means that fEMG is restricted to measure facial displays in ecologically valid face-to-face interactions.

The Facial Action Coding System is a much more flexible technique to measure facial displays. It relies on video recordings of faces to detect movement of facial muscles over the whole face (Ekman & Friesen, 1976). This system is exclusively descriptive and it provides information about the presence and intensity of different muscle movements. A second step is then required to identify facial Action Units (AUs), which are visible facial movements that correspond to the contraction of one or several facial muscles (Barrett et al., 2019). The detection of facial AUs has traditionally required manual coding by highly trained researchers, but this is time-consuming and hard to do on spontaneous facial movements. Luckily, the development of computer-vision algorithms that can automatically taxonomise facial AUs from video recordings has largely addressed this issue, although they require faces to be well-illuminated and recorded from the front (Benitez-Quiroz, Srinivasan, & Martinez, 2016). This thesis used the OpenFace algorithm (Baltrusaitis, Robinson, & Morency, 2016) to measure the levels of facial motion produced by participants during a structured conversation. Note that, although the original Facial Action Coding System detected over 60 facial AUs (Ekman & Friesen, 1976), OpenFace recognises a subset of 18 facial AUs, distributed over the eyes, nose, cheeks, mouth and chin.

1.7.3. Measuring brain activity

Traditional functional neuroimaging techniques (e.g. fMRI, EEG) have been crucial to understand how our brain implements a variety of cognitive processes, such as attention, memory or decision-making. However, these techniques can only be implemented in controlled laboratory settings that require participants to stay still. This means that they are restricted for the study of brain systems recruited in social interactions, where participants naturally move their face, head and body to communicate with others. Luckily, these limitations can be overcome by functional near-infrared spectroscopy, a novel neuroimaging technique that can record brain activity during face-to-face interactions (Pinti, Tachtsidis, et al., 2018).

Functional near-infrared spectroscopy (fNIRS) is an optical and non-invasive neuroimaging technique that records changes in concentration of oxygenated (OxyHb) and deoxygenated (deOxyHb) haemoglobin in the cortex (Boas, Elwell, Ferrari, & Taga, 2014; Ferrari & Quaresima, 2012; Pinti, Tachtsidis, et al., 2018). This technique uses a headset with light sources and detectors that is placed on the scalp of participants (Figure 1-5). Sources send near-infrared (NIR) light into the head at a wavelength between 650-950 nm. Since NIR light is not absorbed in tissues with high amount of water, it will travel through the scalp, skull and cerebrospinal fluid, until it reaches the brain. In the brain, NIR light will be partly absorbed by OxyHb (>800 nm) and deOxyHb (<800 nm) in the blood, which are the most dominant absorbing chromophores for NIR light. The light that is not absorbed will be scattered by the brain tissue and captured by detectors in the headset. Then, the amount of detected NIR light is converted to optical density and, using the modified

Beer-Lambert Law, to concentration of OxyHb and deOxyHb. Importantly, the amount of OxyHb and deOxyHb in a specific brain region depends on metabolic demands for oxygen when that region is active. Thus, similar to fMRI, the haemodynamic signal is taken as a proxy for brain activity (Cui, Bray, Bryant, Glover, & Reiss, 2011).

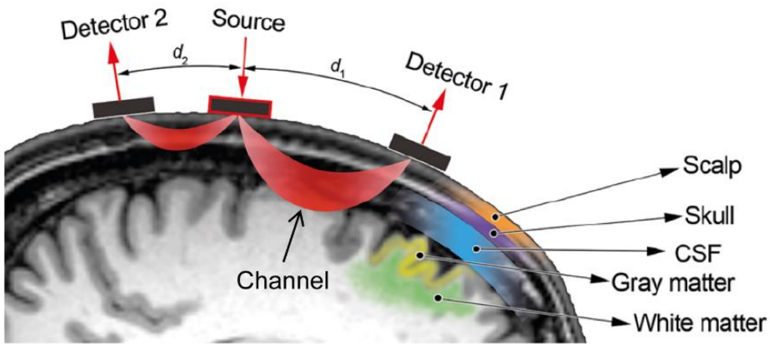

Figure 1-5. fNIRS system.
Diagram showing the NIR light stream (in red) between sources and detectors, through different biological tissues (modified from Pinti et al. 2018 under the Creative Commons Attribution License).

It is also important to compare the quality from fNIRS signals to those from other neuroimaging techniques. On the one hand, fNIRS measurements are taken at the midpoint between the source and the detector (i.e. channel; Figure 1-5), where the depth of the NIR light corresponds to half the distance between the source and the detector (usually around 1.5 cm deep) (Pinti, Tachtsidis, et al., 2018). This means that fNIRS has low penetration depth and can only measure brain activity in outer layers of the cortex. Moreover, it has poor spatial resolution compared to fMRI (but better than EEG) and is sensitive to systemic artifacts associated with breathing and blood pressure (Lloyd-Fox, Blasi, & Elwell, 2010). On the other hand, fNIRS has better temporal resolution than fMRI (but poorer than EEG) and, as mentioned earlier, lower sensitivity to motion artifacts and high portability (Lloyd-Fox et al., 2010; Pinti, Tachtsidis, et al., 2018). This is particularly important for the study of brain systems involved in face-to-face interactions, where participants naturally move their body to communicate with each other. In line with this, fNIRS has been widely used in two-person studies and has been shown to be a promising and reliable tool for the study of brain systems linked to social interactions (e.g. Cui, Bryant, & Reiss, 2012; Hirsch, Noah, Zhang, Dravida, & Ono, 2018; Hirsch, Zhang, Noah, & Ono, 2017; Jiang et al., 2012). Taking advantage of this, this thesis used fNIRS to simultaneously measure brain activity of two participants while they were interacting face-to-face, with the aim to investigate which brain systems are engaged during reciprocal social interactions.

1.7.4. Summary

Taking a second-person neuroscience approach when studying social interactions imposes a challenge to previous theoretical models of social information processing, but also to the techniques used to quantify social interactions. The development and optimisation of novel methodologies, such as wearable eye-trackers, face tracking algorithms or fNIRS, allow researchers to measure eye gaze, facial displays and brain activity in high ecologically valid settings, where participants engage in face-to-face interactions. These state-of-the-art methodologies were used throughout this thesis to investigate which cognitive and neural mechanisms underlie audience effects.

1.8. Overview of experimental chapters

In this chapter I have reviewed four theories that provide plausible explanations of audience effects. On the one hand, the dual function of gaze, the behavioural ecology view of facial displays and reputation management theory propose different mechanisms whereby eye gaze, facial displays and prosocial behaviour are modulated to send signals when being watched. On the other hand, the Watching Eyes model (self-referential processing) can help us explain how being watched activates these cognitive mechanisms. I have also described how reciprocity in social interactions might further modulate the use of these social signals, beyond mere audience effects. Finally, I have reviewed novel methodologies that are key to measure social behaviours and brain activity in live interactions.

This thesis aimed to address limitations in the current research to rigorously investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched (and in reciprocal interactions), particularly focusing on eye gaze, facial displays and prosocial behaviour. The specific questions addressed in each chapter are outlined below:

1. Does being watched modulate gaze and prosocial behaviour?

Chapter 2 used a novel well-controlled ecologically valid paradigm to test which mechanisms underlie audience effects on eye gaze and prosocial behaviour, as well as the relationship between changes in these social behaviours. For this, participants completed a communicative task where they disclosed their prosocial tendencies in everyday life situations. I found that the opportunity to signal good reputation increases prosocial behaviour, while the signalling function of the eyes decreases gaze to the confederate. Moreover, participants seek the confederate's feedback when they make less prosocial choices.

2. Is self-referential processing related to audience effects when being watched?

Chapter 3 tested the hypothesis that changes in behaviour are related to an increase in self-referential processing when being watched. Using the same paradigm as in Chapter 2, this chapter combined tasks measuring prosocial behaviour, self-referential processing and self-awareness. Results showed no evidence in favour of this hypothesis.

3. Does being watched modulate the time-course of typical and autistic eye gaze and facial displays during conversation?

Chapter 4 comprises two studies that explored how being watched modulates gaze patterns and spontaneous facial displays in typical and autistic individuals. This chapter especially focused on the time-course of eye gaze and facial displays in relation to speech, and how the dual function of gaze is used over time. Contrary to our hypotheses, results showed that high-functioning autistic participants are able to use eye gaze and facial displays as social signals.

4. Do reciprocal interactions modulate social signals and brain activity during mutual information sharing?

Chapter 5 investigated whether, beyond being watched, reciprocity between partners modulates social signalling and brain activity when pairs of participants disclose biographical information. I found that reciprocity increases gaze directed to the partner's face and spontaneous production of facial displays. Moreover, it recruits brain regions linked to mentalising and strategic decision-making. Finally, I also identified two brain regions engaged during spontaneous production and observation of facial displays during face-to-face interactions.

Chapter 2. Effects of being watched on eye gaze and prosocial behaviour

The results of Chapter 2 were published in Acta Psychologica:

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2.1. Abstract

When someone is watching you, you may change your behaviour in various ways: this is called the “audience effect”. Social behaviours such as acting prosocially or changing gaze patterns may be used as signals of reputation and thus may be particularly prone to audience effects. This chapter aimed to test the relationship between prosocial choices, gaze patterns and the feeling of being watched within a novel ecologically valid paradigm, where participants communicate with a video-clip of a confederate and believe she is (or is not) a live feed of a confederate who can see them back. Results showed that when participants believe they are watched, they tend to make more prosocial choices and they gaze less to the confederate. We also found that the increase in prosocial behaviour when being watched correlates with social anxiety traits. Moreover, we show for the first time a relationship between prosocial choices and subsequent gaze patterns of participants, although this is true for both live and pre-recorded interactions. Overall, these findings suggest that the opportunity to signal a good reputation to other people is a key modulator of prosocial decisions and eye gaze in live communicative contexts. They further indicate that gaze should be considered as an interactive and dynamic signal.

2.2. Introduction

We naturally care about how other people judge us, that is, our reputation. When our reputation is at stake, we change our behaviour in order to maintain it, because this makes us appear likeable to others (Emler, 1990; Tennie et al., 2010). A subtle but recurrent “threat” to our reputation is whether other people are watching us or not. This chapter explored how the belief in being watched modulates two behaviours that acquire a signalling function in the presence of an observer: prosocial actions (Bradley et al., 2018; Izuma et al., 2011) and eye gaze (Gobel et al., 2015; Laidlaw et al., 2011). We studied these changes in a conversation context, using a novel well-controlled experimental paradigm. For the first time we also examine the relationship between gaze of participants and their prosocial choices, and propose that this relationship can help identifying which social cognitive processes modulate gaze behaviour in live versus pre-recorded interactions. In the following, we briefly review studies of how people respond when being watched in a variety of contexts.

2.2.1. Reputation management and being watched

Theories about how people change their behaviour in the presence of other people were first introduced by Triplett in 1898, when he discovered that cyclists were faster when competing against each other than against a clock (Triplett, 1898). He stated that the “bodily presence of another” caused a change in the behaviour of participants, making them more competitive when racing. As highlighted in Chapter 1, it is important here to distinguish between “social facilitation” (Zajonc, 1965), which is an enhancement of performance in the presence of any conspecific (who may or may not be looking), and “audience effects”, which are changes in behaviour specifically caused by the belief in being watched. Here we focus on the latter.

An increasing number of studies suggest that audience effects can best be understood in terms of reputation management (Emler, 1990; Resnick, Zeckhauser, Swanson, & Lockwood, 2006; Tennie et al., 2010). Reputation is a social construct that emerges from how we think others see us, and is changeable over time depending on our actions (Cage, 2015; Izuma, 2012). For instance, acting for the benefit of other people or conforming to social norms are two examples of how individuals can signal their good reputation to gain approval of others. The maintenance or management of reputation requires individuals to infer what others think of them, care about how they are seen, and have the desire to be viewed positively (Cage, 2015; Izuma, 2012). This means that reputation management requires both mentalizing and social motivation (Cage, 2015; Izuma, 2012; Saito et al., 2010; Tennie et al., 2010). This is supported by neuroimaging studies showing that brain regions involved in these two cognitive processes are activated during different phases of reputation management. For instance, the medial prefrontal cortex (a neural correlate for mentalizing; Frith & Frith, 2006) is activated when processing one’s reputation in the eyes of other people (Izuma, 2012; Izuma et al., 2010). Moreover, a region involved in motivation and reward processing, the ventral striatum, is engaged when participants anticipate positive reputation after presenting themselves in front of others (Izuma, 2012; Izuma et al., 2009, 2010).

When people are observed by others, one way to signal their reputation is by behaving in a more prosocial fashion (Bradley et al., 2018; Smith & Bird, 2000). Several real-life studies have shown that the possibility of gaining reputation in front of others is a key factor to increase prosocial behaviour (e.g. Bereczkei, Birkas, & Kerekes, 2007; Raihani & Smith, 2015; Soetevent, 2005). Lab-based studies, which allow for better experimental control, also show similar results. For instance, Satow (1975) used a single-trial task and found that in the presence of an experimenter participants donate more money to a research fund than in its absence. Other studies have used economic games, which facilitate reputation building between subjects in the game by having more trial repetitions than single-trial tasks (Bradley et al., 2018; T. Pfeiffer & Nowak, 2006). Using the Public Goods game, Filiz-Ozbay & Ozbay (2014) showed that being watched by another participant increases the amount of effort exerted to contribute to public, but not private, goods. In another study Izuma and colleagues used the Dictator game (Izuma et al., 2011): on each trial participants were given a specific amount of money and had to decide whether to give some of this money to someone else (e.g. charity; prosocial behaviour) or keep it all for themselves (non-prosocial behaviour). They found that participants donated money more often while monitored by a confederate than when alone in a room, which can be interpreted as reputation management. Cage and colleagues (Cage et al., 2013) replicated this finding and also found that, when the recipient was an individual (not a charity) who could later reciprocate to the participant, the number of donations was higher in the presence than in the absence of an observer. These studies are clear examples of participants manipulating the information they signal to other people in order to maintain good reputation.

These studies have two main limitations. On the one hand, the control and test conditions are not optimally matched to strictly isolate effects of the belief in being watched: they compare a control condition where the participant is alone in the room, versus a test condition where an observer is present in the room or in a video-feed (see Izuma et al., 2010, 2009 for examples of studies with a video-feed). Instead, control and test conditions that are both social would be more suitable to test true audience effects. In this chapter we used more closely matched experimental conditions that vary only in the belief in being seen, to understand how a belief manipulation alone (without any changes in the presence of the confederate) affects reputation management. On the other hand, although prosocial behaviour has been traditionally measured by economic games, such as the Public Goods or Dictator games, concerns have been raised about their external validity (Galizzi & Navarro-Martinez, 2017; Winking & Mizer, 2013). Thus, here we compared how the belief in being watched modulates prosocial behaviour in the Dictator game and in a novel task where participants disclose their prosocial tendencies in everyday life situations.

2.2.2. Gaze behaviour and being watched

Our eyes have a dual function in social interactions: they gather information from the world, but also send signals to other people (Gobel et al., 2015; Risko et al., 2016). For instance, direct gaze signals a desire to communicate (Ho et al., 2015; Kendon, 1967), it monitors facial displays of the other person to ensure mutual understanding (Kleinke, 1986), it expresses affiliation or (dis)agreement (Kendrick & Holler, 2017), attractiveness (Georgescu et al., 2013), and threat or dominance (Emery, 2000; Gobel et al., 2015). Conversely, averted gaze has been linked to preference for no interaction (Foulsham et al., 2011), conformity with social or cultural norms (Gobel, Chen, & Richardson, 2017; Gobel et al., 2015; Laidlaw et al., 2011; also known as "civil inattention", Goffman, 1963), and fear or submissive behaviour (Emery, 2000; Gobel et al., 2015). The variety of social meanings that our eyes can convey makes our gaze a powerful tool for social interactions.

Although the dual function model of eye gaze was first introduced in the 70s (Argyle & Cook, 1976), many studies have ignored it. In traditional experimental settings, participants see pictures or videos of a person while their gaze or other actions are recorded (see Risko et al., 2012 for a review), but they are fully aware that the pictures or videos cannot see back. Thus, participants are not signalling anything to the person in the stimulus because it makes no sense to communicate with a picture unable to perceive them. These traditional approaches allow good experimental control but are not interactive (Gobel et al., 2015; Schilbach et al., 2013), and it is increasingly recognised that understanding the cognitive mechanisms of social behaviour will require more than just one-way picture stimuli.

A few recent studies have examined how people’s gaze behaviour changes when they believe they are being watched, that is, when gaze acquires a signalling function. For instance, Laidlaw and colleagues (2011) measured the looking behaviour of participants with eye-tracking as they were sitting in a waiting room, either in a presence of a confederate or in the presence of a video-clip of the same confederate. It was found that participants tended to look at the confederate in the video-clip, but seldom looked at the live confederate. In another study, Gobel and colleagues (Gobel et al., 2015) used eye-tracking to explore how participants changed gaze patterns when they believed they would later be viewed by another person. Participants watched video-clips of high and low rank people while their face was recorded. Results showed that, if participants believed the person in the video would later see the recordings, the ratio of gaze directed to eyes relative to gaze directed to mouth increased for the low rank model, and decreased for the high rank model. In these studies, the authors suggest that averted gaze in live (versus pre-recorded) settings signals the activation of previously acquired social norms, by which it is not polite to stare at someone (Gobel et al., 2017). The effect of these social norms translates into active gaze disengagement because participants do not want to appear as either someone impolite or as an interaction partner to the stranger (Foulsham et al., 2011).

There is a main limitation to these previous studies: participants believe they are interacting with a stranger with whom they are not supposed to talk to, that is, there is no communicative exchange between them. These results may not generalise to all social contexts. For instance, it has recently been shown that it is the potential for social interaction, rather than online social presence, which modulates eye gaze in video-conference contexts (Gregory & Antolin, 2018). Mansour & Kuhn (2019) have also shown that when participants are required to actively engage with the confederate, they direct more gaze to the eyes of the confederate in the live video-call than in the pre-recorded video-call. Thus, communicative (e.g. conversation) and non-communicative environments may engage a series of cognitive processes that modulate differently the amount of gaze directed to a live person. In this chapter, we tested if gaze signalling patterns change between a live and pre-recorded setting in the context of a question-answer task, where it is clear that participant and confederate should communicate.

2.2.3. Relationship between prosocial and gaze behaviour

In communicative situations we send information through eye gaze, but also through speech, facial expressions and gestures. To further understand the meaning of gaze patterns, it is useful to consider gaze in relation to other events in the communicative exchange: this can help identifying which cognitive mechanisms modulate eye gaze in live interactions. Previous studies on eye gaze have found that eye contact elicits more prosocial behaviour (Bull & Gibson-Robinson, 1981) and that we engage in mutual gaze to seek approval from others (Efran, 1968; Efran & Broughton, 1966). However, we are not aware of previous studies examining temporal relationships between gaze patterns and prosocial behaviour. Thus, a core question in the present study was to see if and how these behaviours are related. We can draw out at least two plausible hypotheses.

First, we can consider how gaze patterns before a prosocial decision relate to what decision is made. For example, if two people share mutual gaze, this may increase their prosocial behaviour (see Bull & Gibson-Robinson, 1981 for an example). Similarly, gaze to another person can be an indicator of how much you are interested in that person or care about them, which might predict later prosocial responses to that person. In this case, a relationship between gaze patterns before making a choice and a prosocial choice itself would indicate that social attention influences prosocial choices (social attention hypothesis). This could occur regardless of whether the participant is interacting with a video or another person.

Second, we can consider how making a prosocial or antisocial decision changes gaze patterns after this decision. For example, after making a donation to a charity someone may look to others to receive their approval or to seek more information about what they think (Efran, 1968; Efran & Broughton, 1966; Kleinke, 1986). Building on this idea, we suggest that if there is a relationship where choices predict later gaze patterns, this might indicate that participants are engaged in a process of reputation management (reputation management hypothesis). However, this should only occur if people believe they are engaged in a live interaction with a real person.

Thus, the relationship between gaze patterns and prosocial choices can help us understand some of the underlying cognitive processes which drive these behaviours, and show if either social attention or reputation management are important in these contexts.

2.2.4. The present study

This chapter aimed to gain a better understanding of how the belief in being watched modulates prosocial and gaze behaviours as signals to maintain a good reputation. Our specific aims were the following. First, to compare whether two different types of prosocial behaviour that can signal good reputation - monetary donations and disclosure of prosocial tendencies - show similar changes between a live and pre-recorded interaction. Economic games have been recently reported to have poor external validity (Galizzi & Navarro-Martinez, 2017; Winking & Mizer, 2013), so it is helpful to know whether changes in monetary donations and changes in disclosure of prosocial tendencies are consistent. Second, to examine the signalling function of eye gaze (between a live and pre-recorded interaction) when participant and confederate are in a communicative situation. This will clarify whether results from previous studies using non-communicative contexts (Gobel et al., 2015; Laidlaw et al., 2011) generalise to other social contexts. Finally, we aimed to study for the first time the relationship between prosocial behaviour and eye gaze. This can help us understand which cognitive processes - social attention or reputation management - drive these behaviours.

To do this, we designed a deceptive video-conference interface that participants would use to complete the study. This novel experimental paradigm allows for well-matched control and test conditions but at the same time preserves enough ecological validity (see Mansour & Kuhn, 2019 for a recent paper using a similar paradigm), which ensures that changes in behaviour are true audience effects. The main desktop of the interface showed three different boxes: the Video box, where the video-feed was presented, the Question box, where the questions appeared, and the Answer box, where the options for the answer were shown (see Figure 2-1a). In our deceptive manipulation we used the same video-clips of two confederates across two settings: one where participants believed the video-feed was real (online setting; ON), and one where they were told the videos were pre-recorded (offline setting; OFF). This ensured high ecological validity for the ON setting and, at the same time, the use of well-matched stimuli across ON and OFF settings. Participants believed the two confederates were students volunteering in a charity.

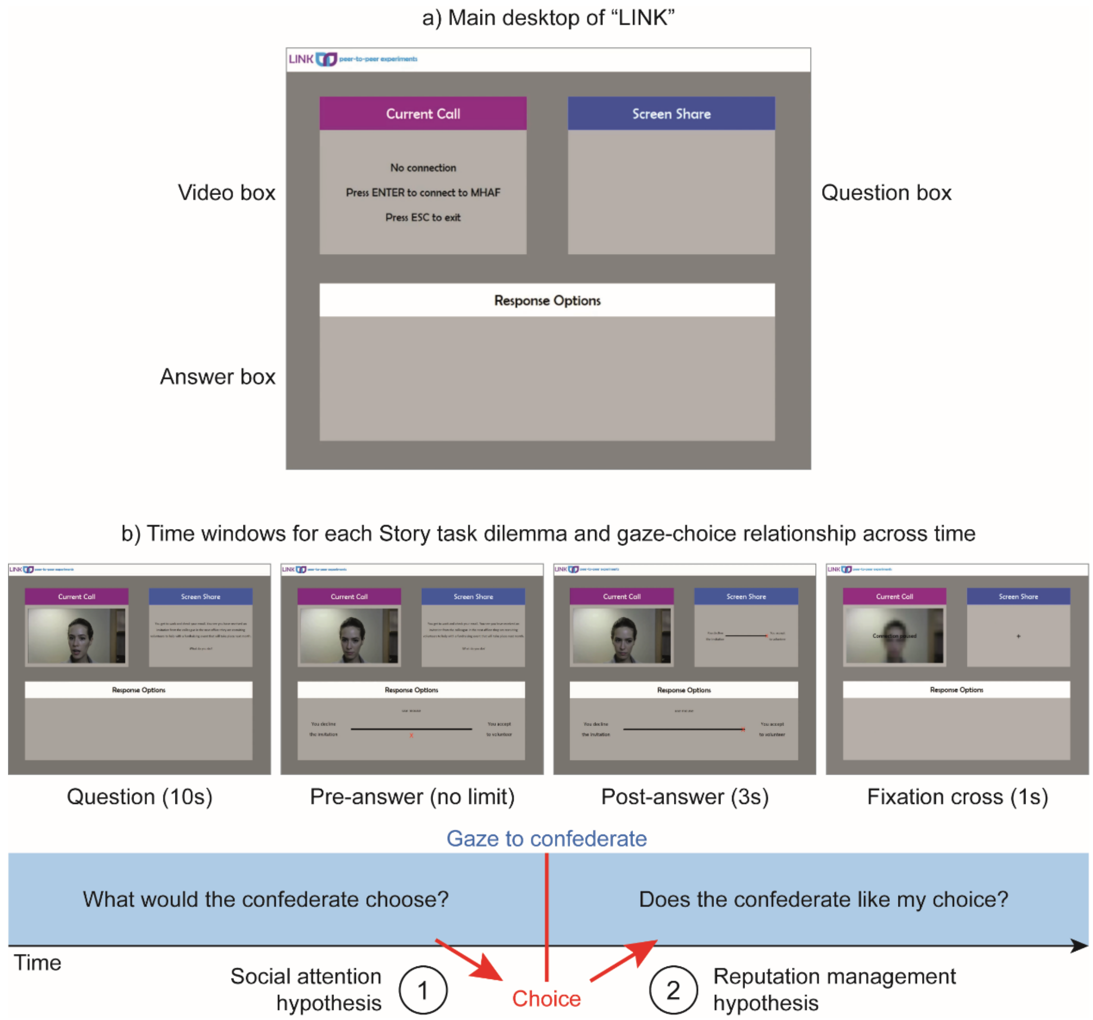

Figure 2-1. Study design.
a) Main desktop of the fake video-conference interface "LINK". b) Screenshots of the time windows for each dilemma/trial of the Story task, and model describing potential relationships between gaze and prosocial choices across the different time windows.

In our within-subject design, participants completed two tasks measuring prosocial behaviour. Participants played the Dictator game used by Izuma et al. (2011), where we measured the frequency of accepted donations (Offer task). Although prosocial behaviour has been traditionally measured by economic games, such as the Dictator game, concerns have been raised about their external validity (Galizzi & Navarro-Martinez, 2017). For this reason, we also used a novel Story task inspired by Izuma et al. (2010), where participants disclose their prosocial tendencies in everyday life situations. During the task, we ensured a communicative environment by 1) having videos where the confederate read the questions to the participant, and 2) telling participants to say their choice aloud before entering it in the computer. Based on previous evidence (Cage et al., 2013; Izuma et al., 2011), we hypothesized that the belief in being watched would increase prosocial behaviour of participants across both tasks, because it signals good reputation to the observer.

During the tasks, participants' eye gaze was recorded with eye-tracking, and we measured the looking time to the three boxes on the screen – the Video box, the Question box, and the Answer box. We contrasted two possible hypotheses for gaze behaviour. If in our communicative context participants need to gain or signal useful information from/to the live confederate, then they might look more to the Video box under the ON setting compared to the OFF setting. However, if participants still conform to a social norm of avoiding staring, we may replicate the results of Gobel et al. (2015) and Laidlaw et al. (2011), and find more gaze to the Video box under the OFF setting.

A core question in this study concerned the relationship between prosocial choices and gaze directed at the confederate (Video box) on a trial-by-trial basis. The presence and direction of this relationship across different time windows can help identifying which social cognitive processes modulate gaze behaviour (see Figure 2-1b). As introduced earlier, we tested if gaze before the choice predicts the later choice behaviour (social attention hypothesis), or if the choice predicts gaze behaviour during the post-answer phase (reputation management hypothesis). Importantly, we expected that the social attention hypothesis would be true for both settings, while the reputation management hypothesis would only happen in the ON setting.

After the tasks, participants filled a questionnaire about their perception of the confederates in each setting, and a questionnaire measuring their social anxiety traits. People with social anxiety fear or negatively perceive other people, and they show increased concern to gain social approval (Cremers & Roelofs, 2016; Morrison & Heimberg, 2013). A meta-analysis by Uziel (2007) shows that negative personality traits (e.g. low self-esteem, neuroticism or introversion, which are associated with social anxiety) are strong predictors of how social presence will affect individual performance. In line with this, Satow (1975) found that, when answers were public, people in high need for social approval (i.e. those who score high in the Social Desirability Scale; Crowne & Marlowe, 1960) donated more money than people in low need for social approval. This indicates that people with social anxiety traits might be more susceptible to audience effects. Here, we performed an exploratory analysis of the relationship between social anxiety traits and audience effects.

2.3. Materials and Methods

2.3.1. Participants

We aimed for a sample of 32 participants (8 for each counterbalancing condition). Overall, a group of 43 adults (25 females, 18 males; mean age: 23.95±3.59) were recruited because, as we were testing, 9 participants did not believe the deceptive manipulation for the online setting, and 2 participants had poor-quality eye-tracking data. Thus, the final valid sample consisted of a group of 32 adults (20 females, 12 males; mean age: 23.41±3.55). All participants gave written informed consent before doing the experiment and were compensated £8 for their time and travel expenses; they were aware that they could receive a bonus of maximum £4 depending on their performance during the Offer task (see section *2.3.5. Offer task* for details on the Offer task bonus). The study was granted ethical approval by the local Research Ethics Committee, and was in accordance with the Declaration of Helsinki.

2.3.2. Cover story

In order to manipulate the beliefs of participants in an efficient and credible way, participants were told that we were investigating social attention during charitable behaviour, and that they would complete a task with two student volunteers working in a charity (confederates). Participants were given an information sheet about the aims and work of the charity. Although the name of the charity was not real (Mental Health Awareness Foundation), the description was very similar to that of the real charity Mental Health Foundation and money collected during the task was donated to the latter.

Participants were told that we would connect online with the two confederates at the charity using “an interface similar to Skype but for experimental research” that we called “LINK: peer-to-peer experiments”. The experimenter pretended to launch LINK through MATLAB. However, the screens shown during the task were designed with MATLAB (R2016b, MathWorks) and Cogent Graphics in a way that tried to escape from the typical experimental layout. The LINK main desktop would show a banner on the top with the LINK logo, a box called Current Call (where the video call would appear; Video box in the analyses), a Screen Share box (both the participant and the confederate were supposed to see this box; the questions and chosen answers were displayed here; Question box in the analyses), and the Response Options box (where the participant could see the option to answer the question; Answer box in the analyses) (see Figure 2-1a). Participants were also told in the beginning that, in case the students in the charity (confederates) were not available, a set of videos recorded during the piloting of the study would be used instead.

2.3.3. Counterbalancing conditions

There were four different conditions, in which we counterbalanced the order of the settings (online = ON, offline = OFF), the confederate linked to each setting and session (confederate 1 or 2), and the story linked to each setting and session (story 1 or 2) (see section *2.7.1. Counterbalancing conditions* for Table 2-6 with all counterbalancing conditions). Each participant was allocated to one condition: they completed all tasks for each setting.

2.3.4. Story task

In order to test how the audience effect changes reputation management, we designed a task inspired by Izuma et al. (2010), where participants have to disclose their tendencies relative to social norms. We created a set of 2 stories that depicted real day-to-day situations emulating a moral dilemma. These moral dilemmas were part of a larger pool of dilemmas that we created and piloted through an online form on 23 adults: the dilemmas included in the Story task were those (or slight modifications of those) for which at least 60% of the answers were non-prosocial in a non-social condition (i.e. there was room for more prosocial answers under the belief in being watched). In each story, there were 5 different dilemmas (i.e. 5 trials) with two options: one option was prosocial but had a temporal or monetary cost (e.g. volunteer for an afternoon, give money to a homeless person), whereas the other option was non-prosocial and had no cost (see section *2.7.2. Stories* for full stories). Both stories were matched for the number of dilemmas with monetary or temporal costs, and they both had an additional neutral trial where both options were non-prosocial.

For each trial, the confederate in the video read a statement describing the dilemma and asked participants “What do you do?”. Participants could also read the statement on the Screen Share. The two possible answers were displayed on each end of a continuous scale in the Response Options box, and participants indicated with the mouse how likely they were to do one or the other option (halfway the line was a neutral answer). Participants were instructed to say their choice aloud to the confederate before clicking the mouse, in order to create a communicative environment. The choice was displayed on the Screen Share for 3 seconds, and the confederate in the video stayed in silence as if she was checking the choice. In between trials a fixation cross was displayed on the Screen Share for 1 second, and a blurred frame of the video-clip plus the message “Connection paused” were displayed on the Current Call box (see Figure 2-1b for screenshots of each time window).

2.3.5. Offer task

As a second measure of the audience effect, we used a variation of the Dictator game previously used by Izuma et al. (2011) and Cage et al. (2013). We used a modified version of the payoff matrix used by Cage and colleagues (2013), in which we reduced the amounts at play to adapt them to our participation fee (see Figure 2-2a). Each cell in the payoff matrix corresponds to one trial, which was tested once for each setting (ON, OFF); within each setting, the 25 trials were randomized. To avoid participants memorizing their choices, we applied a jittering on the amounts of money by adding a random number from a normal distribution N(0,0.2). If the original amount was 0, no jittering was applied; if the amounts the participant would give and the charity would gain were equal, the jittering was the same for both amounts. The trials in which the participant would give £0 and the charity would gain £0 were removed from the analyses since the choices would be random.

For each offer, the confederate in the video asked to the participant “would you accept or reject this offer?”, and both the question and the monetary offer were displayed on the Screen Share. The two possible answers (“accept” and “reject”) were displayed on the Response Options box, and the side where they appeared was counterbalanced across trials. To select an option, participants had to press a blue key (“D” or “K”) that matched the position of the chosen option. Participants were instructed to say the answer aloud to the confederate before pressing the key. After the key press, the answer was displayed on the Screen Share for 3 seconds, during which the confederate in the video stayed in silence as if she was looking at the answer. In between trials, a fixation cross was displayed on the Screen Share for 1 second, while a blurred frame of the video-clip plus the words “Connection paused” were displayed on the Current Call box (see Figure 2-2b for screenshots of each time window).

Importantly, in the beginning participants were told that, on top of the fixed payment of £8, they would receive a bonus of maximum £4 depending on their choices in the Offer task. They were told that in the end of the experiment a random trial would be selected: if in that trial participants had accepted the offer, they would give that amount to the charity and keep the rest; conversely, if they had rejected the offer, they would keep the full £4 bonus.

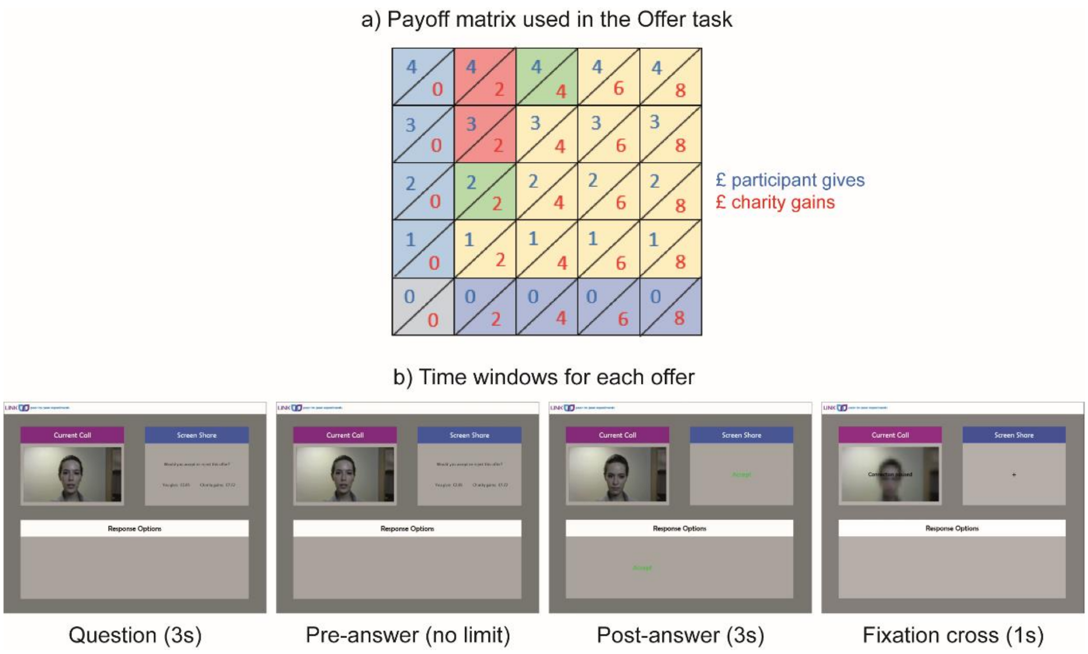

Figure 2-2. Offer task design.
a) Payoff matrix. b) Screenshots of the time windows for each offer/trial of the Offer task.

2.3.6. Stimuli: video-clips

We recorded 3 sets of video-clips for each of the two confederates: Alice and Sophie. During the filming session, the confederate went through the two tasks and was recorded with a webcam on top of a monitor, in order to simulate an online connection. The first set of video-clips was composed of 2 different videos where the confederate was pretending to have a conversation with someone else, although only her part of the dialogue was recorded: in the first conversation she was greeting the participant and experimenter, testing that the Screen Share worked, and receiving the instructions for the Story and Offer tasks; in the second conversation she said goodbye to the participant and experimenter. The second set of video-clips was composed of 6 short videos for the Story task (one for each trial): for each video-clip, the confederate would first look at the screen and read a statement, then look at the camera and ask a question, and finally look at her screen again for 10 seconds. The third set of video-clips was composed of 25 short videos for the Offer task (one for each trial). For each video clip, the confederate would first look at her screen for 2 seconds, then look at the camera and ask the question, and finally look back to her screen for 10 seconds.

2.3.7. General procedure: deceptive video-conference paradigm

As an example, below we present the procedure for conditions 1 and 2, where participants complete the tasks under the ON setting and then under the OFF setting (Figure 2-3).

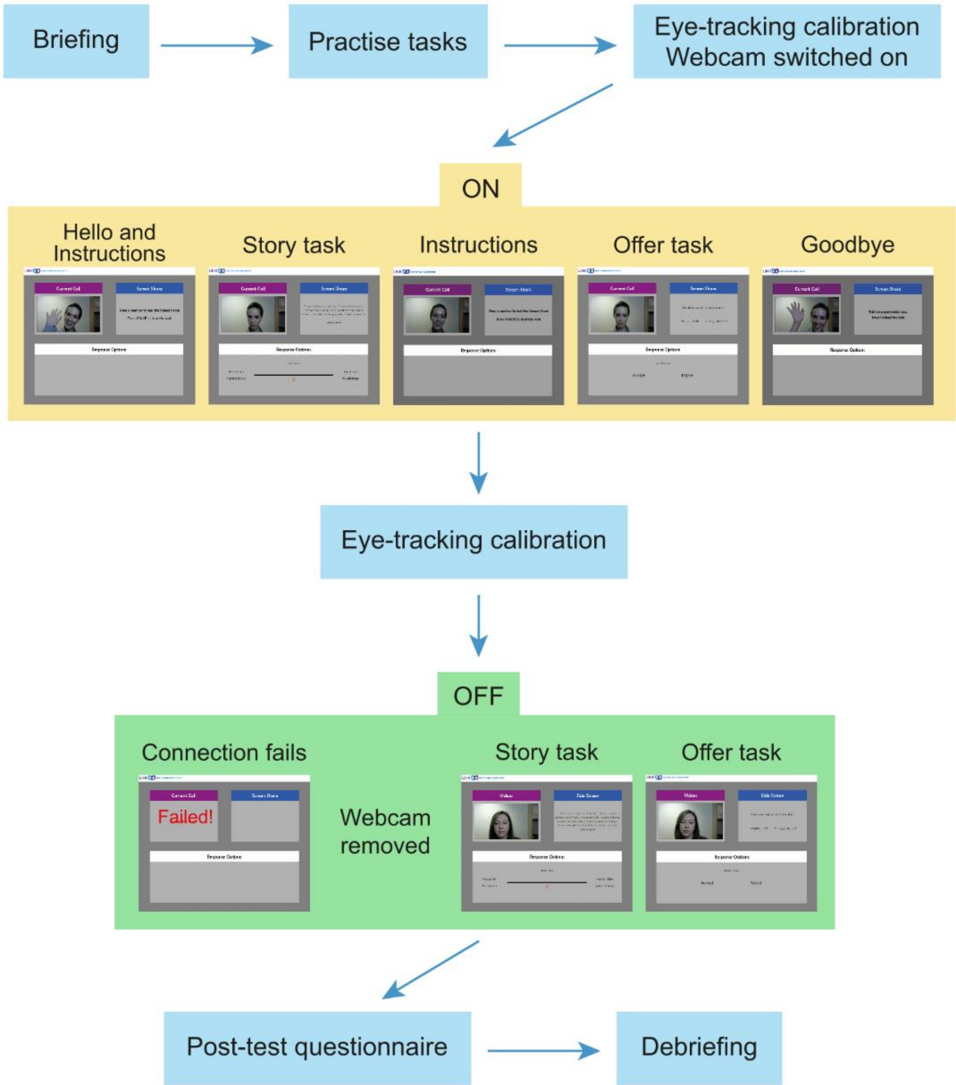

Figure 2-3. Overview of the procedure for each participant.

Once the participant had read the information about the charity and practised the two tasks without video-clips, the eye-tracker was calibrated. The experimenter also pretended to check the webcam was working by launching the “Webcam video” on Movie Maker and leaving it open, so the green light on the webcam would indicate it was switched on. The experimenter loaded LINK and explained to the participant the meaning of the boxes on the LINK main desktop. Following the instructions on the Current Call box, the experimenter would then connect to the charity.

For the ON setting, the connection was successful and the video of the confederate (Alice) was played. Although the video was pre-recorded, the experimenter pretended to have a conversation with Alice and she had previously rehearsed its timing to ensure credibility. During the conversation, the experimenter introduced Alice to the participant and pretended to run a test with Alice to check the Screen Share was working, thereby enhancing the belief that Alice was real and could see the information shown on the Screen Share. The experimenter then gave some instructions for the Story task to both Alice and the participant, explicitly telling Alice “don’t make any facial expression or say anything that could influence the participant’s choices”, so that the participant would not suspect of Alice being too unresponsive (see section *2.7.3. Conversation with Alice* for the full conversation). The experimenter left the testing room and waited outside until the participant announced the task was completed. Then the experimenter loaded the Offer task and gave instructions to Alice and the participant, and left the testing room again until the participant announced the task was completed. Then, a short video of Alice saying goodbye was played. In between settings, the eye-tracker was re-calibrated to make sure data was recorded properly for the OFF setting.

For the OFF setting, the connection would fail, automatically try to connect again, and fail again. Three options were displayed on the Current Call box: “try connection again”, “use offline mode with stored videos”, or “exit”. During this time, the experimenter pretended to get concerned about the connection and to send a text to the second confederate (Sophie). Shortly after, she pretended that Sophie had answered back saying that she was in a meeting that was taking longer than expected. At this point the experimenter told participants to use the pre-recorded videos: she would remove the webcam and load the offline mode of LINK. The LINK layout would change slightly: now the Current Call box was called Videos, and the Shared Screen was called Side Screen. Participants completed the tasks after receiving the corresponding instructions.

2.3.8. Post-test questionnaire and debriefing

After completing the two tasks under the two settings, all participants completed a post-test questionnaire that had 3 sections. In the first section, participants had to indicate on a scale from 0 (disagree) to 8 (agree) to what extent they agreed with some statements. These statements were related to their perception of the two models (e.g. “I liked Alice very much”) and the interaction with them (e.g. “I think the interaction with Alice was very natural”), and their perception of the relevance of the charity and charitable behaviour in their life (e.g. “I think it is very important to donate money to a charity”). In the second section, participants were asked some questions to check they did not realise the real purpose of the experiment and to know about their strategies to give an answer. Finally, in the third section participants completed the Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987). It consists of 24 questions assessing social anxiety and phobia across different real-life situations. The overall score can range from 0 (low social anxiety) to 144 (high social anxiety), with scores over 65 reflecting marked/severe social phobia. See section *2.7.4. Post-test questionnaire* for the full post-test questionnaire.

After participants completed the post-test questionnaires, the experimenter ran the code to select the random trial that would determine how much participants kept from the £4 bonus. If participants were meant to give part of the bonus to the charity, they would place the corresponding amount in a collection box. Once the data collection was completed, the experimenter added up all the monetary amounts that participants had given and made a donation to the Mental Health Foundation. Finally, the experimenter asked whether they noticed that the confederate in the ON setting was a pre-recorded video, and subsequently debriefed participants about the manipulation, the real purpose of the experiment and the real name of the charity. The overall duration of the experiment was around 40 minutes.

2.3.9. Eye-tracking

An Eye Tribe ET1000 eye-tracker (IT University of Copenhagen, Denmark) was positioned at the base of a 19’’ monitor. Participants sat approximately 50 cm from the screen, and placed their head on a homemade chin rest fixed on the table. They went through a 9-point calibration routine that took between 1 and 2 minutes; they completed the calibration twice, once before each setting was loaded. The eye-tracker recorded the eye movements of both eyes at a rate of 30 Hz.

Three time windows and 3 regions of interest (ROIs) were defined. The 3 time windows corresponded to 1) the period of time where the confederate asked the question ("question"; around 10 s), 2) the period of time before clicking the mouse, where participants were thinking about the answer and saying it aloud ("pre-answer"; unlimited) and 3) the period of time after participants clicked the mouse, during which the answer was displayed on the Screen Share ("post-answer"; 3 seconds). The ROIs corresponded to 1) the Video box, 2) the Question box and 3) the Answer box (see Figure 2-1a). To measure eye gaze, we computed the proportion of looking time, which corresponds to the amount of time that participants spent looking at each ROI (video box, question box and answer box) relative to the total duration of each time window (question, pre-answer, post-answer).

2.3.10. Data analyses

To check that the deceptive manipulation changed how the confederate was perceived by the participant, two-tailed paired *t*-tests between ON and OFF setting were computed for each of the traits rated in the post-test questionnaire: likeability, naturalness and reciprocity.

For prosocial behaviour, we compared choices under the ON setting to those under the OFF setting, taking also into account the order in which the two settings appeared. For the Story task, the prosocial option was matched to 1 and the non-prosocial option to 0, and we measured the prosociality ratings of the choices. For the Offer task, the number of trials in which participants accepted to donate money to the charity was computed (range: from 0 to 24 trials). A 2-way repeated measures ANOVA with Setting (ON and OFF) as within-subject factor, Order of setting (first or second) as between-subject factor, and dependent variable Choice was performed for each task. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. Moreover, Pearson correlations were computed to assess the relationship between prosocial behaviour and social anxiety scores: we tested whether a greater difference in prosocial choices between ON and OFF settings correlated with higher social anxiety traits.

For the eye-tracking measures, we tested the effect of the setting (ON, OFF) on the proportion of looking time to the Video box, Question box and Answer box in the three time windows (question, pre-answer, post-answer). Data for the three regions is not independent because participants can only look at one place at a time. Therefore, we analysed gaze to the three regions separately, using a two-way repeated measures ANOVA with Setting and Time window as within-subject factors for each task. Where sphericity could not be assumed, corrected *p*-values using the Huynh-Feldt estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. Here we did not test correlations with social anxiety traits, because they would be underpowered to correct for multiple comparisons when all possible combinations between time windows and boxes on the screen were taken into account.

A critical question concerns the relationship between gaze and prosocial behaviour on a trial-by-trial basis. We used different models to test our two hypothesis on this relationship (social attention hypothesis and reputation management hypothesis). First, we tested whether choice was predicted by the belief in being seen and gaze behaviour prior to giving an answer. We fitted a multilevel ANOVA with Choice as dependent variable, Participant as random factor (random intercept), and Setting and Gaze (% looking time to Video box during question phase) as fixed factors. For the Story task we included 320 data-points (32 participants, 2 settings, 5 social trials/setting), and for the Offer task we included 1536 data-points (32 participants, 2 settings, 24 offers/setting). Second, we tested whether gaze behaviour after giving an answer was predicted by choice and belief in being seen: we fitted a multilevel ANOVA with Gaze (% looking time to Video box during post-answer phase) as dependent variable, Participant as random factor (random intercept), and Setting and Choice as fixed factors. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed.

Since data was not normally distributed for all measures, we performed a bootstrap analysis with 10,000 permutation tests for each of the analyses, and examined the probability that the results could have arisen by chance, given the distribution of our existing data. The pattern of results for the bootstrap analysis (i.e. results above or below $p < 0.05$) was identical to the classical ANOVA analyses, so we report only the classic ANOVAs.

2.4. Results

2.4.1. Manipulation check: post-test questionnaire ratings

In the post-test questionnaire, participants rated the ON and OFF confederate on three traits: likeability, naturalness and reciprocity. Two-tailed paired *t*-tests between ON and OFF setting were computed for each trait. Results showed that under the ON setting the confederate was perceived as significantly more likeable, $t(31) = 2.31$, $p < .05$, $d_z = .408$, and natural, $t(31) = 2.14$, $p < .05$, $d_z = .378$, and tended to be perceived as more reciprocal $t(31) = 1.72$, $p = .096$, $d_z = .304$ (Figure 2-4a). See Table 2-1 for descriptives (mean and SD) on post-test questionnaire ratings.

Table 2-1. Descriptives post-test questionnaire ratings

Rating	Setting	*M*	*SD*
Likeable	ON	5.62	1.54
	OFF	5.03	1.77
Natural	ON	5.66	1.64
	OFF	4.84	2.08
Reciprocal	ON	4.25	2.00
	OFF	3.75	1.95

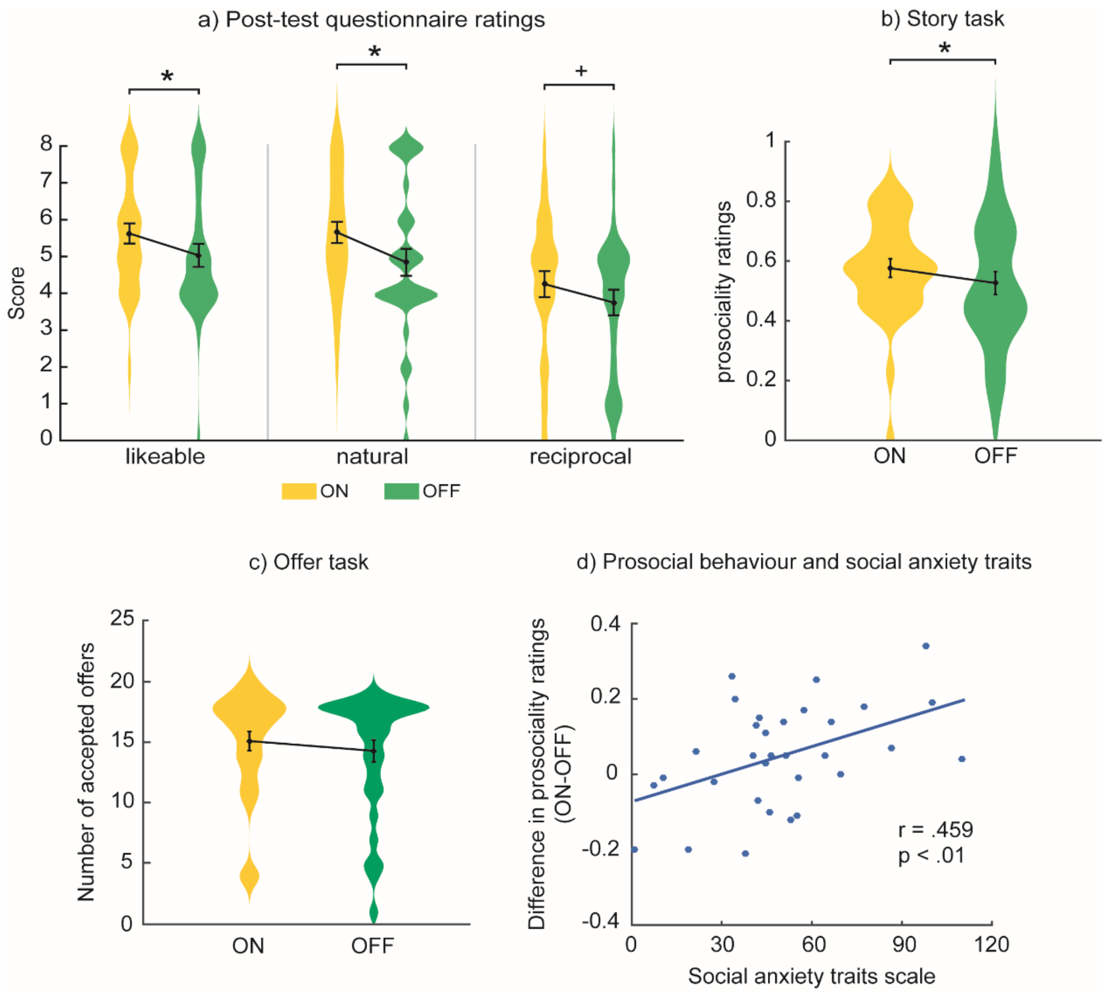

Figure 2-4. Results for behavioural measures.
a) Post-test questionnaire ratings about the confederates: mean (filled circle), SE (error bars), and frequency of values (width of distribution). b) Prosociality ratings in Story task. c) Number of accepted offers in the Offer task. d) Correlation between prosocial behaviour and social anxiety traits in Story task. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

2.4.2. Prosocial measures

To analyse prosocial measures, we fitted a 2-way repeated measures ANOVA for each task, with Setting (ON and OFF) as within-subject factor and Order of setting (first or second) as between-subject factor.

For the Story task, results showed a marginally significant effect of Setting on prosocial choices, $F(1,30) = 4.16$, $p = .05$, $n_p^2 = .122$ (Figure 2-4b): choices were more prosocial under the ON setting ($M = .576$, $SD = .174$) than under the OFF setting ($M = .526$, $SD = .215$). There was no main effect of Order nor interaction between Setting and Order.

For the Offer task, there was a tendency to accept more offers under the ON setting ($M = 15.1$, $SD = 4.49$) than OFF setting ($M = 14.3$, $SD = 5.07$), $F(1,30) = 3.43$, $p = .074$, $n_p^2 = .103$ (Figure 2-4c). There was no main effect of Order, but we found a tendency for an interaction between Setting and Order, $F(1,30) = 2.92$, $p = .098$, $n_p^2 = .089$: participants who performed the task first under the ON setting and then under the OFF setting showed no change in prosocial behaviour, whereas in the reversed order prosocial behaviour was lower in the OFF than in the ON setting.

Regarding social anxiety scores, we found a significant positive correlation between change in prosocial behaviour (ON – OFF) and social anxiety traits for the Story task, $r = .459$, $p = .008$: the more participants changed their behaviour from OFF to ON setting, more anxiety traits they had (Figure 2-4d). No significant correlation was found between prosocial behaviour change and social anxiety traits in the Offer task, $r = .225$, $p > .05$.

2.4.3. Eye gaze: Story task

For eye gaze, we fitted a two-way repeated measures ANOVA for each box (Video, Question, Answer), with Setting (ON and OFF) and Time window (question, pre-answer, post-answer) as within-subject factors. See Table 2-2 for descriptives (mean and SD) on the proportion of looking time to each box and time window. Only significant main effects and interactions are reported in the text; full results and post-hoc tests are given in section *2.7.5. Tables with full eye gaze results* (Table 2-7).

For looking time to the Video box, there was a main effect of Time window, $F(2,62) = 38.5$, $p < .001$, $n_p^2 = .554$, and a tendency for an interaction effect between Setting and Time window, $F(2,62) = 3.6$, $p = .054$, $n_p^2 = .104$. Participants looked more to the Video box during the question and post-answer phases, especially in the OFF setting (Figure 2-5a,d).

For looking time to the Question box, there was a main effect of Time window, $F(2,62) = 437.1$, $p < .001$, $n_p^2 = .934$, and an interaction effect between Setting and Time window $F(2,62) = 5.81$, $p = .005$, $n_p^2 = .158$. Participants looked more to the Question box in the question and post-answer phases, especially in the ON setting (Figure 2-5b,d).

For looking time to the Answer box, there was a main effect of Setting, $F(1,31) = 5.17$, $p = .03$, $n_p^2 = .143$, and a main effect of Time window, $F(2,62) = 710.1$, $p < .001$, $n_p^2 = .958$, but no interaction effect between these two factors. Participants looked more to the Answer box in the pre-answer phase and in the ON setting (Figure 2-5c,d).

Overall, these results are consistent with gaze shifting between the different boxes as the task progresses, with less gaze towards the Video box and more towards the Question or Answer boxes in the ON setting, when participants believe the confederate can see them.

Table 2-2. Descriptives for the proportion of looking time to each box (Story task)

Setting	Time window	Video box	Question box	Answer box
ON	question	*M* = .094 *SD* = .093	*M* = .774 *SD* = .068	*M* = .045 *SD* = .032
	pre-answer	*M* = .010 *SD* = .015	*M* = .073 *SD* = .068	*M* = .861 *SD* = .096
	post-answer	*M* = .135 *SD* = .148	*M* = .447 *SD* = .153	*M* = .306 *SD* = .161
OFF	question	*M* = .148 *SD* = .082	*M* = .713 *SD* = .104	*M* = .037 *SD* = .029
	pre-answer	*M* = .016 *SD* = .023	*M* = .097 *SD* = .077	*M* = .816 *SD* = .119
	post-answer	*M* = .135 *SD* = .117	*M* = .472 *SD* = .166	*M* = .274 *SD* = .149

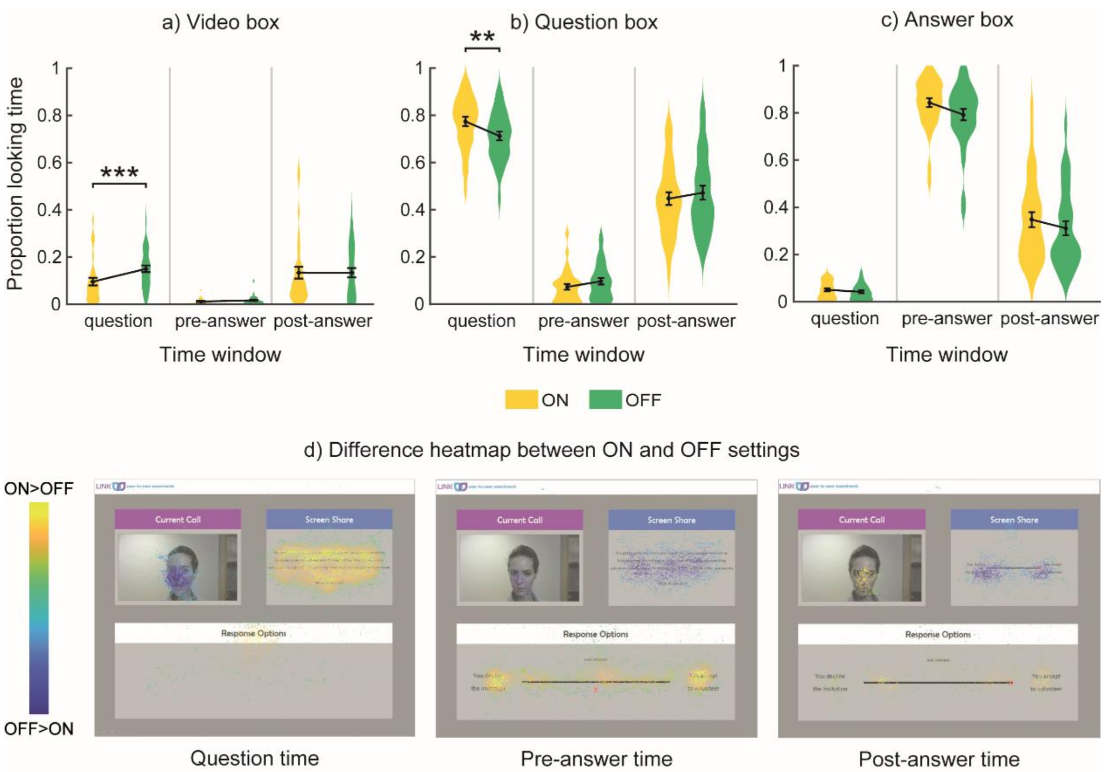

Figure 2-5. Results for eye gaze in Story task.
Proportion of looking time for each box, time window and setting: mean (filled circle), SE (error bars), and frequency of values (width of distribution). a) Video box. b) Question box. c) Answer box. d) Heatmaps showing difference in proportion of looking time between ON and OFF settings for each box and time window. Asterisks signify difference between ON and OFF setting at p < .05 (*), p < .01 (**) and p < .001 (***).

2.4.4. Eye gaze: Offer task

For eye gaze, we fitted a two-way repeated measures ANOVA for each box (Video, Question, Answer), with Setting (ON and OFF) and Time window (question, pre-answer, post-answer) as within-subject factors. See Table 2-3 for descriptives (mean and SD) on the proportion of looking time to each box and time window. See section *2.7.5. Tables with full eye gaze results* (Table 2-8) for full results; significant main effects and interactions are reported below.

For the Video box, there was a main effect of Setting, $F(1,31) = 13.5$, $p = .001$, $n_p^2 = .303$, so that participants tended to look more to the Video box under the OFF setting compared to the ON setting. There was also main effect of Time window, $F(2,62) = 37.0$, $p < .001$, $n_p^2 = .544$, and an interaction effect between Setting and Time window $F(2,62) = 8.0$, $p = .001$, $n_p^2 = .205$: participants looked more to the Video box during the question and post-answer phases, especially in the OFF setting (Figure 2-6a,d).

For the Question box, there was a main effect of Setting, $F(1,31) = 23.5$, $p < .001$, $n_p^2 = .431$: participants looked more to the Question box under the ON setting compared to the OFF setting. There was also a main effect of Time window, $F(2,62) = 122.0$, $p < .001$, $n_p^2 = .797$, and an interaction effect between Setting and Time window, $F(2,62) = 21.3$, $p < .001$, $n_p^2 = .408$: participants looked more to the Question box during the question and post-answer phases, especially in the ON setting (Figure 2-6b,d).

For the Answer box, there was a main effect of Time window, $F(2,62) = 210.7$, $p < .001$, $n_p^2 = .872$, but no main effect of Setting or interaction: participants looked more to the Answer box in the pre-answer phase (Figure 2-6c,d).

Overall, these results are consistent with those obtained in the Story task: gaze moves around the screen according to task demands, and participants look less to the video-feed in the ON setting compared to the OFF setting.

Table 2-3. Descriptives for the proportion of looking time to each box (Offer task)

Setting	Time window	Video box	Question box	Answer box
ON	question	*M* = .117 *SD* = .152	*M* = .730 *SD* = .150	*M* = .059 *SD* = .043
	pre-answer	*M* = .015 *SD* = .021	*M* = .217 *SD* = .127	*M* = .522 *SD* = .176
	post-answer	*M* = .165 *SD* = .155	*M* = .513 *SD* = .209	*M* = .136 *SD* = .108
OFF	question	*M* = .158 *SD* = .150	*M* = .652 *SD* = .160	*M* = .057 *SD* = .043
	pre-answer	*M* = .027 *SD* = .037	*M* = .209 *SD* = .124	*M* = .544 *SD* = .206
	post-answer	*M* = .247 *SD* = .153	*M* = .356 *SD* = .177	*M* = .147 *SD* = .092

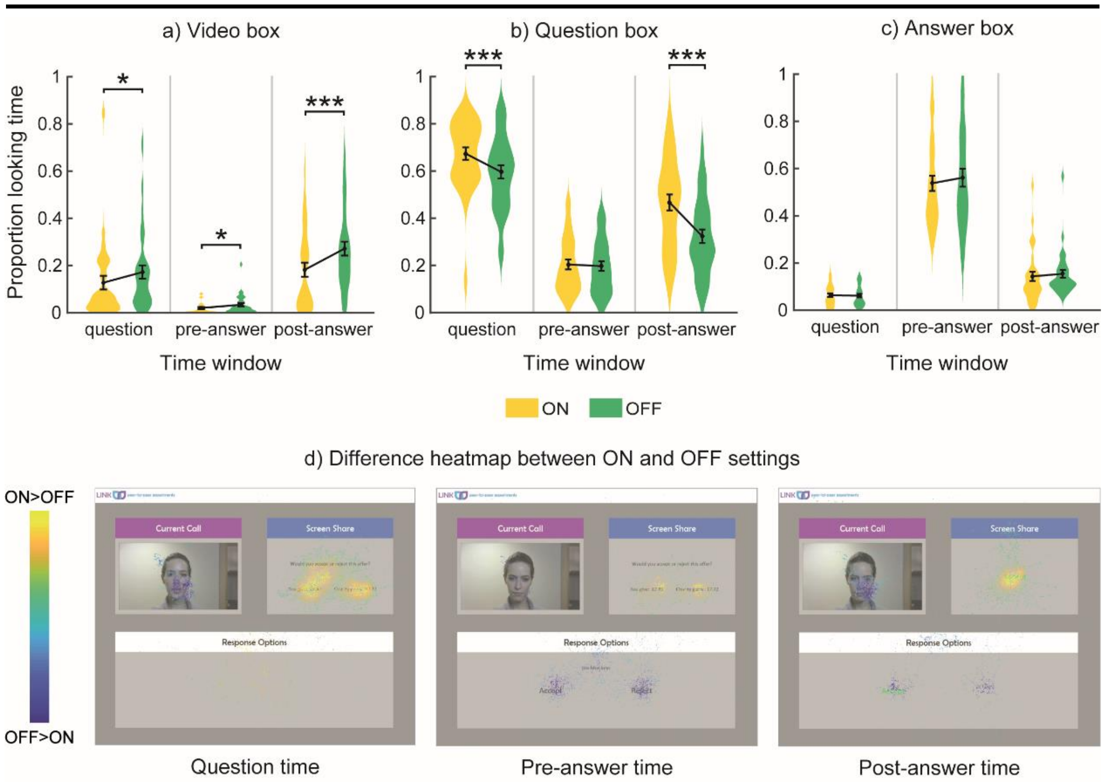

Figure 2-6. Results for eye gaze in Offer task.
Proportion of looking time for each box, time window and setting: mean (filled circle), SE (error bars), and frequency of values (width of distribution). a) Video box. b) Question box. c) Answer box. d) Heatmaps showing difference in proportion of looking time between ON and OFF settings for each box and time window. Asterisks signify difference between ON and OFF setting at p < .05 (*), p < .01 (**) and p < .001 (***).

2.4.5. Relationship between prosocial behaviour and eye gaze

The data above shows that participants changed both their gaze behaviour and their prosocial choices according to whether they were being watched or not. Thus, it is useful to know if these two measures of social behaviour are related to each other on a trial-by-trial basis.

First, we tested if choices are related to previous gaze behaviour (during the question phase), that is, are people more prosocial when they look more to the video-feed? For this, we fitted a multilevel ANOVA with Choice as dependent variable, Participant as random factor (random intercept), and Setting and Gaze (% looking time to Video box during question phase) as fixed factors. For the Story task, results showed that there was no main effect of Setting or Gaze, nor an interaction effect of Setting X Gaze, on prosocial choices (see Table 2-4a). For the Offer task, there was no strong evidence for a main effect of Setting or Gaze, nor interaction between Setting and Gaze (see Table 2-5a).

Second, we tested if choices are related to gaze behaviour in the post-answer phase: do participants look to the confederate to see if she evaluates their choice? For this, we fitted a multilevel ANOVA with Gaze (% looking time to Video box during post-answer phase) as dependent variable, Participant as random factor (random intercept), and Setting and Choice as fixed factors. For the Story task, the proportion of looking time to the Video box after giving an answer was negatively predicted by the prosociality of that answer, $F(1,314.1) = 9.85$, $p < .01$, *Beta* = -.106 (see Table 2-4b), although there was no interaction between Setting and Choice. This means that a decrease in the prosociality of the choices was associated with an increase in the proportion of looking time to the Video box during the post-answer time window, regardless of belief. For the Offer task we found a main effect of Setting, $F(1,1502.1) = 18.1$, $p < .001$ (see Table 2-5b): participants looked more to the Video box under the OFF setting, regardless of the type of choice.

Table 2-4. Relationship prosocial behaviour and eye gaze (Story task)

a) Does gaze before the choice predict choices?		*b) Do choices predict gaze after the choice?*	
Setting	$F(1,293.8) = .059$ $p > .05$	Setting	$F(1,288.2) = .411$ $p > .05$
GazeBefore	$F(1,276.5) = 3.18$ $p > .05$	Choice	$F(1,314.1) = 9.85$ $p = .002$** *Beta* = -.106
Setting X GazeBefore	$F(1,302.9) = .256$ $p > .05$	Setting X Choice	$F(1,289.6) = .344$ $p > .05$

Table 2-5. Relationship prosocial behaviour and eye gaze (Offer task)

a) Does gaze before the choice predict choices?		*b) Do choices predict gaze after the choice?*	
Setting	$F(1,1506.9) = 3.19$ $p > .05$	Setting	$F(1,1502.1) = 18.1$ $p < .001$***
GazeBefore	$F(1,1311.3) = 1.60$ $p > .05$	Choice	$F(1,1522.4) = .179$ $p > .05$
Setting X GazeBefore	$F(1,1519.5) = 1.59$ $p > .05$	Setting X Choice	$F(1,1502.8) = .041$ $p > .05$

2.5. Discussion

This chapter aimed to examine audience effects on prosocial and gaze behaviour, and test whether they can be explained in terms of reputation managements. More specifically, we found the following. First, prosocial behaviour (both disclosure of prosocial tendencies and monetary donations) somewhat increases when it is possible to signal a good reputation to an observer. We also found that the increase of prosocial behaviour when disclosing prosocial tendencies positively correlates with social anxiety traits. Second, we extend findings from non-communicative studies by showing that gaze signalling also conforms to a social norm of avoiding staring in communicative situations. Finally, we found that participants look longer towards the confederate after making a non-prosocial choice, but this is true for both the live and pre-recorded interactions. These findings also show that the deceptive video-conference paradigm is an efficient experimental setting to test audience effects. The implications of these findings for social cognitive research are discussed below.

2.5.1. Reputation management and being watched

Using our novel deceptive video-conference paradigm we found marginal evidence that, both in the Story and Offer tasks, participants are more likely to act for the benefit of other people (i.e. they choose more prosocially) when they believe they are being watched than when they do not hold this belief. This corroborates previous studies showing that people increase their prosocial behaviour when being watched (Cage et al., 2013; Emler, 1990; Filiz-Ozbay & Ozbay, 2014; Izuma et al., 2011, 2010, 2009; Satow, 1975; Tennie et al., 2010). Because control and test conditions in our paradigm are tightly matched (we use the same stimuli across both ON and OFF settings), they differ only in the belief in being watched. Thus, these findings indicate that this change in behaviour may be driven by the need to signal good reputation in front of an observer (Bradley et al., 2018; Smith & Bird, 2000), rather than by the mere presence of another person. A key element in reputation management is that individuals seek to be viewed positively by others (Cage, 2015; Izuma, 2012), and achieving this is processed as a social reward (Izuma et al., 2009, 2010). In the context of our tasks, the social reward associated with making prosocial choices in front of others likely exceeds the individual temporal or monetary benefits associated with non-prosocial choices.

Although audience effects on prosocial behaviour are marginal in both tasks, we found that they are somewhat stronger in the Story task than in the Offer task. This suggests that changes in prosocial behaviour in lab-based studies happen beyond decisions made in economic games (Cage et al., 2013; Filiz-Ozbay & Ozbay, 2014; Izuma et al., 2011), that is, even when decisions apply to daily life situations. Given that economic games may have poor external validity (Galizzi & Navarro-Martinez, 2017; Winking & Mizer, 2013), it would be interesting to see how our findings generalise to real world contexts. This might be a promising (and challenging) avenue for future research on audience effects.

There are several possible reasons why, compared to previous studies (Cage et al., 2013; Izuma et al., 2011), we found only a tendency for an audience effect in the Offer task. On the one hand, in previous studies participants were given an endowment of around £40 (payment for attending a full testing day), but in our experiment participants were given an endowment of only £4: this amount might be too low to make participants feel they are losing money if they decide to donate it. On the other hand, in previous studies participants would have a 50-90 minutes break between the two sessions/settings, whereas in our study there was no break. This could explain the trend toward an effect of the order in which the settings appeared: doing the task first under the ON setting seemed to have a carryover effect of being watched on prosocial behaviour in the OFF setting. Finally, our study is somewhat underpowered to detect effects of being watched on prosocial behaviour (see section *2.5.4. Limitations*). One way to explore the effectiveness of our method further is to compare the behaviour of the 9 participants who did not believe our manipulation to the 32 who did, and we report this comparison in detail in section *2.7.6. Analyses with excluded participants*. Briefly, the analysis suggests that believing the manipulation is critical to obtaining our results.

Interestingly, we found that higher social anxiety traits correlate with greater increase of prosocial behaviour in the Story task when being observed. These findings are in line with previous evidence suggesting that people with social anxiety traits might be more susceptible to audience effects and reputation management. For instance, negative personality traits (e.g. low self-esteem, neuroticism or introversion, which are associated with social anxiety) are strong predictors of how social presence will affect individual performance (Uziel, 2007). Moreover, it has been shown that the need for social approval has a positive effect on the amount of money participants donate, particularly when donations are made in front of an observer (Satow, 1975). Our exploratory analysis corroborates these studies by showing that people with social anxiety traits, who have increased concerns to gain social approval (Cremers & Roelofs, 2016; Morrison & Heimberg, 2013), are more likely to change their behaviour (to signal good reputation) when other people are observing. However, this correlation is not found for the Offer task. A reason for this could be that economic games, such as the Dictator game used in the Offer task, have poor external validity (Galizzi & Navarro-Martinez, 2017; Winking & Mizer, 2013), so changes in this measure may not be sensitive to real-life behaviours rated in the social anxiety questionnaire.

2.5.2. Gaze behaviour and being watched

Gaze behaviour was recorded throughout the Story and Offer tasks to determine how people use gaze to gain and signal social information during a communicative interaction. Overall, both tasks showed the same pattern of results. As expected, participants looked more at the Video and Question boxes when the question was asked, and more at the Answer box before giving an answer. An interesting pattern emerged with regard to the comparison between ON and OFF settings. During the question phase, participants spent less time looking at the Video box in the ON setting than in the OFF setting, while the opposite was found for the Question box. The same applied during the post-answer phase, although this was only true for the Offer task.

According to the dual function model of eye gaze (Gobel et al., 2015; Risko et al., 2016), these findings indicate that, when participants believe they are being watched, they use their gaze to signal to the other person and not just to acquire information. Averted gaze in live social interactions has been associated with preference for no interaction (Foulsham et al., 2011) and conformity with social norms (e.g. it is not polite to stare at someone; Gobel et al., 2015; Gobel et al., 2017; Laidlaw et al., 2011). Thus, it seems that in a communicative situation, gaze signalling also conforms to the social norm of avoiding staring, despite the closer social link between the participant and confederate. In line with this, the analysis with the group of excluded participants suggests that this pattern of results is specific to the group of participants who believe the manipulation (see section *2.7.6. Analyses with excluded participants*). However, this finding contrasts with a recent study by Mansour and Kuhn (2019), where participants in a communicative situation directed more gaze to the eyes of the confederate in a live video-call than in a pre-recorded video-call. A critical difference is that in their paradigm the confederate was talking about herself for around 2.5 min in a rather relaxed context, whereas in our tasks the confederate asked a short question of around 10 s (Story task) or 3 s (Offer task) in a more rigid context. As Mansour & Kuhn suggest, it could be that different social norms of eye gaze apply to different communicative situations: looking to the confederate to show interest is likely to be the norm when she is sharing personal information, whereas civil inattention may be the norm for more structured forms of interaction.

To further understand the meaning of these gaze patterns it is critical to consider the function of gaze as a social, but also interactive signal. The claim that gaze patterns change to conform to social norms provides a useful description of behaviour (Gobel et al., 2015; Gobel et al., 2017; Laidlaw et al., 2011), but this is not the same as having a detailed cognitive model of the control of social gaze. Such a model should integrate temporal and spatial aspects of gaze across different contexts to give a sensible account of eye gaze in real life, but also a more accurate interpretation of previous studies using photos and videos. In the following, we show how analysing the relationship between eye gaze and other behaviours (prosocial choices) can help identifying social cognitive mechanisms that modulate eye gaze in live interactions.

2.5.3. Relationship between prosocial and gaze behaviour

To our knowledge, our study is the first one to simultaneously measure prosocial behaviour and eye gaze in a conversation context: this creates a suitable communicative environment to examine the relationship between prosocial choices and gaze behaviour, and how they are modulated by the belief in being watched. In our design, we distinguish between three time windows (question, pre-answer and post-answer) locked to a key event in the interaction: the participant making a choice. We consider two different hypotheses.

The social attention hypothesis suggests that gaze behaviour at the start of the trial will predict later choices. For instance, it has been shown that mutual gaze increases prosocial behaviour of participants (see Bull & Gibson-Robinson, 1981 for an example). In both the Story and Offer task, there was no evidence to support this: looks at the start of the trial did not relate to subsequent choices in either setting. This could suggest that the amount of attention directed to the confederate does not impact on prosocial decision-making. A main limitation to this analysis is that it looks at the effect of different gaze behaviours on how much we like or care about one single confederate. Instead, the social attention hypothesis aims to explain how different gaze behaviours might be an indicator of how much we like or care about different individuals. By testing the effect of gaze patterns on subsequent prosocial behaviour at the trial level we might not be able to detect relationships that would arise if this was compared across two (or more) different confederates. Future studies could test whether prosocial behaviour is modulated by the presence of different confederates that display varying amounts of direct gaze.

The reputation management hypothesis suggests that prosocial choices will predict gaze behaviour after the choice in the ON setting, because participants will look at the confederate to seek information about how they are evaluated (e.g. check if she approves or disapproves their choices) (Efran, 1968; Efran & Broughton, 1966; Kleinke, 1986). For the Story task, we found that participants looked more to the confederate after making a non-prosocial choice than a prosocial choice, but this is true for both ON and OFF settings. Although this is not entirely consistent with the reputation management hypothesis (the effect was found in both ON and OFF settings; discussed below), it suggests that participants were generally worried about what the confederate would think of them when they made a non-prosocial choice: by gazing to the confederate, participants could monitor whether she disapproved their choice, and gave them the chance to re-engage with her again. In line with this, Nasiopoulos, Risko and Kingstone (2015) have recently suggested that participants' gaze may weigh the potential gain of attending to a specific location with the cost of revealing their attentional state. In the context of our task, both attending to what the confederate thinks and revealing that "I want to re-engage with her" are strongly beneficial to restore reputation after making a non-prosocial choice, and this might result in more looking to the confederate. Moreover, we did not find this relationship in the group of excluded participants (see section *2.7.6. Analyses with excluded participants*), which indicates that the feeling that the confederate can evaluate their choices fades away once the manipulation is uncovered.

There are some limitations to this result. First, we could not replicate this finding in the Offer task. It could be that participants care more about reactions to the choices in the Story task because they are more meaningful to them (i.e. they depict real-life situations). Another possibility is that the different costs associated to each trial in the Offer task (see payoff matrix in Figure 2-2a) further modulate the relationship between prosocial choices and gaze behaviour. Thus, future studies could test whether this relationship is true for different types of prosocial choices, but also whether it is modulated by the cost-benefit trade-off involved in the choice. Second, this relationship was not modulated by the belief in being watched: participants behaved equally in ON and OFF settings. It is not yet clear if this is because of too much social gaze in the OFF setting (OFF is like ON) or too little social gaze in the ON setting (ON is like OFF). The former could arise if there is a default response of acting in a social fashion whenever we are in front of a social stimulus, and if top-down knowledge that “this is not a real person” is not enough to inhibit the natural social behaviour. Similar effects are seen when a person gestures even when talking on the telephone, despite knowing that the other cannot see them. Alternatively, it could be that our video-conference condition is not a perfect match for real life, because it is a computer-mediated interface without true eye contact: participants might not engage in social signalling as fully as they would in real life. Further studies comparing face-to-face interactions with video-conferencing and video watching conditions will help distinguish between these possibilities. Third, it could be that the extremeness of the choice, rather than the choice being prosocial or not, predicts subsequent gaze behaviour. The reputation management hypothesis assumes that participants will gaze more or less to the confederate depending on how prosocial their choice is. However, the confederate’s reaction to both prosocial and non-prosocial choices could be informative about one’s reputation. Thus, another possibility is that the extremeness of the choice (regardless of being prosocial or not) is a better predictor of subsequent gaze patterns. Finally, although we find a relationship between prosocial choices and subsequent gaze behaviour, we are cautious about claiming a causal relationship between them: there could be other factors not accounted for by in the present study (e.g. positive/negative mood of participants) that modulate prosocial behaviour and eye gaze patterns in the same direction.

2.5.4. Limitations

Although these are promising findings for cognitive research on audience effects, the design of this study also has some general limitations. First, there is not enough evidence for a strong effect of being watched on prosocial behaviour. Post-hoc power analyses with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009) showed that the study is underpowered to detect effects of being watched on prosocial behaviour in both tasks (power ≈ 0.5), but is well-powered to detect effects of being watched on gaze (power ≈ 0.9). This could be due to low number of behavioural trials (5 in the Story task, and 24 in the Offer task), in contrast with the large number of data-points collected for eye-tracking. Keeping the number of behavioural trials low was essential to keep the study short and increase ecological validity (i.e. with too many repetitions it would be easy to detect that the confederate was always pre-recorded). Future studies with bigger sample sizes would increase power and yield enough evidence to reliably find (or not) an effect of Setting on prosocial behaviour in both tasks. However, we do not think that finding strong effects on prosocial behaviour is fundamental for the rest of the study (i.e. eye gaze results). The fact that eye gaze (a quick and spontaneous behaviour) is strongly modulated by Setting, but making prosocial choices (a strategic decision-making process) shows weaker modulation, suggests that different forms of reputation management have different sensitivity to the belief in being watched, at least when using our deceptive video-conference paradigm.

Second, we found that evidence for audience effects on prosocial behaviour was stronger in the Story task than in the Offer task, also when testing the relationship with social anxiety traits. Although this could be due to the different nature of the questions asked in each task (disclosure of prosocial tendencies in real-life situations, or monetary decisions in an economic game), it is important to consider that participants always completed the tasks in the same order: Story task followed by Offer task. Thus, it could be that after completing the Story task participants feel more relaxed toward the confederate monitoring their choices, and consequently do not change their prosocial behaviour in the Offer task. Counterbalancing the order of the tasks would clarify whether some of these effects are also found when using more artificial tasks like economic games. Another important difference between the Story task and Offer task is that the former is measuring the participants' willingness to act prosocially, whereas the latter is measuring their actual prosocial behaviour in the lab: audience effects might be found in the Story task because there was no real cost associated to a prosocial choice. Future studies comparing the external validity of economic games and disclosure of prosocial tendencies will be needed to clarify which type of measure is a better indicator for real-life prosocial behaviour (Galizzi & Navarro-Martinez, 2017).

One last concern is the gaze metric we used, proportion of total looking time. It has been suggested that this type of metric can challenge internal validity, because it involves inappropriate aggregation of gaze data (Orquin & Holmqvist, 2018). For instance, when we find that participants look more to the

Video box in the OFF setting, it could be that there are many short fixations, or that fixations are longer. Thus, using more precise measures such as number of fixations and fixation duration can be more informative to accurately interpret gaze data.

2.5.5. Implications and future research

The present findings have important implications for social neuroscience research. We show that our deceptive video-conference paradigm is effective in promoting cognitive processes triggered by the belief in being watched (e.g. reputation management, signalling function of gaze), while combining high ecological validity and experimental control. Interestingly, we also found that under the belief in being watched the confederate is perceived as more likeable and natural, and tends to be perceived as more reciprocal: being embedded in a true interaction and able to communicate with each other modulates how we behave in front of others, but also has positive consequences on how we perceive our interactive partners. This is supported by the analyses with participants who do not believe the deceptive manipulation, since they perceive both confederates as equally likeable, natural and reciprocal. In light of these results and following advocates for a second-person neuroscience (Risko et al., 2016; Schilbach et al., 2013), we encourage researchers to take a more ecologically valid approach when implementing studies on social cognition, either by having a real interaction or by using alternative approaches, such as this deceptive video-conference paradigm.

We also provide novel evidence of how relationships between gaze and other events in the interaction can potentially help identify social cognitive processes that modulate gaze behaviour. Here, the relationship between prosocial choices and subsequent eye gaze suggests that reputation management engages a strategic use of gaze to maintain reputation: the less prosocial choices are, the more participants look to the confederate to monitor how they are evaluated. This finding highlights the importance of the relationship between gaze and other events in the interaction (such as whether “I am behaving in a prosocial way or not”) in understanding gaze behaviour in live communicative contexts. However, future studies should investigate whether this is a spontaneous gaze response that is normally inhibited in non-live settings, and whether face-to-face interactions (where both partners directly see each other) boost the effects on this relationship. Overall, cognitive models that explain changes of eye gaze in real life need to incorporate its dynamic and interactive aspects: this will be key to understand gaze behaviour in real life, but also to carefully re-interpret previous studies using photos and videos.

2.6. Conclusion

This chapter aimed to advance current knowledge of how prosocial and gaze behaviour acquire a signalling function when being watched, and whether this can be explained by reputation management processes. By using our novel deceptive video-conference manipulation and a communicative context, we found that under the belief in being watched participants tend to increase prosocial decisions, and that this increase correlates with social anxiety traits. We also found that when being watched participants modulate their gaze according to social norms. This extends previous findings in non-communicative situations and indicates that participants change their prosocial and gaze behaviour to signal good reputation to others. To our knowledge, we also show for the first time that prosocial choices influence subsequent gaze patterns of participants. Overall, these results suggest that reputation mechanisms modulate both prosocial and gaze behaviour, and indicate that gaze should be considered as an interactive signal. They also highlight the need to build up a cognitive model of gaze dynamics in live interactions.

2.7. Supplementary Materials

2.7.1. Counterbalancing conditions

Table 2-6. Design of conditions

Condition	First session	Second session
1	ON	OFF
	confederate 1	confederate 2
	story 1	story 2
2	ON	OFF
	confederate 2	confederate 1
	story 2	story 1
3	OFF	ON
	confederate 1	confederate 2
	story 2	story 1
4	OFF	ON
	confederate 2	confederate 1
	story 1	story 2

ON=online setting; OFF= offline setting

2.7.2. Stories

Story 1

It’s Monday morning. You leave home and head toward the tube station to go to work. You are almost arriving to the platform when you hear the beeps announcing the tube's doors will close. What do you do? You run and catch the tube / You wait for the next one

You get to work and check your email. You see you have received an invitation from the colleague in the next office: they are recruiting volunteers to help with a fundraising event that will take place next month. What do you do? You decline the invitation / You accept to volunteer

At noon you go out to a nearby restaurant to have lunch. When you pay the waitress gives you the change, but there's more than should be. What do you do? You tell her the change is wrong / You don't say anything

After lunch you still have a lot of work to do, but you want to leave early this afternoon because you have planned to go to an art exhibition. However, you receive a call from a colleague: you need to discuss some issues related to a project, but she keeps chatting about an argument she had with her partner. What do you do? You keep trying to comfort her / You change the topic to discuss the project

In the end you have enough time to visit the art exhibition. Before leaving, you see a couple of collection boxes asking for a donation to help cover the costs of the exhibition. What do you do? You continue your way out / You donate something

On your way back home, you see a homeless man asking for money. He looks at you and asks if you can give him some coins. What do you do? You give him some money / You continue your way back home

Story 2

It's Friday afternoon and you're working hard to finish your essay before tomorrow, since a friend is arriving to visit you for the weekend. However, your friend John calls you to invite you to the cinema this evening: he had a date with a girl and had bought tickets, but she just cancelled it. What do you do? You go to the cinema / You tell him you are busy

The next morning you go to the train station to pick up your friend. While you wait for her, you check your Facebook on the cell phone and see a post from your flatmate's friend: he's asking for volunteers to help taking care of disabled children in the school where he works. What do you do? You continue checking posts / You say you'd like to help

It seems the train has been delayed, so you decide to have a walk outside the station. Right outside the station you see a homeless man juggling to music. When he finishes, he asks you for money. What do you do? You go back to the station / You give him some money

Finally, the train arrives and you meet your friend. You need to take a bus to go back home and leave the luggage, and you know there is one leaving from the far side of the station in 5 minutes. What do you do? You run to the bus stop / You wait for the next one

Then, you go to a pub to have a drink while you decide what to do. Your friend takes a seat and you go to the bar to order. When you pay, you realise the barman has given you more change than he should have done. What do you do? You tell him the change is wrong / You don't say anything

Finally, you decide to visit a museum. Although the entrance is free, there is a collection box to donate something to maintain the museum. What do you do? You donate something / You don't donate

2.7.3. Conversation with Alice

Experimenter (E) presses "enter" to connect to the charity, and video of Alice (A) appears.

Experimenter (E): Hi Alice, how're you? Can you hear me?

Alice (A): Hi! Yes I hear you; there's a bit of noise, but it's fine.

E: Yeah? Great, and can you see our participant here today?

A: Yes, hi!

E: Ok, so Alice, this is [name of participant]. [Name of participant] this is Alice…

A *(waving her hand)*: Hi, nice to meet you!

E: Now we need to check that the Screen Share is working… *(press number 5)* Can you tell me what number is on the Screen Share now, if you can see it?

A: Yes, number 5.

E: And now? *(press number 3)*

A: Hmm, 3.

E: Cool, it seems that everything's working well… So we'll start the task now. (*A nods*) The first task will be the Story task, and you will read the statement on the Screen Share and ask to the participant "what do you do?". Please, remember not to make any facial expression or say anything that could influence the participant's choices, so just keep it as neutral as possible. And I think that's all… Is everything clear?

A: Yes, everything's clear.

E: Great, are you ready then to start?

A: Yes, I'm ready!

Participant completes Story task.

2.7.4. Post-test questionnaire

Section 1

I liked <u>Alice</u> very much.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction with Alice was very natural.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction with Alice was very reciprocal.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I liked Sophie very much.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction with Sophie was very natural.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction with Sophie was very reciprocal.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

It is very important for me to have the full bonus (£4).

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the impact of MHAF on society is very important.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think that making a donation to MHAF is socially desirable.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think it is very important to donate money to charity.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I typically donate between £ X-X to a charity per month.

£ <5 £ 5-10 £ 10-20 £ 20-30 £ 30-40 £ 40-50 £ >50

I think it is very important to do some voluntary work.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I typically do between X-X h of voluntary work per month.

<1 h 1-2 h 2-5 h 5-10 h 10-20 h 20-30 h >30 h

Section 2

What do you think was the purpose of the experiment?

Did you follow any strategy when giving an answer on the stories task? Please, explain.

Did you follow any strategy when giving an answer on the offer task? Please, explain.

Do you think you gave different answers to Alice and Sophie? If so, why?

Section 3

<u>Fear/Anxiety:</u> 0 = None / 1 = Mild / 2 = Moderate / 3 = Severe

<u>Avoidance:</u> 0 = Never / 1 = Occasionally / 2 = Often / 3 = Usually

	Fear/ Anxiety	Avoidance
1. Telephoning in public.		
2. Participating in small groups.		
3. Eating in public places.		
4. Drinking with others in public places.		
5. Talking to people in authority.		
6. Acting, performing or giving a talk in front of an audience.		
7. Going to a party.		
8. Working while being observed.		
9. Writing while being observed.		
10. Calling someone you don’t know very well.		
11. Talking with people you don’t know very well.		
12. Meeting strangers.		
13. Urinating in a public bathroom.		
14. Entering a room when others are already seated.		
15. Being the center of attention.		
16. Speaking up at a meeting.		
17. Taking a test.		
18. Expressing disagreement/disapproval to people you don’t know very well.		
19. Looking at people you don’t know very well in the eyes.		
20. Giving a report to a group.		

21. Trying to pick up someone.		
22. Returning goods to a store.		
23. Giving a party.		
24. Resisting a high pressure salesperson.		

2.7.5. Tables with full eye gaze results

Table 2-7. Results for gaze behaviour of participants (Story task)

		Video box	Question box	Answer box
Setting	main effect	$F(1,31) = 2.91$ $p = .098$ $n_p^2 = .086$	$F(1,31) = .118$ $p > .05$ $n_p^2 = .004$	$F(1,31) = 5.17$ $p < .05^{*}$ $n_p^2 = .143$
Time window	main effect	$F(2,62) = 38.5$ $p < .001^{***}$ $n_p^2 = .554$	$F(2,62) = 437.1$ $p < .001^{***}$ $n_p^2 = .934$	$F(2,62) = 710.1$ $p < .001^{***}$ $n_p^2 = .958$
	q vs. pre	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	q vs. post	$p > .05$	$p < .001^{***}$	$p < .001^{***}$
	pre vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
Setting X Time window	interaction effect	$F(2,62) = 3.6$ $p = .054$ $n_p^2 = .104$	$F(2,62) = 5.81$ $p < .01^{**}$ $n_p^2 = .158$	$F(2,62) = .839$ $p < .05$ $n_p^2 = .026$
	q: ON vs. OFF	$p < .001^{***}$	$p < .01^{**}$	$p > .05$
	pre: ON vs. OFF	$p > .05$	$p = .082$	$p < .05^{*}$
	post: ON vs. OFF	$p > .05$	$p > .05$	$p > .05$
	ON: q vs. pre	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	ON: q vs. post	$p = .042^{*}$	$p < .001^{***}$	$p < .001^{***}$
	ON: pre vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	OFF: q vs. pre	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	OFF: q vs. post	$p > .05$	$p < .001^{***}$	$p < .001^{***}$
	OFF: pre vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$

q = question; pre = pre-answer; post = post-answer; ON=online; OFF= offline
Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***)

Table 2-8. Results for gaze behaviour of participants (Offer task)

		Video box	Question box	Answer box
Setting	main effect	$F(1,31) = 13.5$ $p < .01^{**}$ $n_p^2 = .303$	$F(1,31) = 23.5$ $p < .001^{***}$ $n_p^2 = .431$	$F(1,31) = .503$ $p > .05$ $n_p^2 = .016$
Time window	main effect	$F(2,62) = 37.0$ $p < .001^{***}$ $n_p^2 = .544$	$F(2,62) = 122.0$ $p < .001^{***}$ $n_p^2 = .797$	$F(2,62) = 210.7$ $p < .001^{***}$ $n_p^2 = .872$
	q vs. pre	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	q vs. post	$p < .01^{**}$	$p < .001^{***}$	$p < .001^{***}$
	pre vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
Setting X Time window	interaction effect	$F(2,62) = 8.0$ $p < .01^{**}$ $n_p^2 = .205$	$F(2,62) = 21.3$ $p < .001^{***}$ $n_p^2 = .408$	$F(2,62) = .565$ $p > .05$ $n_p^2 = .018$
	q: ON vs. OFF	$p < .05^{*}$	$p < .001^{***}$	$p > .05$
	pre: ON vs. OFF	$p < .05^{*}$	$p > .05$	$p > .05$
	post: ON vs. OFF	$p < .001^{***}$	$p < .001^{***}$	$p > .05$
	ON: q vs. pre	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	ON: q vs. post	$p < .05^{*}$	$p < .001^{***}$	$p < .001^{***}$
	ON: pre vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	OFF: q vs. pre	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	OFF: q vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	OFF: pre vs. post	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$

q = question; pre = pre-answer; post = post-answer; ON=online; OFF= offline
Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***)

2.7.6. Analyses with excluded participants (do not believe manipulation)

Nine participants (4 females, 5 males; mean age: 25.33±2.96) were excluded from the main analyses because they did not believe the deceptive video-conference manipulation. We run all the analyses on this group of participants to see how they differ from the sample included in the main analyses. Since this sample is rather small, we are very cautious of putting too much interpretation on these results. However, these analyses can also give some insight into which behaviours are strongly modulated by the deceptive manipulation (if both groups behave differently) and which behaviours are not (if both groups behave the same).

Manipulation check: post-test questionnaire ratings

Two-tailed paired *t*-tests between ON and OFF setting were computed for each trait (likeability, naturalness and reciprocity). Results showed that there was no difference between ON and OFF settings on how the confederate was perceived. See Table 2-9 for descriptives (mean and SD) on post-test questionnaire ratings.

Table 2-9. Descriptives post-test questionnaire ratings

Rating	Setting	*M*	*SD*
Likeable	ON	5.55	2.19
	OFF	5.33	1.32
Natural	ON	4.33	2.60
	OFF	4.55	1.88
Reciprocal	ON	3.22	1.64
	OFF	4.11	1.36

These findings show that participants who are aware that both confederates are pre-recorded in a video-clip will perceive both confederates as equally likeable, natural and reciprocal. This contrasts with the results in the main sample, where participants perceive the confederate in the ON setting as more likeable and natural. Taken together, this indicates that being embedded in a true interaction and able to communicate with each other has positive consequences on how we perceive our interactive partners.

Prosocial behaviour

For the Story task, results showed that choices were significantly more prosocial under the ON setting (*M* = .610, *SD* = .274) than under the OFF setting (*M* = .544, *SD* = .273), $F(1,7) = 11.3$, $p < .05$, $n_p^2 = .618$. Although there was no main effect of Order, results showed an interaction between Setting and Order, $F(1,7) = 10.2$, $p < .05$, $n_p^2 = .592$: participants who performed the task first under the OFF setting (*M* = .587, *SD* = .303) and then under the ON setting (*M* = .592, *SD* = .318) showed no change in prosocial behaviour, whereas in the reversed order prosocial behaviour was higher in the ON (*M* = .647, *SD* = .212) than in the OFF setting (*M* = .460, *SD* = .229). A crucial difference between these findings and the main analysis relies in the interaction between Setting and Order for the Story task. Participants who complete the Story task first under the OFF setting and then under the ON setting show no difference in prosocial behaviour: this suggests that seeing pre-recorded video-clips in the OFF setting makes participants sceptic about the live nature of the consecutive ON setting, and they have no reason to increase their prosocial choices to signal good reputation. However, participants who complete the Story task first in the ON setting and then in the OFF setting show the same pattern of behaviour as participants in the main sample: these participants may realise that the videos in the ON setting are pre-recorded once they complete the task in the OFF setting.

For the Offer task, there was no main effect of Setting (ON: *M* = 15.1, *SD* = 5.29; OFF: *M* = 14.9, *SD* = 5.08), Order, or interaction between Setting and Order. This contrasts with the findings in the main analysis, where there was a tendency for a main effect of Setting and for an interaction between

Setting and Order. Since participants always complete the Offer task after the Story task, it is likely that if they become aware of the manipulation during the Story task, any effects of Setting will be completely gone in the consecutive Offer task.

Regarding social anxiety scores, we found a significant positive correlation between the change in prosocial behaviour (ON – OFF) and social anxiety traits for the Story task, $r = .753$, $p < .05$: the more participants changed their behaviour from OFF to ON setting, the more anxiety traits they had. This result corroborates the correlation found in the main analysis. There was no significant correlation between social anxiety traits and change in prosocial behaviour for the Offer task. Overall, these findings are in line with the Story task and Offer task analyses, where participants change (Story task) and do not change (Offer task) prosocial behaviour between ON and OFF settings.

Gaze behaviour: Story task

See Table 2-10 for descriptives (mean and SD) on the proportion of looking time to each box and time window. Only significant main effects and interactions are reported in the text; full results and post-hoc tests are given in Table 2-11. For looking time to the Video box, there was a main effect of Setting, $F(1,8) = 8.28$, $p < .05$, $n_p^2 = .509$, and Time window, $F(2,16) = 7.70$, $p < .01$, $n_p^2 = .490$. Participants looked more to the Video box in the ON setting than in the OFF setting, and during the question and post-answer phases than in the pre-answer phase. This was qualified by an interaction effect between Setting and Time window, $F(2,16) = 14.1$, $p < .001$, $n_p^2 = .639$: participants looked more to the Video box in the ON setting than in the OFF setting, particularly during the post-answer phase. For looking time to the Question box, there was a main effect of Time window, $F(2,16) = 41.4$, $p < .001$, $n_p^2 = .838$, but no main effect of Setting or interaction between Setting and Time window. Participants looked more to the Question box in the question phase, followed by the post-answer phase and pre-answer phase. For looking time to the Answer box, there was a main effect of Time window, $F(2,16) = 160.3$, $p < .001$, $n_p^2 = .952$, and an interaction effect between Setting and Time Window, $F(2,62) = 9.31$, $p < .01$, $n_p^2 = .538$. Participants looked more to the Answer box in the pre-answer phase, followed by the post-answer phase and question phase. Moreover, the proportion of looking time during the post-answer phase was higher in the OFF setting than in the ON setting.

Table 2-10. Descriptives for the proportion of looking time to each box (Story task)

Setting	Time window	Video box	Question box	Answer box
ON	question	*M* = .146 *SD* = .107	*M* = .751 *SD* = .105	*M* = .024 *SD* = .021
	pre-answer	*M* = .027 *SD* = .025	*M* = .117 *SD* = .150	*M* = .823 *SD* = .155
	post-answer	*M* = .259 *SD* = .199	*M* = .444 *SD* = .193	*M* = .201 *SD* = .098
OFF	question	*M* = .159 *SD* = .114	*M* = .730 *SD* = .140	*M* = .026 *SD* = .023
	pre-answer	*M* = .017 *SD* = .018	*M* = .151 *SD* = .211	*M* = .788 *SD* = .130
	post-answer	*M* = .080 *SD* = .081	*M* = .464 *SD* = .160	*M* = .337 *SD* = .118

While the effects of Time window are consistent with the findings in the main analyses (i.e. gaze shifts between the different boxes as the task progresses), there is a critical difference between gaze behaviour in both groups of participants. In the main analyses participants look more to the Video box in the OFF setting than in the ON setting, especially during the question phase. In contrast, participants who do not believe the manipulation look more to the Video box in the ON setting than in the OFF setting, especially during the post-answer phase. This suggests that participants are scrutinizing the confederate in the ON setting to verify if she is a pre-recorded video or not. They might do this particularly during the post-answer phase because, if she were a live video-feed, it is more likely that during this phase she would show some sort of reaction to the answer of the participant. Moreover, in the main analyses participants look more to the Question and Answer box in the ON setting than in the OFF setting, whereas here they either direct equal amount of gaze in both settings (Question box), or look more in the OFF than in the ON setting (Answer box). Overall, this suggests that once the deceptive manipulation is uncovered, participants no longer care about their reputation and social norms. Instead, their gaze patterns are reversed and they spend more time looking at the confederate in the ON setting to verify if she is a true live video-feed or not.

Table 2-11. Results for gaze behaviour of participants (Story task)

		Video box	Question box	Answer box
Setting	main effect	$F(1,8) = 8.28$ $p < .05^{*}$ $n_p^2 = .509$	$F(1,8) = .210$ $p > .05$ $n_p^2 = .026$	$F(1,8) = 2.88$ $p > .05$ $n_p^2 = .265$
Time window	main effect	$F(2,16) = 7.70$ $p < .01^{**}$ $n_p^2 = .490$	$F(2,16) = 41.4$ $p < .001^{***}$ $n_p^2 = .838$	$F(2,16) = 160.3$ $p < .001^{***}$ $n_p^2 = .952$
	q vs. pre	$p < .05^{*}$	$p < .001^{***}$	$p < .001^{***}$
	q vs. post	$p > .05$	$p < .01^{**}$	$p < .001^{***}$
	pre vs. post	$p < .05^{*}$	$p < .05^{*}$	$p < .001^{***}$
Setting X Time window	interaction effect	$F(2,16) = 14.1$ $p < .001^{***}$ $n_p^2 = .639$	$F(2,16) = .529$ $p > .05$ $n_p^2 = .062$	$F(2,16) = 9.31$ $p < .01^{**}$ $n_p^2 = .538$
	q: ON vs. OFF	$p > .05$	$p > .05$	$p > .05$
	pre: ON vs. OFF	$p > .05$	$p > .05$	$p > .05$

post: ON vs. OFF	$p < .01^{**}$	$p > .05$	$p < .05^{*}$
ON: q vs. pre	$p < .05^{*}$	$p < .05^{*}$	$p < .001^{***}$
ON: q vs. post	$p = .058$	$p < .05^{*}$	$p < .001^{***}$
ON: pre vs. post	$p = .062$	$p = .084$	$p < .001^{***}$
OFF: q vs. pre	$p < .05^{*}$	$p = .059$	$p < .001^{***}$
OFF: q vs. post	$p < .05^{*}$	$p = .067$	$p < .001^{***}$
OFF: pre vs. post	$p < .05^{*}$	$p > .05$	$p < .001^{***}$

q = question; pre = pre-answer; post = post-answer; ON=online; OFF= offline
Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***)

Gaze behaviour: Offer task

See Table 2-12 for descriptives (mean and SD) on the proportion of looking time to each box and time window. Full results are reported in Table 2-13 and significant main effects and interactions are described below. For all ROIs (Video, Question, Answer box), there was a main effect of Time window on looking time to each box. Participants looked more to the Video box during the question and post-answer phases than in the pre-answer phase ($F(2,16) = 12.4$, $p < .01$, $n_p^2 = .607$). Participants looked more to the Question box during the question phase, followed by the post-answer phase and pre-answer phase ($F(2,16) = 98.9$, $p < .001$, $n_p^2 = .925$). Participants looked more to the Answer box in the pre-answer phase, followed by the post-answer phase and question phase ($F(2,16) = 79.3$, $p < .001$, $n_p^2 = .908$). There was no main effect of Setting or interaction between Setting and Time window for any of the ROIs.

Table 2-12. Descriptives for the proportion of looking time to each box (Offer task)

Setting	Time window	Video box	Question box	Answer box
ON	question	*M* = .151 *SD* = .146	*M* = .730 *SD* = .182	*M* = .044 *SD* = .031
	pre-answer	*M* = .046	*M* = .229	*M* = .553

		SD = .102	*SD* = .120	*SD* = .153
	post-answer	*M* = .217 *SD* = .254	*M* = .430 *SD* = .252	*M* = .159 *SD* = .067
OFF	question	*M* = .147 *SD* = .139	*M* = .685 *SD* = .161	*M* = .056 *SD* = .047
	pre-answer	*M* = .040 *SD* = .061	*M* = .212 *SD* = .117	*M* = .534 *SD* = .186
	post-answer	*M* = .213 *SD* = .183	*M* = .370 *SD* = .189	*M* = .161 *SD* = .063

Similar to the Story task, the effects of Time window across the three ROIs are consistent with the findings in the main analyses and the task progression. A critical difference between gaze behaviour in both groups of participants is that in the main analyses there was an effect of Setting, and an interaction effect between Setting and Time window: participants looked more to the Video box in the OFF setting, and more to the Question box in the ON setting, particularly during question and post-answer phases. Here, we do not find any effect of Setting or interaction. As mentioned before, participants always completed the Offer task after the Story task: if during the Story task they already realised that the manipulation was not true, in the Offer task it was not necessary to further scrutinize the confederate in the ON setting. Consistent with the findings in the Story task, these findings suggest that once the deceptive manipulation is uncovered, the signalling function of gaze and the need to follow social norms fade away.

Table 2-13. Results for gaze behaviour of participants (Offer task)

		Video box	Question box	Answer box
Setting	main effect	$F(1,8) = .010$ $p > .05$ $\eta_p^2 = .001$	$F(1,8) = 1.66$ $p > .05$ $\eta_p^2 = .172$	$F(1,8) = .008$ $p > .05$ $\eta_p^2 = .001$
Time window	main effect	$F(2,16) = 12.4$ $p < .01^{**}$ $\eta_p^2 = .607$	$F(2,16) = 98.9$ $p < .001^{***}$ $\eta_p^2 = .925$	$F(2,16) = 79.3$ $p < .001^{***}$ $\eta_p^2 = .908$

	q vs. pre	$p < .01^{**}$	$p < .001^{***}$	$p < .001^{***}$
	q vs. post	$p > .05$	$p < .001^{***}$	$p < .01^{**}$
	pre vs. post	$p < .05^{*}$	$p < .05^{*}$	$p < .001^{***}$
Setting X Time window	interaction effect	$F(2,16) = .002$ $p > .05$ $n_p^2 < .001$	$F(2,16) = .343$ $p > .05$ $n_p^2 = .041$	$F(2,16) = .760$ $p > .05$ $n_p^2 = .087$
	q: ON vs. OFF	$p > .05$	$p > .05$	$p > .05$
	pre: ON vs. OFF	$p > .05$	$p > .05$	$p > .05$
	post: ON vs. OFF	$p > .05$	$p > .05$	$p > .05$
	ON: q vs. pre	$p < .05^{*}$	$p < .001^{***}$	$p < .05^{*}$
	ON: q vs. post	$p > .05$	$p < .001^{***}$	$p < .05^{*}$
	ON: pre vs. post	$p < .05^{*}$	$p < .01^{**}$	$p < .05^{*}$
	OFF: q vs. pre	$p < .05^{*}$	$p < .001^{***}$	$p = .057$
	OFF: q vs. post	$p < .05^{*}$	$p < .001^{***}$	$p < .05^{*}$
	OFF: pre vs. post	$p < .01^{**}$	$p < .05^{*}$	$p = .053$

q = question; pre = pre-answer; post = post-answer; ON=online; OFF= offline
Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***)

Relationship between prosocial and gaze behaviour

First, we tested if choices are related to previous gaze behaviour (during the question phase), that is, are people more prosocial when they look more to the video-feed? For both Story and Offer tasks, results showed that there was no main effect of Setting or Gaze, nor an interaction effect of Setting X Gaze, on prosocial choices (see Table 2-14a and 2-15a).

Second, we tested if choices are related to gaze behaviour in the post-answer phase: do participants look to the confederate to see if she evaluates their choice? For the Story task, we found a main effect of Setting on the proportion of looking time to the Video box after making a choice, $F(1,78.6)$ =

4.76, $p < .05$ (see Table 2-14b): participants looked more to the Video box under the ON setting, regardless of the type of choice. For the Offer task, results showed that there was no main effect of Setting or Choice, nor an interaction effect of Setting X Choice (see Table 2-15b).

A critical difference between these findings and the main analysis is that here there is no correlation between prosociality of choice and gaze behaviour during post-answer phase, for the Story task. This result suggests that these participants do not feel the need to check whether the confederate evaluates their choices: when the deceptive manipulation is uncovered, the feeling that the confederate can judge them fades away.

Table 2-14. Relationship prosocial behaviour and eye gaze (Story task)

a) Does gaze predict choices?		*b) Do choices predict gaze?*	
Setting	$F(1,79.7) = 1.41$ $p > .05$	Setting	$F(1,78.6) = 4.76$ $p < .05$*
Gaze	$F(1,85.3) = .012$ $p > .05$	Choice	$F(1,85.2) = .974$ $p > .05$
Setting X Gaze	$F(1,80.5) = .364$ $p > .05$	Setting X Choice	$F(1,78.7) = .205$ $p > .05$

Table 2-15. Relationship prosocial behaviour and eye gaze (Offer task)

a) Does gaze predict choices?		*b) Do choices predict gaze?*	
Setting	$F(1,423.2) = .376$ $p > .05$	Setting	$F(1,420.03) = .121$ $p > .05$
Gaze	$F(1,421.6) = .007$ $p > .05$	Choice	$F(1,424.1) = .216$ $p > .05$
Setting X Gaze	$F(1,426.9) = 1.40$ $p > .05$	Setting X Choice	$F(1,420.04) = .067$ $p > .05$

Chapter 3. Is self-referential processing related to audience effects?

The design of Chapter 3 was pre-registered in Open Science Framework:

Cañigueral, R., & Hamilton, A. F. de C. (2017). Effects of being watched on self-referential processing, self-awareness and prosocial behaviour. Retrieved July 31, 2017, from osf.io/xtmh8

The results of Chapter 3 were published in Consciousness and Cognition:

Cañigueral, R., & Hamilton, A. F. de C. (2019). Effects of being watched on self-referential processing, self-awareness and prosocial behaviour. Consciousness and Cognition, 76(September), 102830. https://doi.org/10.31234/osf.io/2vaby

3.1. Abstract

Reputation management theory suggests that our behaviour changes in the presence of others to signal good reputation (audience effect). However, the specific cognitive mechanisms by which being watched triggers these changes are poorly understood. This chapter tested the hypothesis that these changes are related to an increase in self-referential processing when being watched. We used a novel deceptive video-conference paradigm, where participants believe a video-clip is (or is not) a live feed of a confederate watching them. Participants completed four tasks measuring self-referential processing, prosocial behaviour and self-awareness under these two belief settings. Although the belief manipulation and self-referential effect task were effective, there were no changes on self-referential processing between the two settings, nor on prosocial behaviour and self-awareness. Based on previous evidence and these findings, we propose that further research on the

role of the self, social context and personality traits will help elucidating the mechanisms underlying audience effects.

3.2. Introduction

When we feel someone is watching us, our behaviour changes in different ways. For instance, our actions become more prosocial (Izuma et al., 2011, 2009), our memory improves (Fullwood & Doherty-Sneddon, 2006), and we smile more (Fridlund, 1991). Changes in behaviour specifically caused by the belief in being watched are called “audience effects” (Bateson et al., 2006; Haley & Fessler, 2005), which are different from “social facilitation” effects (i.e. changes in behaviour in the presence of a conspecific, who may or may not be watching; Triplett, 1898; Zajonc, 1965). Bond (1982) originally described audience effects in terms of self-presentation theory, where he suggested that people seek to maintain a positive public image to increase their self-esteem in front of others. In an updated version of this account, reputation management theory suggests that our behaviour changes to signal good reputation to others (Bradley et al., 2018; Emler, 1990; Tennie et al., 2010). However, it is not yet known how being watched translates into behaviours aimed at signalling good reputation (e.g. prosocial behaviour). In this chapter we tested the hypothesis that these behavioural changes happen because, similarly to observing another individual’s direct gaze (Conty et al., 2016), the mere belief in being watched increases self-referential processing.

3.2.1. Reputation management theory

Reputation is a social construct based on how we think others see us, and emerges from the desire to promote good self-impressions on others (Cage, 2015; Emler, 1990; Resnick et al., 2006; Silver & Shaw, 2018; Tennie et al., 2010). For instance, individuals can signal good reputation and gain the approval of others when they take actions for the benefit of others or when they behave according to social norms. Several studies have shown how participants manipulate the information that others receive in order to signal good reputation, in real-life (Bereczkei et al., 2007; Raihani & Smith, 2015) but also in lab-based studies (Bradley et al., 2018; Filiz-Ozbay & Ozbay, 2014; T. Pfeiffer & Nowak, 2006; Satow, 1975). For instance, Izuma and colleagues (Izuma et al., 2011) tested how the belief in being seen influences prosocial behaviour using the Dictator game (Guala & Mittone, 2010; Kahneman et al., 1986). In this game participants are given a sum of money and must decide whether to give some of this money to a charity (prosocial behaviour) or keep it all for themselves (non-prosocial behaviour). Each participant completed the task while alone in a room and while monitored by a confederate in the same room. Results showed that when participants were in the presence of the confederate watching, they decided to donate money more often than when alone in the room. This has been replicated by Cage and colleagues (Cage, Pellicano, Shah, & Bird, 2013), who also found that participants accepted more donations in the presence of the observer when the observer could later reciprocate.

The maintenance or management of reputation requires two main cognitive processes. On the one hand, individuals need to infer what others think of them and know that they can manipulate their views. This means that attributing mental states to others in relation to oneself is key to make sense of one's reputation (Cage, 2015). In line with this, it has been shown that the medial prefrontal cortex (a neural correlate for mentalizing and self-related processing; Frith & Frith, 2006; Lombardo et al., 2010) is activated when processing one's reputation in the eyes of other people (Izuma et al., 2010). On the other hand, to manage reputation individuals need to care about how they are seen, as well as have the desire to be viewed positively. Thus, reputation management also requires social motivation processes (Cage, 2015; Izuma et al., 2010). This is supported by neuroimaging studies showing that brain regions involved in motivation and reward processing (e.g. ventral striatum) are engaged when participants anticipate positive reputation after presenting themselves in front of others (Izuma et al., 2009, 2010).

Although reputation management theory provides a plausible account of the audience effect, the specific cognitive mechanisms by which the presence of a real observer triggers changes in behaviour remain poorly understood. The Watching Eyes model (Conty et al., 2016) may help us understand this.

3.2.2. Watching Eyes model and self-referential processing

The Watching Eyes model (Conty et al., 2016) proposes a two-stage process to explain how direct gaze changes our behaviour. According to this model, in the first stage direct eye gaze automatically captures the beholder's attention (Senju & Hasegawa, 2005), which is thought to be triggered by low-level visual cues in the eyes (e.g. luminance distribution in the eye; Kobayashi & Kohshima, 2001; von Grünau & Anston, 1995). The detection of direct eye gaze is implemented by a subcortical route involving the pulvinar and amygdala that in turn modulates the activation of higher cortical regions (Senju & Hasegawa, 2005). Among these regions, mentalising brain areas will play a key role in processing the perceptual state of the observer (i.e. is the observer watching us or not?) (Teufel, Fletcher, et al., 2010). In the second stage, the belief in being watched embedded in direct gaze will engage self-referential processing and this will increase the sense of self-involvement in the interaction. Consequently, there will be a variety of Watching Eyes effects on behaviour, such as increments in self-relevant memory, self-awareness (Baltazar et al., 2014; Hazem et al., 2017; Pönkänen et al., 2011) and prosocial behaviour (Izuma et al., 2011, 2009).

Previous studies have shown that direct gaze and the belief in being watched increase bodily self-awareness. For instance, Baltazar and colleagues (Baltazar et al., 2014) presented participants with pictures of faces with direct or averted gaze, followed by emotional pictures. They found that, when the first picture showed direct gaze, participants were more accurate in rating the intensity of their physiological signal in response to the emotional picture. Hazem and colleagues (Hazem et al., 2017) used the same paradigm but, instead of showing pictures with direct and averted gaze, they showed videos of a confederate wearing two different pairs of sunglasses. They manipulated the beliefs of participants by telling them that there was an online connection with the confederate, and that one pair of sunglasses was opaque (the confederate cannot see through) whereas the other was clear (the confederate can see through). They found that when the confederate was wearing clear sunglasses, participants rated their physiological response to the emotional picture more accurately. These findings suggest that the belief in being watched is key to increase self-awareness.

Hietanen & Hietanen (2017) have recently directly tested the Watching Eyes model on self-referential processing. In the first experiment, participants watched video-clips of a person showing either direct or averted gaze while they completed a foreign-language task. In this task, participants read a sentence in a language they do not understand and choose which pronoun (in their native language) corresponds to the underlined word in the sentence. The amount of first person singular pronouns used by participants provides an implicit measure of self-referential processing. Results showed no effect of gaze direction on the use of pronouns. In a second experiment, participants watched live faces with direct or averted gaze through a liquid crystal shutter and completed the same task. Participants in the live direct gaze group used more first person pronouns and less third person pronouns than participants under the live averted gaze group. Overall, these findings indicate that self-referential processing cannot be triggered by direct eye gaze alone but rather requires the belief in being watched embedded in direct gaze.

3.2.3. Deceptive video-conference paradigm

Studies investigating the cognitive mechanisms underlying the audience effect require a truly interactive environment, where participants genuinely believe that there is someone watching them. A common drawback in previous experiments is the lack of well-matched control and test conditions, since they test differences between a control condition where the participant is alone in the room, and a test condition where an observer is present in the room or in a video-feed (see Izuma et al., 2010, 2009 for examples of studies with a video-feed). This means that control and test conditions are not optimally matched to isolate true audience effects (i.e. the belief that someone is watching us or not). Instead, social control and social test conditions would be more suitable to test these effects.

In Chapter 2 we implemented a novel deceptive video-conference paradigm that allows to strictly test the audience effect (see Mansour & Kuhn, 2019 for a similar paradigm). In this paradigm, participants connect with two different confederates using a fake video-conference interface and complete a task under two settings: one where participants believe the video-feed is real and the confederate can monitor their performance during the task (online setting; ON), and one where they are told the videos are pre-recorded (offline setting; OFF). Since both video-feeds are pre-recorded video-clips, this manipulation only varies in the belief in being seen, without any changes in the physical or video-feed presence of the confederate. Moreover, video-conference is nowadays a common means of communication, so there is high ecological validity for the ON setting while keeping well-matched stimuli with the OFF setting.

Our findings in Chapter 2 proved that the deceptive video-conference paradigm is a valid method to test the audience effect. In this study, participants were told that both confederates were students volunteering in a charity, and completed two tasks assessing prosocial behaviour while recorded with eye-tracking. The first task (Story task) was inspired by Izuma et al. (2010), where participants had to disclose their tendencies relative to social norms. The second task was based on Izuma et al. (2011) Offer task, where participants are given specific amounts of money and accept or reject to give some of this money to the charity where the students volunteer. To ensure an interactive environment, the tasks were structured as a question and answer conversation between confederate and participant: the confederate in the video-clip first asked the question to the participant and the participant then said the answer aloud to the confederate, before entering it on the computer. Out of 43 adult participants, 34 believed the live video-feed manipulation for the ON setting, and overall the confederate in the ON setting was perceived as more natural and likeable than the confederate in the OFF setting. This shows that our paradigm is an effective manipulation of the belief in being seen. We also found that for the Story task choices were more prosocial under the ON setting compared to the OFF setting, and a similar pattern was found for the Offer task. This finding suggests that in live social contexts the opportunity to signal good reputation increases and this promotes prosocial behaviour, but also shows that the deceptive video-conference paradigm is a valid approach to test audience effects.

3.2.4. The present study

Hietanen & Hietanen (2017) have shown that participants use more first person pronouns when a live face is directly gazing at them, rather than when the same face is looking away, suggesting that live direct gaze increases self-related processing. It has also been shown that the mere belief in being watched increases self-awareness (Hazem et al., 2017). However, it is unknown whether the belief in being watched is enough to trigger an increase in self-referential processing. The deceptive video-conference paradigm can help to examine this question rigorously. By using this paradigm, in this chapter we aimed to test whether audience effects (e.g. increase in prosocial behaviour when being watched) are related to an increase in self-referential processing when being watched.

Based on predictions from the Watching Eyes model (Conty et al., 2016) and reputation management theory (Izuma et al., 2011), we tested whether the belief in being watched increases self-referential processing, prosocial behaviour and self-awareness. To do so, we used four cognitive tasks in sequence: the Self-Referential Effect memory task (two phases: Encoding phase and Memory phase) to measure self-referential processing, the Story task to measure prosocial behaviour, and the Confidence Bias task and Optimism Bias questionnaire to measure self-awareness. Participants completed these tasks on two sessions on two consecutive days. During the first session (baseline session) they performed the tasks in a non-social context. In the second session (test session) participants were split in two groups: one group completed the tasks under the online setting (ON), and the other group completed the tasks under the offline setting (OFF) (see Figure 3-1a and 3-1b for an overview of the study and procedure over the two days). Similar to Hietanen & Hietanen (2017), this between-subjects design was chosen to avoid carryover effects of self-referential processing between the ON and OFF settings. Note that, different to Chapter 2, here participants believed the confederate was a student doing her PhD in the psychology department of the university. In the following we describe how each task addresses the specific aims and hypotheses of our study.

First, we aimed to test whether self-referential memory is enhanced under the belief in being watched. Participants completed the commonly used Self-Referential Effect memory task (Craik & Tulving, 1975; Lombardo, Barnes, Wheelwright, & Baron-Cohen, 2007), under the belief that they were being watched or not. In this task, participants first judge how good different trait adjectives are at describing two targets: “myself” or another person (Encoding phase). After a 30 minutes delay, participants are shown the same adjectives and new distracter adjectives, and they have to judge whether each of these adjectives was presented during the Encoding phase (Memory phase). Previous studies using this task have consistently shown that people are better at remembering adjectives related to the self, compared to adjectives related to the other (Lombardo et al., 2007; Symons & Johnson, 1997). If the belief in being watched alone is enough to trigger self-referential processing, this should be reflected as better memory sensitivity for self-related adjectives in the online setting. Thus, we predicted that there would be a main effect of Target ("self" adjectives are better encoded than "other" adjectives), an interaction between Session and Belief (better memory sensitivity for ON than OFF only in the test session), and an interaction between Target, Session and Belief – memory sensitivity for "self" adjectives under the ON test session will be significantly higher than for all other cases.

Second, we aimed to replicate our findings in Chapter 2 showing that prosocial behaviour increases when being watched. For this, participants completed the Story task, which proved to be a good measure of prosocial behaviour in Chapter 2. The stories in this task describe real day-to-day situations emulating a moral dilemma, and for each dilemma participants have to choose whether to act prosocially or not, in trade off with a temporal or monetary cost. Based on our findings in Chapter 2, we expected that participants would choose to act more prosocially under the belief in being watched. This should be reflected as an interaction between Session and Belief: choices under the ON test session will be more prosocial than for all other cases.

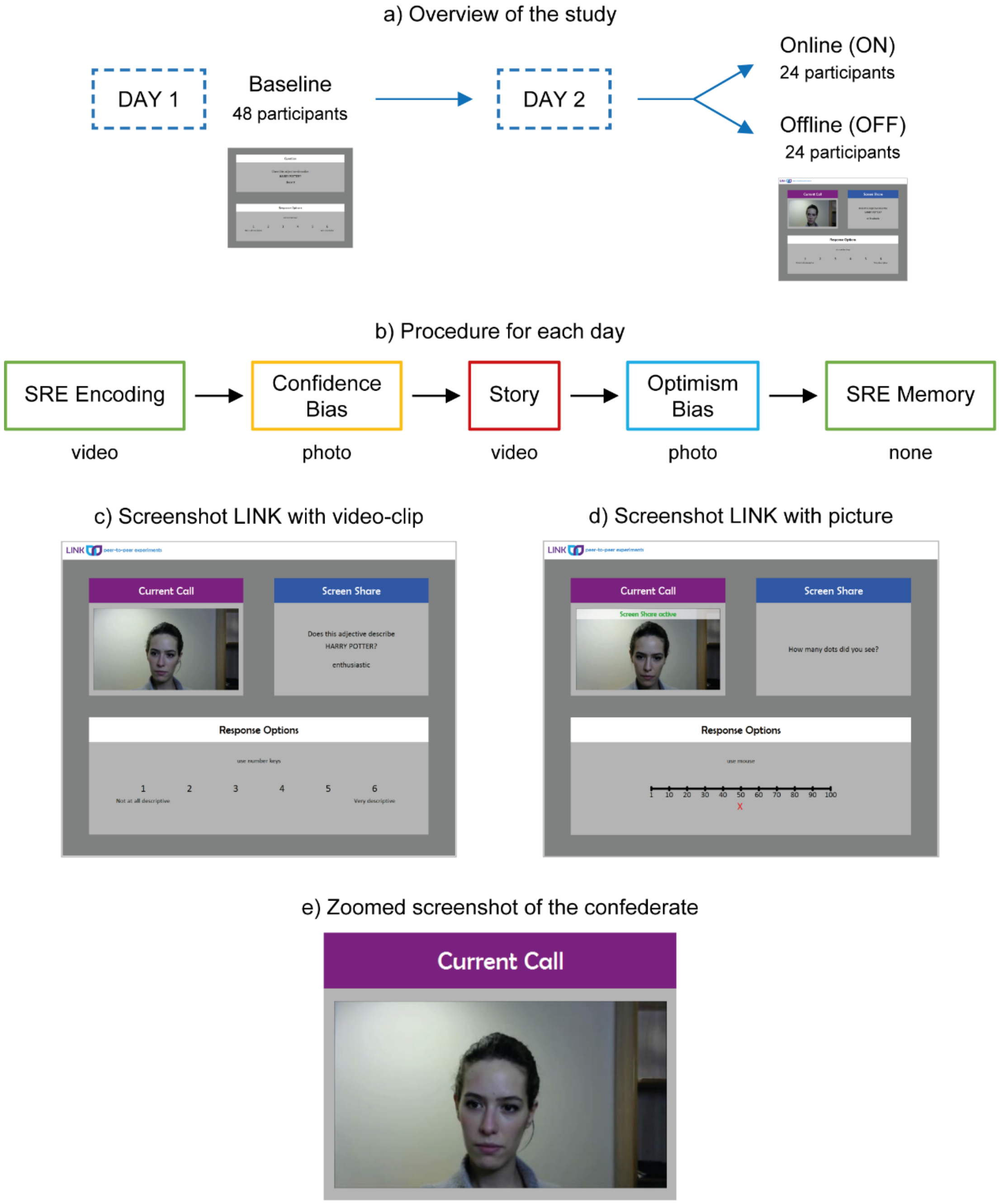

Figure 3-1. Study design.
a) Overview of the study over the two days. b) Procedure of the study and type of stimuli used in each task (SRE = Self-Referential Effect). c-d) Screenshots of LINK during a task with a video-clip (c) and a picture (d) in the ON condition. For the OFF condition the top boxes were called Videos and Side Screen, respectively. e) Zoomed screenshot of the confederate with slightly averted gaze to make participants believe she is watching them and their choices.

Third, we used two tasks to test how the belief in being watched influences self-awareness. First, the Confidence Bias task was used to measure confidence bias, that is, the accuracy in people's judgements when assessing their own performance (Harvey, 1997). Confidence bias is closely related to metacognitive function, and is considered to be a reliable measure of self-awareness and self-knowledge (Fleming & Dolan, 2012). In this paradigm, participants complete a simple perceptual task and, after each trial, they are asked to rate their accuracy on that trial (see Kunimoto, Miller, & Pashler, 2001 for an example). The accuracy rating (confidence) is then compared to the actual accuracy to compute the confidence bias. Second, the Optimism Bias questionnaire (Sharot, 2011) was used to measure one's flawed self-assessment. In this questionnaire, participants estimate the likelihood of experiencing different types of adverse life events for oneself and for another person. Previous findings show that people have better expectations for themselves than for other people, that is, people have an optimism bias toward the self (Sharot, 2011). Based on previous studies (Hazem et al., 2017), we hypothesized that the belief in being watched would increase metacognitive self-awareness and improve self-assessment: consequently, confidence bias and optimism bias should decrease when being watched. We predicted an interaction between Session and Belief: the magnitude of the biases under the ON test session would be lower than for all other cases.

We also explored potential relationships between self-referential processing, prosocial behaviour and self-awareness when being watched. If self-referential processing is related to audience effects, higher self-referential processing when being watched should correlate with higher prosocial behaviour (and likely higher self-awareness).

Finally, participants also answered a questionnaire about their perception of the confederates in each setting, and completed questionnaires measuring self-consciousness, use of gaze, social anxiety, autistic traits, and alexithymia traits. We specifically aimed to replicate our finding in Chapter 2 showing that higher change in prosocial behaviour from OFF to ON setting correlates with higher social anxiety traits.

In the following, we first present our general methods and results for experimental checks. Then, we present the detailed methods and results for each of the four cognitive tasks. The methodology and hypotheses of this study were preregistered at Open Science Framework (Cañigueral & Hamilton, 2017: https://osf.io/xtmh8/).

3.3. General Methods

3.3.1. Participants

We pre-registered a sample of 48 participants (6 for each of the 8 counterbalancing conditions). Overall, a group of 59 adults (44 females, 15 males, mean age: 23.36±3.11) were recruited because, according to our pre-registration inclusion criteria, we excluded the following participants: 6 who did not believe the manipulation for the online setting, 4 who did not follow the instructions for one task properly, and 1 due to a technical failure. Thus, the final valid sample consisted of a group of 48 adults (36 females, 12 males, mean age: 23.15±3.10), split in two groups (online setting: 18 females, 6 males, mean age: 23.08±3.22; offline setting: 18 females, 6 males, mean age: 23.21±3.05). Participants came on two consecutive days, and for each day they spent around 1 hour doing the experiment. All participants gave written informed consent before doing the experiment and were compensated £15 at the end of the second day for their time and travel expenses. This study was granted ethical approval by the local Research Ethics Committee, and is in accordance with the Declaration of Helsinki.

3.3.2. Baseline session (non-social)

At the start of the first day, participants were told that they would complete some tasks in which they would make different types of judgements. They were not told anything about what they would do during the second day. With the experimenter present, participants practised all the tasks except the Memory phase of the Self-Referential Effect memory task (SRE). The experimenter waited outside the testing room while participants completed the tasks in the following order: SRE Encoding phase task, Confidence Bias task, Story task, Optimism Bias questionnaire and SRE Memory phase task. These tasks were all designed with MATLAB (R2016b, MathWorks) and Cogent Graphics, and are described in more detail below. Both the practise and baseline session happened in a non-social environment: the screen displayed a Question box at the top (where the question was shown), and a Response Option box at the bottom (where the possible answers were shown). Finally, participants completed a computerised version of the following questionnaires: Self-Consciousness Scale (Fenigstein, Scheier, & Buss, 1975), Gaze questionnaire (designed in our group), Liebowitz Social Anxiety Scale (Liebowitz, 1987), Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), and Toronto Alexithymia Scale (Bagby, Parker, & Taylor, 1994). See sections *3.11.1.* to *3.11.5.* for the full questionnaires. The overall duration of the baseline session was 1 h 15 min.

3.3.3. Test session: deceptive video-conference paradigm

On the second day, participants were told that this study was a collaboration with another PhD student at the psychology department of the university, and that they would complete the same tasks as the day before while the PhD student (confederate) was monitoring their answers online. The experimenter pretended to check the webcam was working by launching the "Webcam video" on Movie Maker and leaving it open, so the green light on the webcam would indicate it was switched on. The experimenter pretended to launch the video-conference software (called "LINK: peer-to-peer experiments") through MATLAB, although the screens shown during the task were designed with MATLAB (R2016b, MathWorks) and Cogent Graphics in a way that tried to escape from the typical experimental layout. The LINK main desktop showed a banner on the top with the LINK logo, a box called Current Call (where the video call appeared), a Screen Share box (both the participant and the confederate were supposed to see this box; the questions and chosen answers were displayed here), and the Response Options box (where participants could choose their answers) (Figure 3-1c-d).

For the online setting (ON), the connection was successful and the video of the confederate (named Alice) was played. Although the video was pre-recorded, the experimenter pretended to have a conversation with Alice and she had previously rehearsed its timing to ensure credibility. In this conversation, the experimenter introduced Alice and the participant, and pretended to run a test with Alice to check the Screen Share was working. This enhanced the belief that Alice was real and could see the information shown on the Screen Share. The experimenter then gave some instructions for the

SRE Encoding phase task and Confidence Bias task to both Alice and the participant. She explicitly told Alice to "not make any facial expression or say anything that could influence the participant's choices", so that the participant would not suspect of Alice being too unresponsive (see section *3.11.6. Conversation with Alice* for the full conversation). The experimenter waited outside the room while the participant completed the tasks. The experimenter then loaded the Story task and Optimism Bias questionnaire and gave the corresponding instructions to both Alice and the participant. The experimenter waited outside the room during completion of the tasks. Then, a short video of Alice saying goodbye was played and the participant completed the SRE Memory phase task while the experimenter waited outside the room.

For participants in the offline setting (OFF), the connection failed, automatically tried to connect again, and failed again. During this time, the experimenter pretended to get concerned about the connection and to send a text to the second confederate (Alice). Shortly after, she pretended that Alice had answered back saying that she was in a meeting that was taking longer than expected. At this point the experimenter told participants to use pre-recorded videos, so she removed the webcam and loaded the offline mode of LINK. The LINK layout slightly changed: now the Current Call box was called Videos, and the Shared Screen was called Side Screen. The experimenter left the testing room and waited outside while participants finished the tasks.

Finally, participants completed a short post-test questionnaire where they rated how natural, likeable and reciprocal Alice was (on a scale from 0 to 8), and answered some questions about the purpose of the experiment and their strategies when completing each of the tasks (see section *3.11.7. Post-*

test questionnaire for full post-test questionnaire). If there was an answer that challenged compliance with the instructions, that participant was not included in the analyses. Participants in the ON setting were also asked whether they noticed the confederate was a pre-recorded video-clip and were subsequently debriefed about the manipulation. If they did not believe the manipulation, they were excluded from the analyses. Both groups were told about the real purpose of the study. The overall duration of the test session was 1 hour.

3.3.4. Stimuli: video-clips and photos

In the test session (ON and OFF) participants saw a video-clip or a picture of the student (depending on the task) on the Current Call/Videos box.

For the SRE Encoding phase task and Story task participants saw video-clips (Figure 3-1c). These video-clips were reused from Chapter 2, which used the same deceptive video-conference paradigm. During the filming session, the confederate was recorded with a webcam on top of a monitor in order to simulate as best as possible that it was an online connection. The same video-clips were used across the two settings (ON and OFF).

For the Confidence Bias task and Optimism Bias questionnaire a photo of the confederate was displayed instead of the video-clip (Figure 3-1d): in these tasks trials happened very quickly, and since the video-clips would have to change at a high rate it would be hard to deceive participants. The photo of the confederates was a screenshot of one of the recorded video-clips. This screenshot was selected so that it was as similar as possible to the general appearance of the video-clips. The same pictures were used across the two settings (ON and OFF).

In both video-clips and photos, our stimuli were carefully designed to match the ambiguous gaze pattern characteristic of Skype calls, where gaze is usually slightly averted and it is not clear where the other person is exactly looking at. This ambiguity happens because in a video-call eye contact (direct gaze) and being watched are not the same. In the context of our study, gazing to the webcam means that participants will see the confederate directly gazing at them, but they will also know that the confederate is not watching them and their choices (since these appear lower on the screen). Instead, gazing to the presumed image of the participant means that participants will see the confederate with slightly averted gaze, but they will also know the confederate is watching them and their choices (Figure 3-1e). Thus, while gazing at the webcam ensures that participants see a pair of eyes gazing at them, there is no belief in being watched: participants can only hold this belief when they see the confederate gazing to their presumed image on the screen. Given the scope of our study, here we prioritised that participants truly believe they are being watched, over participants just seeing a pair of eyes that are not actually watching them.

3.3.5. Counterbalancing conditions

There were 8 different counterbalancing conditions, in which we counterbalanced the story (1 or 2) linked to each session (baseline or test) and setting (ON or OFF), and the confederate (1 or 2) linked to each setting and story (see section *3.11.8. Counterbalancing conditions* for Table 3-3 with all counterbalancing conditions). Since it was a between-subjects design, we always used the same name for the confederate (Alice). Each participant was allocated to one condition, and they completed all tasks in each session.

3.4. General results: Questionnaires

3.4.1. Manipulation check: post-test questionnaire ratings

In the post-test questionnaire, participants rated the ON and OFF confederate on three traits: likeability, naturalness and reciprocity (see Table 3-1 for descriptives). To check that the belief manipulation was successful, two-tailed *t*-tests between ON and OFF setting were computed for each of the traits rated in the post-test questionnaire: likeability, naturalness and reciprocity of the confederates. Results showed that under the ON setting the confederate was perceived as significantly more likeable, $t(46) = 3.13$, $p = .003$, $d_z = .451$, natural, $t(46) = 4.32$, $p < .001$, $d_z = .623$, and reciprocal $t(46) = 4.23$, $p < .001$, $d_z = .610$ (Figure 3-2a).

Table 3-1. Descriptives for post-test ratings and questionnaires

	Measure	ON	OFF
Ratings	likeable	*M* = 6.17 *SD* = 1.39	*M* = 4.88 *SD* = 1.42
	natural	*M* = 5.88 *SD* = 1.95	*M* = 3.46 *SD* = 1.72
	reciprocal	*M* = 4.92 *SD* = 2.13	*M* = 2.58 *SD* = 1.57
Questionnaires	self-consciousness	*M = 58.79* *SD* = 9.95	*M* = 56.88 *SD* = 12.23
	use of gaze	*M* = 2.27 *SD* = .499	*M* = 2.26 *SD* = .38
	social anxiety	*M* = 54.83 *SD = 27.86*	*M* = 51.25 *SD* = 22.05
	autism quotient	*M* = 22.75 *SD* = 6.33	*M* = 20.79 *SD* = 6.49
	alexithymia	*M* = 52.08 *SD* = 14.50	*M* = 49.71 *SD* = 8.48

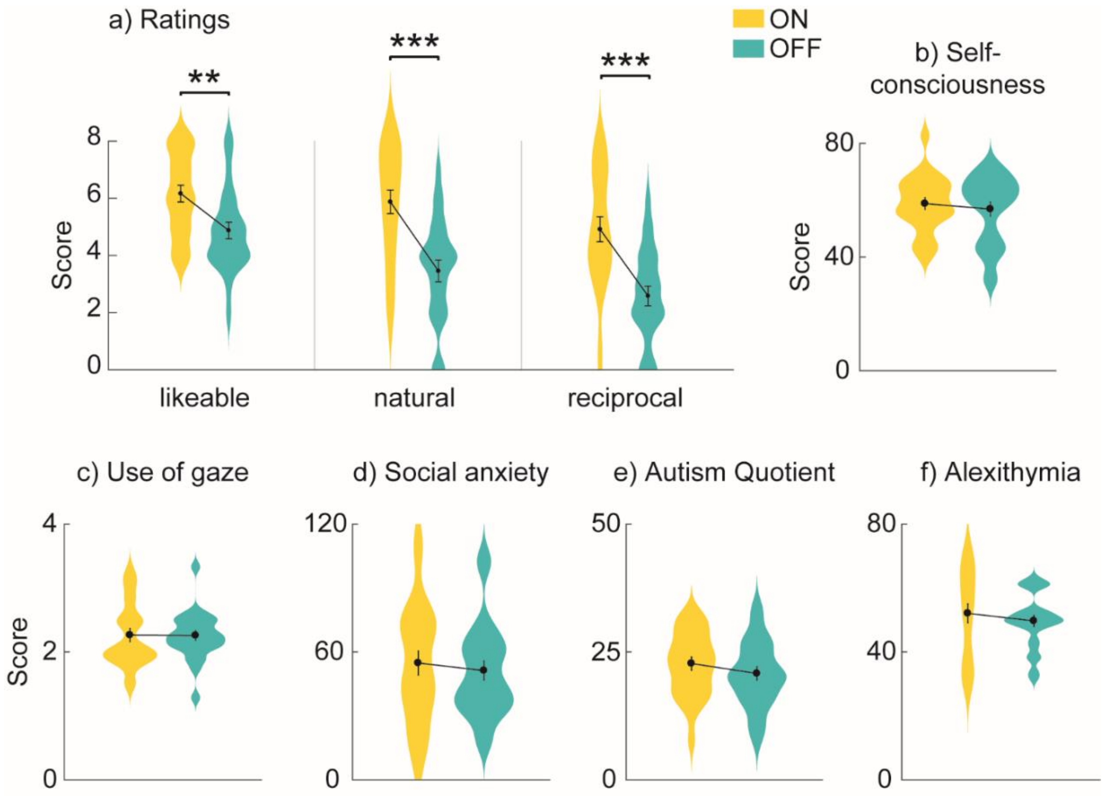

Figure 3-2. Results for ratings and questionnaire scores.
a) Ratings on traits. b) Self-consciousness. c) Use of gaze. d) Social anxiety. e) Autism Quotient. f) Alexithymia. Mean (filled circle), SE (error bars), and frequency of values (width of distribution). Asterisks signify difference between ON and OFF setting at p < .1 (+), p < .05 (*), p < .01 (**) and p < .001 (***).

3.4.2. Matching groups check: questionnaire ratings

In the end of the baseline session, participants completed a computerised version of the following questionnaires: Self-Consciousness Scale, Gaze questionnaire, Liebowitz Social Anxiety Scale, Autism Quotient, and Toronto Alexithymia Scale (see Table 3-1 for descriptives). To check that the two groups were well-matched, two-tailed *t*-tests between ON and OFF setting were computed for each of the scores obtained in the questionnaires. Results showed that there were no differences between ON and OFF groups for any questionnaires ($p > .05$ for all) (Figure 3-2b-f).

3.5. Self-referential processing: SRE memory task

3.5.1. Methods

To measure self-referential processing, we used the Self-Referential Effect paradigm (SRE), which has been previously used to assess self-referential processing on memory (Craik & Tulving, 1975; Lombardo et al., 2007). The SRE memory task comprises two different phases. During the first phase (SRE Encoding phase task; Figure 3-3a) participants judge whether different trait adjectives describe the self or another person. In our task, the other person was Harry Potter. To control for the level of familiarity with Harry Potter, eligible participants should have read at least one Harry Potter book, or seen at least one Harry Potter film. Participants were shown 30 adjectives for each target condition ("self" or "Harry Potter"), so there were a total of 60 trials. All adjectives were drawn from a previously validated and widely used set of adjectives (Anderson, 1968). Half of the adjectives in each condition were positively valenced (e.g. cordial), and the other half were negatively valenced (e.g. lazy). Moreover, there were no differences in number of characters and syllables, valence or likableness of adjectives between conditions. After the Encoding phase there was a 30 minute delay, during which participants completed the Confidence Bias task, the Story task and the Optimism Bias questionnaire. During the second phase (SRE Memory phase task; Figure 3-3b), participants judged whether a number of trait adjectives were previously presented during the SRE Encoding phase task. Participants were presented with all 60 adjectives from the SRE Encoding phase task ("old") and 60 new distractor adjectives ("new"), so they completed a total of

120 trials (see section *3.11.9. Adjectives* for the full list of adjectives). Two different sets of 120 adjectives were used for baseline and test sessions.

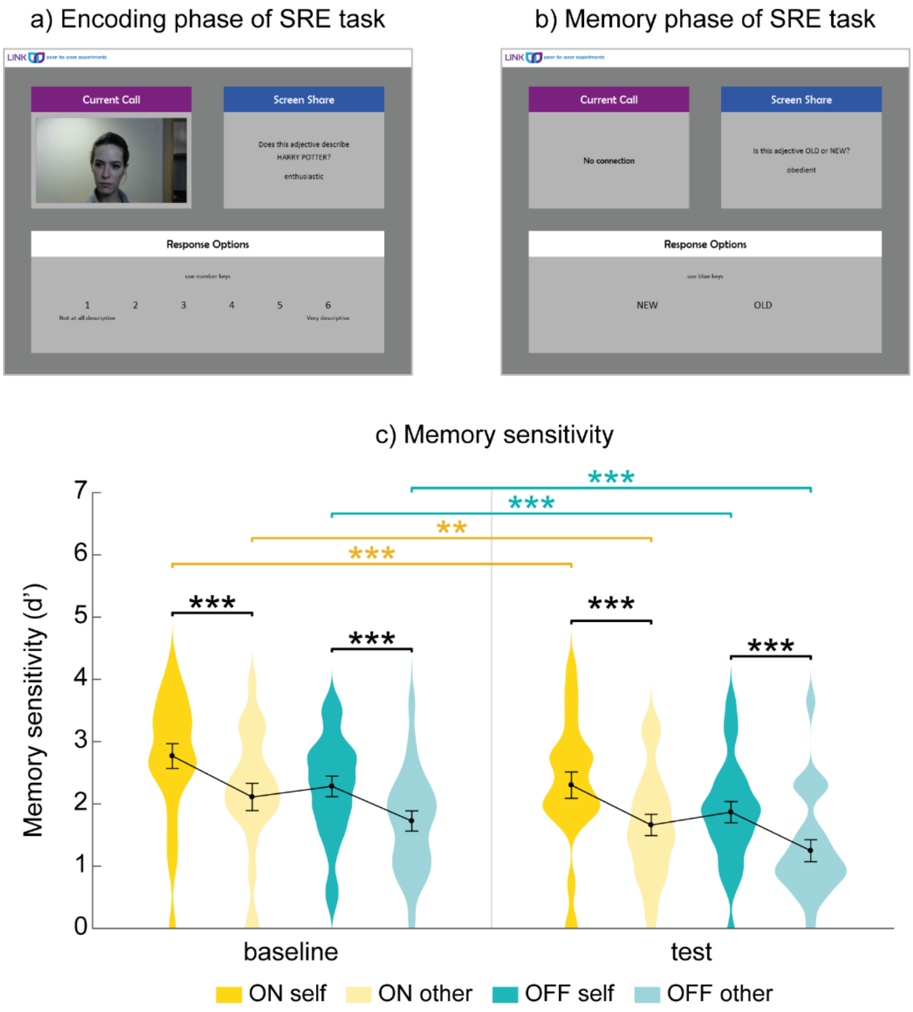

Figure 3-3. Design and results for self-referential processing task.
a) Encoding phase of SRE task during ON condition. Screen Share shows question "Does this adjective describe HARRY POTTER? - enthusiastic". b) Memory phase of SRE task during ON condition. Screen Share shows question "Is this adjective OLD or NEW? - obedient". c) Mean (filled circle), SE (error bars), and frequency of values (width of distribution) for memory sensitivity. Asterisks signify difference between ON and OFF setting at p < .1 (+), p < .05 (*), p < .01 (**) and p < .001 (***).

In the baseline session, for each trial of the SRE Encoding phase task the Question box showed the question "Does this adjective describe SELF/HARRY POTTER?" and the Response Options box showed a 6 point scale where 1 indicates "not at all descriptive" and 6 indicates "very descriptive". Participants chose their answer by pressing the corresponding number key on the keyboard, and the answer was shown in the Response Options box for 2 seconds. Between trials, a fixation cross was displayed on the Question box for 2 seconds. After the 30 minutes delay, participants were surprised with the SRE Memory phase task. For each trial, the Question box showed the question “Is this adjective OLD or NEW?” and the adjective below, and the two possible answers (“OLD” and “NEW”) were displayed on the Response Options box (side counterbalanced across trials). To choose an option participants pressed a blue key (“D” or “K”) that matched the position of the desired option, and the answer was shown in the Response Options box for 2 seconds. Between trials, a fixation cross was displayed on the Question box for 2 seconds.

In the test session, the belief manipulation only happened during the SRE Encoding phase task, since there is evidence showing that only the encoding phase of self-relevant information is influenced by the level of self-consciousness (Hull, Van Treuren, Ashford, Propsom, & Andrus, 1988). For each trial, a video of the confederate was played on the Current Call/Videos box. Moreover, between trials a blurred frame of the video-clip was shown on the Current Call/Videos box (in the ON setting, the frame was shown together with the message “Connection paused”). After the 30 minutes delay, participants completed the SRE Memory phase task, during which no videos were played. Although participants might have guessed that there would be a memory task based on the baseline session structure, we expected this knowledge to be equivalent across ON and OFF settings, since all participants went through the baseline session.

There are two measures of interest. First, memory sensitivity (d') for "self" and "other" was computed as the standardized score of correctly remembered adjectives minus the standardized score of false alarms. Second, the self bias was computed as the difference between d' self and d' other. For each participant, the mean across trials was computed to obtain the mean d' self, mean d' other, and mean self bias.

3.5.2. Data analysis and Results

For memory sensitivity (d'), a three-way repeated measures ANOVA with factors Session (baseline or test; within-subject), Target (self or other; within-subject) and Belief (ON or OFF; between-subject) was performed (see Table 3-2 for descriptives). We found a main effect of Target, $F(1,46) = 105.2$, $p < .001$, $n_p^2 = .696$: participants had higher memory sensitivity for self-related adjectives than other-related adjectives for all sessions and beliefs (Figure 3-3c, Table 3-2). There was also a main effect of Session, $F(1,46) = 42.2$, $p < .001$, $n_p^2 = .478$: participants had better memory sensitivity in the baseline compared to the test session, regardless of type of target and belief (Figure 3-3c). Unexpectedly, there was no main effect of Belief, $F(1,46) = 3.14$, $p > .05$, $n_p^2 = .064$, no interaction between Session and Belief, $F(1,46) = .009$, $p > .05$, $n_p^2 = .001$, no interaction between Session and Target, $F(1,46) = .066$, $p > .05$, $n_p^2 = .001$, and no interaction between Target, Session and Belief, $F(1,46) = .208$, $p > .05$, $n_p^2 = .004$.

For self bias (difference between d' self and d' other), a two-way repeated measures ANOVA with factors Session (baseline or test; within-subject) and Belief (ON or OFF; between-subject) was performed (see Table 3-2 for descriptives). Consistent with the previous results, there was no main effect of Session, $F(1,46) = .070$, $p > .05$, $n_p^2 = .002$, no main effect of Belief, $F(1,46) = .256$, $p > .05$, $n_p^2 = .006$, and no interaction between Session and Belief, $F(1,46) = .211$, $p > .05$, $n_p^2 = .005$.

Table 3-2. Descriptives for task measures

Measure	Session	ON	OFF
Memory sensitivity	Baseline Self	*M* = 2.77 *SD* = .985	*M* = 2.28 *SD* = .822
	Baseline Other	*M* = 2.11 *SD* = 1.10	*M* = 1.72 *SD* = .814
	Test Self	*M* = 2.30 *SD* = 1.06	*M* = 1.87 *SD* = .856
	Test Other	*M* = 1.66 *SD* = .854	*M* = 1.26 *SD = .886*
Self bias	Baseline	*M* = .658 *SD* = .448	*M* = .557 *SD* = .536
	Test	*M* = .640 *SD* = .634	*M* = .619 *SD* = .401
Prosocial ratings	Baseline	*M* = .488 *SD* = .162	*M* = .451 *SD* = .116
	Test	*M* = .515 *SD* = .166	*M* = .561 *SD = .177*
Confidence bias	Baseline	*M* = .331 *SD* = .200	*M* = .249 *SD* = .191
	Test	*M* = .281 *SD* = .172	*M* = .232 *SD* = .219
Optimism bias	Baseline	*M* = 3.19 *SD* = 10.9	*M* = 5.72 *SD* = 7.53
	Test	*M* = 2.78 *SD* = 9.18	*M* = 5.48 *SD* = 7.69

3.6. Prosocial behaviour: Story task

3.6.1. Methods

To measure prosocial behaviour, we used the set of 2 stories used in Chapter 2. The stories describe real day-to-day situations emulating a moral dilemma. In each story, there are 6 different dilemmas where the participant has to choose what to do next. These moral dilemmas are part of a larger pool of dilemmas that we created and piloted through an online form on 23 adults: the dilemmas included in the Story task are those (or slight modifications of those) for which at least 60% of the answers were non-prosocial in a non-social condition (i.e. there is room for more prosocial answers under the belief in being watched). For each dilemma one option is prosocial but has a temporal or monetary cost (e.g. volunteer for an afternoon, give money to a homeless person; see section *3.11.10. Stories* for full stories), whereas the other option is non-prosocial and has no cost (Figure 3-4a). Both stories are matched for the number of dilemmas with monetary or temporal costs, and both have a neutral trial where the two possible responses are non-prosocial, although this trial was excluded from the analyses.

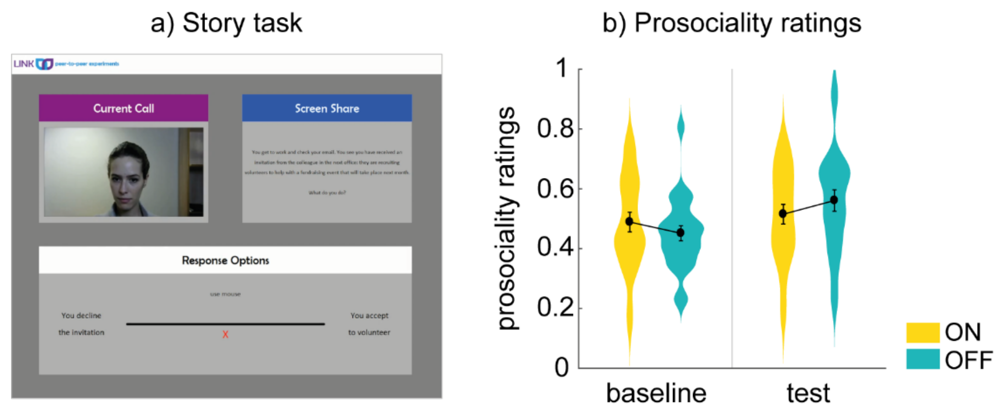

Figure 3-4. Design and results for Story task.
a) Screenshot of Story task during ON condition. Screen Share shows the dilemma, and the Reponse Options box shows the two possible answers. b) Mean (filled circle), SE (error bars), and frequency of values (width of distribution) for prosociality ratings.

In the baseline session, each dilemma was shown on the Question box (e.g. “At noon you go out to a nearby restaurant to have lunch. When you pay the waitress gives you the change, but there's more than should be”), together with the question “What do you do?”. Two possible answers were displayed on each end of a continuous scale in the Response Options box (e.g. “You tell her the change is wrong” or “You don't say anything”), and participants clicked with the mouse to indicate how likely they were to do one or the other option (halfway the line was a neutral answer). The answer was shown in the Response Options box for 2 seconds. Between trials, a fixation cross was displayed on the Question box for 2 seconds. In the test session, the confederate read the statement describing the dilemma and asked to the participant “What do you do?”. Participants could also read the statement on the Screen Share/Side Screen. Once participants entered their answer, it was displayed on the Screen Share/Side Screen for 2 seconds and the confederate in the video stayed in silence as if she was looking at the answer. Between trials a blurred frame of the video-clip was shown on the Current Call/Videos box (in the ON setting, the frame was shown together with the message “Connection paused”).

Prosocial behaviour was measured on a scale from 0 (non-prosocial) to 1 (prosocial) based on ratings of participants. If participants clicked beyond the ends of the scale when choosing an answer, this trial was excluded. We set an excluding criterion whereby participants with more than 20% of invalid trials would be excluded, but no participants reached this threshold. The mean across trials was computed to obtain the mean prosociality rating for each participant.

3.6.2. Data analysis and Results

A two-way repeated measures ANOVA with factors Session (baseline or test; within-subject) and Belief (ON or OFF; between-subject) was performed (see Table 3-2 for descriptives). Results showed there was no main effect of Session, $F(1,46) = 3.380$, $p > .05$, $n_p^2 = .068$, no main effect of Belief,

$F(1,46) = .026$, $p > .05$, $n_p^2 = .001$, and no interaction between Session and Belief, $F(1,46) = 1.27$, $p > .05$, $n_p^2 = .027$ (Figure 3-4b).

3.7. Self-awareness: Confidence and Optimism Bias tasks

3.7.1. Methods: Confidence Bias task

To measure metacognitive self-awareness, we implemented a paradigm widely used to test confidence bias (Harvey, 1997). In this paradigm, participants complete a simple perceptual task and, after each trial, they are asked to rate their accuracy on that trial (see Kunimoto, Miller, & Pashler, 2001 for an example). Their accuracy rating (confidence) is then compared to their actual accuracy to measure the confidence bias when assessing themselves. In our perceptual task, a random number of dots (ranging from 10 to 100) appeared on the screen for 0.8 seconds. Participants completed 30 trials: in each trial they were shown the dots array, they were asked “How many dots did you see?” and entered their answer, and they were asked “How accurate you think you were?” and entered their answer (Figure 3-5a).

In the baseline session, the Question box showed the dots array and the two questions. For each question, the Response Options box showed a scale from 0 to 100, and participants clicked with the mouse to indicate the number of dots they had seen or their accuracy rating. For both questions, the answer was shown in the Response Options box for 2 seconds. Between trials, a fixation cross was displayed on the Question box for 2 seconds. In the test session, a photo of the confederate was shown on the Current Call/Videos box (in the ON setting, the photo was shown together with the message “Screen Share active”). Between trials, a photo of the confederate was continuously shown on the Current Call/Videos box.

The confidence bias was measured as the correlation coefficient (r) across trials between the confidence of participants (their accuracy rating) and their actual accuracy. The correlation coefficient between confidence and actual accuracy should be significantly non-zero if both measures were related. If a participant clicked beyond the ends of the scale when indicating the number of dots on the screen or their accuracy rating, this trial was excluded from the analyses. We set an excluding criterion whereby participants with more than 20% of invalid trials would be excluded, but no participants reached this threshold.

3.7.2. Methods: Optimism Bias questionnaire

We used the Optimism Bias questionnaire (Sharot, 2011) to measure one's flawed self-assessment. In this questionnaire, participants estimate the likelihood of experiencing different types of adverse life events for two targets: oneself and another person (e.g. "how likely are you/another person to have a car accident?", "how likely are you/another person to have gum problems?"). It has been shown that people have better expectations for themselves than for other people, that is, they have an optimism bias toward the self (Sharot, 2011). Here, we adopted 60 items from the original questionnaire (see section *3.11.11. Items for predictions* for the full list of items). Each item was asked in relation to oneself ("YOU") and "ANOTHER PERSON", so the task had a total of 120 trials. For each participant the item order was randomised, but the same item was asked consecutively for "YOU" and "ANOTHER PERSON" (Figure 3-5b).

In the baseline session, the Question box showed the word "YOU" or "ANOTHER PERSON", plus one of the adverse events below (e.g. "car accident”). The Response Options box showed a scale from 0 to 100, and participants clicked with the mouse to indicate the probability of experiencing that event. Answers were shown at the Response Options box for 2 seconds. Between trials, a fixation cross was displayed on the Question box for 2 seconds. In the test session, a photo of the confederate was shown on the Current Call/Videos box (in the ON setting, the photo was shown together with the message “Screen Share active”). Between trials, a photo of the confederate was continuously shown on the Current Call/Videos box.

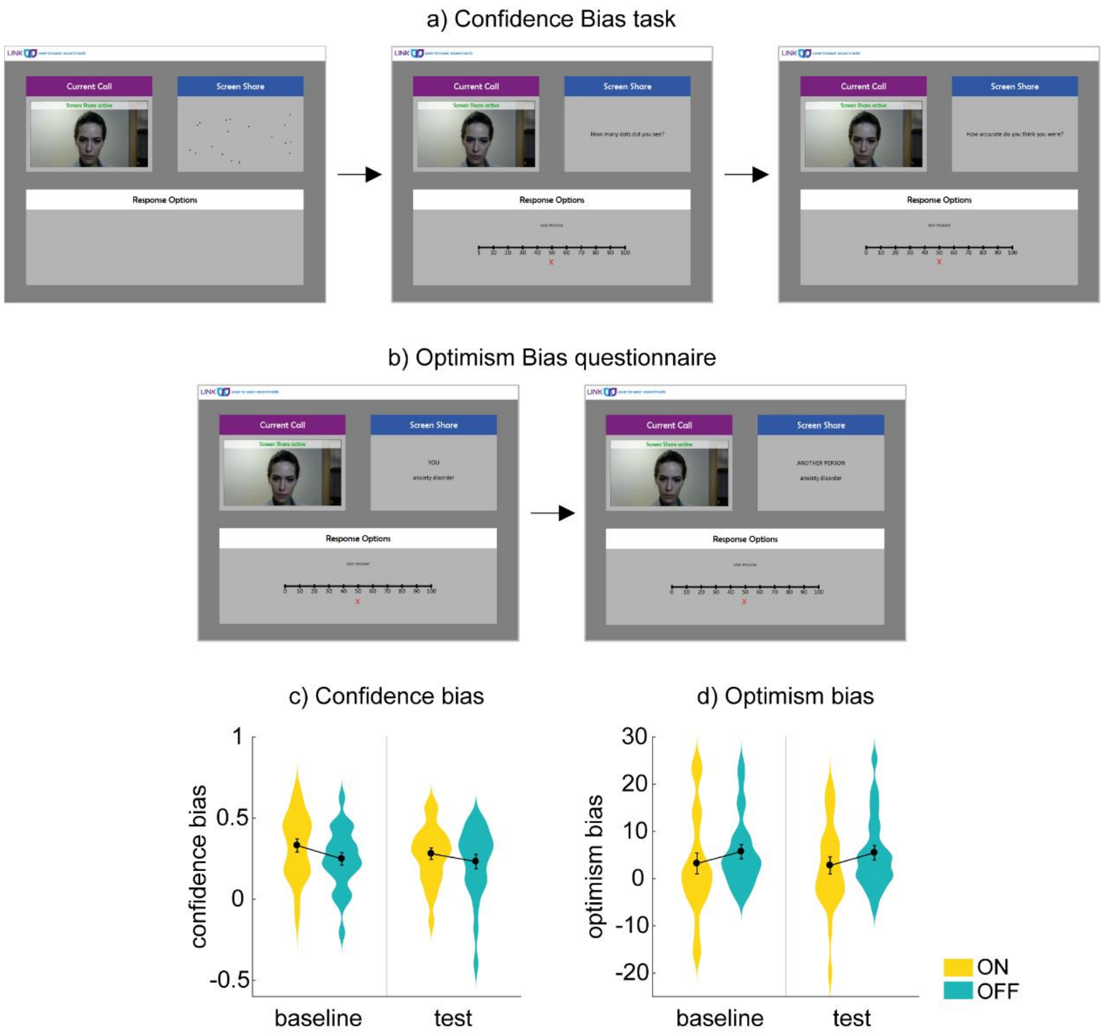

Figure 3-5. Design and results for Confidence Bias and Optimism Bias tasks.
a) Screenshot of Confidence Bias task during ON condition. Screen Share first shows the dots, followed by the questions “How many dots did you see?” and “How accurate you think you were?”. b) Screenshot of Optimism Bias questionnaire during ON condition. Screen Share first shows “YOU - anxiety disorder”, followed by “ANOTHER

PERSON - anxiety disorder". c-d) Mean (filled circle), SE (error bars), and frequency of values (width of distribution) for confidence (c) and optimism (d) bias.

The optimism bias for each item was measured as the probability of the event happening to another person minus the probability of the event happening to oneself. Both probabilities were indicated by the participant on a scale from 0 to 100. If a participant clicked beyond the ends of the scale when giving the answer, this trial and its target pair were excluded from the analyses. We set an excluding criterion whereby participants with more than 20% of invalid items would be excluded, but no participants reached this threshold. For each participant, the mean across trials was computed to obtain the mean optimism bias.

3.7.3. Data analysis and Results

We did the same analysis for the Confidence Bias and Optimism Bias data. A two-way repeated measures ANOVA with factors Session (baseline or test; within-subject) and Belief (ON or OFF; between-subject) was performed for each measure (see Table 3-2 for descriptives). Results for Confidence Bias showed there was no main effect of Session, $F(1,46) = .951$, $p > .05$, $n_p^2 = .020$, no main effect of Belief, $F(1,46) = 2.17$, $p > .05$, $n_p^2 = .045$, and no interaction between Session and Belief, $F(1,46) = .241$, $p > .05$, $n_p^2 = .005$ (Figure 3-5c). Similarly, for Optimism Bias there was no main effect of Session, $F(1,46) = .398$, $p > .05$, $n_p^2 = .009$, no main effect of Belief, $F(1,46) = 1.09$, $p > .05$, $n_p^2 = .023$, and no interaction between Session and Belief, $F(1,46) = .030$, $p > .05$, $n_p^2 = .001$ (Figure 3-5d).

3.8. Exploratory correlations

Based on the Watching Eyes model (Conty et al., 2016), we proposed that audience effects may be mediated by an increase in self-referential processing when being seen. In order to test the relationship between these processes, we computed exploratory Pearson correlations between the measures obtained in the different tasks (self-referential processing, prosocial behaviour, confidence bias and optimism bias), and between questionnaire scores and task measures. None of the exploratory correlations was significant ($p > .05$ for all).

3.9. Discussion

The cognitive mechanisms by which being watched triggers changes in behaviour to signal good reputation (audience effects) are poorly understood. Here we proposed that these changes happen because the belief in being watched increases self-referential processing. This chapter aimed to test this model by using a novel deceptive video-conference paradigm (presented in Chapter 2), where participants either believed there was a real video-feed with a confederate or knew they were watching pre-recorded video-clips of another confederate. Results showed that, although there was a self-referential memory effect, it did not increase when participants believed they were being watched. We also failed to replicate previous findings showing that the belief in being watched increases prosocial behaviour, and similarly there was no effect of this manipulation on measures of self-awareness. Nonetheless, we have strong evidence that the deceptive video-conference manipulation was effective: participants in the ON setting rated the confederate as more likeable, natural and reciprocal than participants in the OFF setting. Based on previous evidence and these findings, we identify key research areas that will help elucidating the mechanisms underlying audience effects.

3.9.1. Being watched and self-referential processing

To assess how self-referential processing is affected by the belief in being watched, participants completed a Self-Referential Effect memory task, which measures their memory sensitivity to recall adjectives related to the self and to another person (Lombardo et al., 2007). Results showed that items related to the self were better recognised than items related to another person, across baseline and test session, for both ON and OFF group. This result proves that the task worked well when embedded in the deceptive video-conference setting. Contrary to our hypothesis, we did not find evidence that the belief in being watched increased self-referential processing. However, there was strong evidence that self- and other-related adjectives were better remembered in the baseline session than in the test session, both for ON and OFF group. This suggests that instead of a self-referential effect of someone watching us, the presence of a face (regardless of whether it could or could not see us) acted as a distractor: participants paid less attention to the adjectives and this impacted both its encoding and later recognition. Indeed, eye-tracking studies have shown that overt visual attention prioritises social information (e.g. faces) over non-social information, and that this happens reflexively (Rösler, End, & Gamer, 2017). Equally, it could be that seeing a face increased our cognitive load during the task (Beattie, 1981; Kendon, 1967; Markson & Paterson, 2009).

Our results do not corroborate those by Hietanen & Hietanen (2017), where they show that live direct gaze increases self-referential processing. A key difference between both studies is that in Hietanen & Hietanen (2017) participants were face-to-face with the confederate and experienced true direct gaze, whereas in our study participants interacted with the confederate through a screen that resembled a video-conference software. Although we designed our stimuli to match the ambiguous gaze pattern characteristic of video-conferences (i.e. gaze is slightly averted when the other person is watching me), this means that there was no true direct gaze. Thus, this could indicate that the belief in being watched *per se* is not enough to trigger self-referential processing, but rather needs to be embedded in true direct gaze. Another possible explanation is that the tasks used in both studies engage different cognitive processes. While completion of the self-referential memory task requires deep encoding of items for later recognition (Craik & Tulving, 1975), the pronoun-selection task used by Hietanen & Hietanen (2017) is more intuitive and has previously been shown to be sensitive to manipulations of self-awareness (Davis & Brock, 1975).

Moreover, both tasks are limited to the extent they allow us to reliably measure self-reference. On the one hand the self-referential memory task explicitly asks individuals to think about self-relevance of adjectives during the Encoding phase: this could have a carryover effect on the Memory phase regardless of settings, and consequently override any subtle effects of being watched on self-referential processing. On the other hand, the use of "I" during the pronoun-selection task may not be an indicator of self-referential processing but rather preparation to engage in conversation with another (face-to-face) person. Future studies could systematically compare how manipulations of being watched modulate different forms of self-referential processing, as well as which measures are accurate indicators of self-reference.

3.9.2. Being watched and prosocial behaviour

To assess how prosocial behaviour changes when being watched we used the Story task, which was found to be sensitive to the deceptive video-conference manipulation in Chapter 2. Unfortunately, these results are not replicated: prosociality of the answers does not change from baseline session to ON test session, and there is no difference between ON and OFF test sessions. Similarly, we could not replicate the correlation between social anxiety traits and change in prosocial behaviour from baseline to ON setting.

This lack of effect could be accounted for by differences in the cover story used in both studies. While in Chapter 2 participants believed the confederate was a student volunteering in a charity (i.e. she was a positive example of prosocial behaviour), here they believed she was a PhD student working in the university, who had no explicit links to charity or volunteering work. It could be that the social context and identity of the confederate is relevant for audience effects: participants might perceive someone linked to charitable work as more entitled to judge their actions than a random student, and the motivation to show that "I'm prosocial" will be stronger for the former. For instance, low-status participants tend to be more prosocial than high-status participants (Guinote, Cotzia, Sandhu, & Siwa, 2015; Piff, Kraus, Côté, Cheng, & Keltner, 2010), and it has been suggested that they do so to increase their social status (Kafashan, Sparks, Griskevicius, & Barclay, 2014) and, in turn, their reputation in the group. This suggests that the identity or social context of the observer in relation to the participant (e.g. social status) may be a strong modulator of audience effects on prosocial behaviour.

3.9.3. Being watched and self-awareness

Participants completed two tasks that measured self-awareness implicitly: the Confidence Bias task to measure confidence bias (metacognitive self-awareness; Fleming & Dolan, 2012; Harvey, 1997), and the Optimism bias questionnaire to measure the optimism bias (self-assessment; Sharot, 2011). Results showed there was no effect of the belief in being watched in either self-awareness task. These results are similar to those obtained in the Self-Referential Effect memory task, but here performance from baseline session to test session did not decrease. This suggests that even when the task did not require deep encoding of information, and performance of participants was not negatively impacted by the social presence, self-awareness did not increase when being watched. A main limitation in these two tasks is that there was no video-feed of the confederate. Instead, participants were shown a still frame of the video-clip plus the message “Screen Share active”, indicating that the confederate could still see their answers. However, participants might have felt that it was ambiguous whether the confederate could only see their answers or could also see them, and this might have weakened the effect of the belief in being watched.

Another caveat is that different forms of self-awareness might have different sensitivity to the belief in being watched. It has been shown that direct gaze and the belief in being watched increase self-awareness of physiological signals in response to emotional pictures (Baltazar et al., 2014; Hazem et al., 2017). Instead, the tasks we use tap into metacognitive self-awareness and self-assessment, which require participants to reflect on their own judgements and self-knowledge. It could be that, compared to effects on bodily self-awareness, effects on metacognitive self-awareness need stronger (or less ambiguous) belief manipulations. Thus, an interesting question is whether and how different forms of self-awareness are distinctly modulated by the belief in being watched embedded in eye gaze.

3.9.4. Implications and further research

These findings have important implications for future research on the cognitive mechanisms underlying audience effects. We show that our deceptive video-conference paradigm, which combines high ecological validity and experimental control, is successful in manipulating beliefs of participants. This is supported by strong evidence showing that participants in the ON setting rated the confederate as more likeable, natural and reciprocal than participants in the OFF setting. However, our results indicate that the relationship between the belief in being watched, self-referential processing and subsequent behavioural effects (on prosocial behaviour and self-awareness) might not be as straightforward as we proposed. For instance, comparison with previous findings (J. O. Hietanen & Hietanen, 2017) suggests that self-referential processing might be differently modulated by subtle manipulations of true direct gaze. It also suggests that the belief in being watched might have different effects on distinct forms of self-referential processing (e.g. deep encoding of self-related items as used in the present study (Craik & Tulving, 1975) versus intuitive pronoun-selection task used by Hietanen & Hietanen (2017)). Similarly, different forms of self-awareness may have different sensitivity to the belief in being watched: it could be that bodily self-awareness (Baltazar et al., 2014; Hazem et al., 2017) is more sensitive to audience manipulations than metacognitive self-awareness. Future studies that contrast audience effects on different forms of self-referential processing and self-awareness are critical to elucidate the role of the self in audience effects.

Moreover, the social context and the identity of the confederate may also be relevant for audience effects. Using the same Story task and deceptive video-conference paradigm in Chapter 2 and in this chapter, we find that participants act more prosocially in the ON setting (compared to the OFF setting) if they believe the confederate is volunteering in a charity (Chapter 2) but not if she is presented as another student in the university (present study). In line with this, previous studies have shown that low-status individuals tend to be more prosocial, likely because this will help them increase their reputation in the group (Guinote et al., 2015; Kafashan et al., 2014; Piff et al., 2010). This suggests that participants not only process whether they are being seen or not, but also the identity of the observer in relation to them, and whether s/he poses a challenge to their reputation. Future studies could take a closer look at this question by systematically modulating the belief in being watched and the identity or social context associated with the observer.

Finally, it has been suggested that individual differences in public self-awareness and social anxiety modulate changes in prosocial behaviour when being watched (Chapter 2; Pfattheicher & Keller, 2015). Likewise, personality traits such as high prevention-focused self-regulation (i.e. tendency to ensure safety and security instead of striving for ideal gains and goals) increase prosocial cooperation when being watched (Keller & Pfattheicher, 2011). Although exploratory correlations between questionnaires scores (e.g. social anxiety traits, self-awareness) and task measures did not yield any significant relationship in the present study, future studies could directly test the role of personality traits in audience effects.

3.10. Conclusion

This study aimed to test whether audience effects (e.g. increase in prosocial behaviour when being watched) are related to an increase in self-referential processing when being watched. To do so, we used a novel deceptive video-conference paradigm, where participants believe that video-clips of a confederate are live or pre-recorded video-feeds. Results showed that both the deceptive belief manipulation and the self-referential processing task were effective, but there was no influence of the belief in being watched on the latter. Equally, there was no effect of this manipulation on other measures of self-awareness and prosocial behaviour. Our findings indicate that the relationship between the belief in being watched, self-referential processing and subsequent behavioural effects (on prosocial behaviour and self-awareness) is not as straightforward as we hypothesised. We propose that further research on the role of the self, social context and personality traits will help elucidating the mechanisms underlying audience effects.

3.11. Supplementary materials

3.11.1. Self-consciousness scale

Private self-consciousness

I'm always trying to figure myself out. (1)

Generally, I'm not very aware of myself. (3)[b]

I reflect about myself a lot. (5)

I'm often the subject of my own fantasies. (7)

I never scrutinize myself. (9)[b]

I’m generally attentive to my inner feelings. (13)

I'm constantly examining my motives. (15)

I sometimes have the feeling that I'm off somewhere watching myself. (18)

I'm alert to changes in my mood. (20)

I’m aware of the way my mind works when I work through a problem. (22)

Public self-consciousness

I'm concerned about my style of doing things. (2)

I'm concerned about the way I present myself. (6)

I'm self-conscious about the way I look. (11)

I usually worry about making a good impression. (14)

One of the last things I do before I leave my house is look in the mirror. (17)

I’m concerned about what other people think of me. (19)

I’m usually aware of my appearance. (21)

Social Anxiety

It takes me time to overcome my shyness in new situations. (4)

I have trouble working when someone is watching me. (8)

I get embarrassed very easily. (10)

I don't find it hard to talk to strangers. (12)[b]

I feel anxious when I speak in front of a group. (16)

Large groups make me nervous. (23)

(#) = sequence of items in questionnaire

b = item reversed for scoring

3.11.2. Gaze questionnaire

Indicate how you feel about the following statements: strongly disagree | *slightly disagree* | *neither agree nor disagree* | *slightly agree* | *strongly agree*

1. It is easy for me to decide how much eye contact is appropriate.

2. If I want to know how someone feels, then I look at their eyes

3. I notice when people are looking at me.

4. I am not sure how long I should look at someone’s eyes when talking to them.

5. I like to be the centre of attention.

6. I understand someone’s emotions more if they look at me.

7. When I am speaking to someone, I deliberately move my eyes in a particular pattern or look at a particular place.

8. I feel anxious if someone looks directly at my eyes.

9. I need to think about whether or not to make eye-contact.

10. I like to stare at someone until that person looks away.

11. If I want to know what someone’s intentions are, then I look at their eyes.

12. I feel uncertain or confused if someone looks directly at my eyes.

13. As a child or young person, I was told to look at people’s eyes more often during conversations.

14. I prefer to sit next to someone rather than opposite them to avoid eye contact.

15. Sometimes I feel like everyone is staring at me.

16. I do not deliberately control where I am looking during a conversation.

17. I understand someone’s thoughts more if they look at me

18. If I want to know what someone is thinking, then I look at their eyes

19. I find eye-contact intense and overwhelming, like looking straight at a very bright light.

20. As a child I was never taught about eye-contact.

3.11.3. Liebowitz Social Anxiety Scale

Fear/Anxiety: 0 = None / 1 = Mild / 2 = Moderate / 3 = Severe

Avoidance: 0 = Never / 1 = Occasionally / 2 = Often / 3 = Usually

	Fear/ Anxiety	Avoidance
1. Telephoning in public.		
2. Participating in small groups.		
3. Eating in public places.		
4. Drinking with others in public places.		
5. Talking to people in authority.		
6. Acting, performing or giving a talk in front of an audience.		
7. Going to a party.		
8. Working while being observed.		
9. Writing while being observed.		
10. Calling someone you don't know very well.		
11. Talking with people you don't know very well.		
12. Meeting strangers.		
13. Urinating in a public bathroom.		
14. Entering a room when others are already seated.		
15. Being the center of attention.		
16. Speaking up at a meeting.		
17. Taking a test.		
18. Expressing disagreement/disapproval to people you don't know very well.		
19. Looking at people you don't know very well in the eyes.		
20. Giving a report to a group.		
21. Trying to pick up someone.		
22. Returning goods to a store.		
23. Giving a party.		
24. Resisting a high pressure salesperson.		

3.11.4. Autism Quotient

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree

2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree

20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree

39. People often tell me that I keep going on and on about the same thing.	definitely agree / slightly agree / slightly disagree / definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree / slightly agree / slightly disagree / definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree / slightly agree / slightly disagree / definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree / slightly agree / slightly disagree / definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree / slightly agree / slightly disagree / definitely disagree
44. I enjoy social occasions.	definitely agree / slightly agree / slightly disagree / definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree / slightly agree / slightly disagree / definitely disagree
46. New situations make me anxious.	definitely agree / slightly agree / slightly disagree / definitely disagree
47. I enjoy meeting new people.	definitely agree / slightly agree / slightly disagree / definitely disagree
48. I am a good diplomat.	definitely agree / slightly agree / slightly disagree / definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree / slightly agree / slightly disagree / definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree / slightly agree / slightly disagree / definitely disagree

3.11.5. Toronto Alexithymia Scale

Indicate how much you agree or disagree with each of the following statements. Just tick the appropriate box. Use the middle box ('I neither agree or disagree') **only if you are really unable to assess your behaviour.**	I strongly disagree	I quite disagree	I neither agree nor disagree	I quite agree	I strongly agree
1- I am often confused about what emotion I am feeling					
2- It is difficult for me to find the right words for my feelings					

3- I have physical sensations that even doctors don't understand					
4- I am able to describe my feelings easily					
5- I prefer to analyze problems rather than just describe them					
6- When I am upset, I don't know if I am sad, frightened, or angry					
7- I am often puzzled by sensations in my body					
8- I prefer to just let things happen rather than to understand why they turned out that way					
9- I have feelings that I can't quite identify					
10- Being in touch with emotions is essenti					
11- I find it hard to describe how I feel about people					
12- People tell me to describe my feelings more					
13- I don't know what's going on inside me					
14- I often don't know why I am angry					
15- I prefer talking to people about their daily activities rather then their feelings					
16- I prefer to watch « light » entertainment shows rather than psychological dramas					
17- It is difficult for me to reveal my innermost feelings, even to close friends					
18- I can feel close to someone, even in moments of silence					
19- I find examination of my feelings useful in solving personal problems					
20- Looking for hidden meanings in movies or plays distracts from their enjoyment					

3.11.6. Conversation with Alice

Experimenter presses "enter" to connect with student, and video of Alice appears.

Experimenter (E): Hi Alice, how're you? Can you hear me?

Alice (A): Hi! Yes I hear you; there's a bit of noise, but it's fine.

E: Yeah? Great, and can you see our participant here today?

A: Yes, hi!

E: Ok, so Alice, this is [name of participant]. [Name of participant] this is Alice…

A *(waving her hand)*: Hi, nice to meet you!

E: Now we need to check that the Screen Share is working… *(press number 5)* Can you tell me what number is on the Screen Share now, if you can see it?

A: Yes, number 5.

E: And now? *(press number 3)*

A: Hmm, 3.

E: Cool, it seems that everything's working well… So for the first half of the study [name of participant] will complete the Adjectives task [SRE Encoding phase task] and the Counting task [Confidence Bias task]. Alice, as you know for the Counting task we won't be able to have the video-feed, but you can still track the answers on the Screen Share. And whenever there's the video-feed active, please remember not to make any facial expression or say anything that could influence the participant's choices. Is everything clear? *(Inbetween Alice nods and smiles)*

A: Yes, everything's clear.

E: Great, are you ready then to start?

A: Yes, I'm ready!

Participant completes SRE Encoding phase task and Confidence Bias task, calls the experimenter, and she presses "space".

A: Hey, I'm ready for the next task!

E: Great, so the next task is the Story task. Alice, you will read the statement on the Screen Share to [name of participant] and ask him/her "what do you do?". Please, remember to keep your face neutral. Then, the last task will be the Predictions task [Optimism Bias questionnaire], and again you will only share the Screen Share for this one. *(Inbetween Alice nods and smiles)*

A: Yes, OK.

Participant completes Story task and Optimism Bias questionnaire, calls the experimenter, and she presses "space".

A: Well, thank you for doing the task! Speak to you later, [name of experimenter]. Bye!

E: Thank you Alice, speak to you, bye!

3.11.7. Post-test questionnaire

Section 1

I liked <u>Alice</u> very much.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction with <u>Alice</u> was very natural.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction with <u>Alice</u> was very reciprocal.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think it is very important to donate money to charity.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think it is very important to do some voluntary work.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

Section 2

What do you think was the purpose of the experiment?

Please, explain if you followed any strategy when giving an answer on the…

- Adjectives task?
- Dots task?
- Story task?
- Predictions task?
- Recognition task?

3.11.8. Counterbalancing Conditions

Table 3-3. Design of the conditions used in the study

Condition	Baseline session	Test session
1	Story 1	ON, Story 2, Confederate 1
2	Story 1	ON, Story 2, Confederate 2
3	Story 1	OFF, Story 2, Confederate 1
4	Story 1	OFF, Story 2, Confederate 2
5	Story 2	ON, Story 1, Confederate 1
6	Story 2	ON, Story 1, Confederate 2
7	Story 2	OFF, Story 1, Confederate 1
8	Story 2	OFF, Story 1, Confederate 2

ON=online setting; OFF= offline setting

3.11.9. Adjectives

Baseline session

Self (30):

modest	kind	tolerant
cordial	happy	disagreeable
loyal	clever	complaining
relaxed	polite	suspicious
self-critical	efficient	gossipy
talkative	creative	strict
open-minded	active	authoritative

old-fashioned	clumsy	unhealthy
unpleasant	indecisive	dominating
forgetful	demanding	nervous

Other (30):

charming	helpful	discriminating
decent	talented	extravagant
truthful	sensible	impolite
skillful	gentle	insecure
easygoing	amusing	passive
innocent	disobedient	imitative
clear-headed	prejudiced	submissive
clean	depressed	obstinate
friendly	deceptive	unpunctual
brilliant	hesitant	messy

Distracter (60):

considerate	artistic	inconsistent
kind-hearted	precise	disturbed
responsible	social	inefficient
warm-hearted	comical	uninspiring
trustful	convincing	unsympathetic
honorable	meditative	hot-tempered
grateful	lucky	irritable
smart	perfectionistic	careless
respectful	well-spoken	boastful
original	outstanding	vain
constructive	radical	argumentative
sympathetic	anxious	bossy
productive	lonely	opportunist
neat	timid	shy
logical	immodest	unlucky
entertaining	tense	rebellious
romantic	worrying	daredevil
curious	sarcastic	inexperienced
positive	mediocre	preoccupied
skilled	stubborn	resigned

Test session

Self (30):

ingenious	thoughtful	petty
energetic	wise	pessimistic
experienced	reliable	weak
intelligent	patient	nonconfident
frank	intellectual	negligent
optimistic	untidy	incompetent
popular	noisy	reserved
competent	oversensitive	impulsive
sincere	showy	unappreciative
moral	frustrated	unfair

Other (30):

generous	mature	lazy
enthusiastic	warm	unattentive
inventive	interesting	sad
understanding	prudent	antisocial
nice	cooperative	neurotic
adventurous	possessive	superficial
practical	moody	prideful
proficient	overconfident	aggressive
honest	angry	materialistic
tender	cynical	childish

Distracter (60):

trustworthy	realistic	careful
good-humored	progressive	disciplined
educated	good	obedient
broad-minded	accurate	sentimental
cheerful	agreeable	fearless
reasonable	rational	sophisticated
pleasant	modern	unselfish
bright	confident	likable
forgiving	calm	choosy
admirable	decisive	troubled
attentive	tidy	tough

unskilled	illogical	aimless
ungraceful	unproductive	satirical
silly	overcritical	blunt
withdrawn	resentful	self-concerned
compulsive	irrational	eccentric
unhappy	foolish	skeptical
fearful	helpless	undecided
superstitious	dull	unpopular
pompous	hypochondriac	clownish

3.11.10. Stories

Story 1

It’s Monday morning. You leave home and head toward the tube station to go to work. You are almost arriving to the platform when you hear the beeps announcing the tube's doors will close. What do you do? You run and catch the tube / You wait for the next one

You get to work and check your email. You see you have received an invitation from the colleague in the next office: they are recruiting volunteers to help with a fundraising event that will take place next month. What do you do? You decline the invitation / You accept to volunteer

At noon you go out to a nearby restaurant to have lunch. When you pay the waitress gives you the change, but there's more than should be. What do you do? You tell her the change is wrong / You don't say anything

After lunch you still have a lot of work to do, but you want to leave early this afternoon because you have planned to go to an art exhibition. However, you receive a call from a colleague: you need to discuss some issues related to a project, but she keeps chatting about an argument she had with her partner. What do you do? You keep trying to comfort her / You change the topic to discuss the project

In the end you have enough time to visit the art exhibition. Before leaving, you see a couple of collection boxes asking for a donation to help cover the costs of the exhibition. What do you do? You continue your way out / You donate something

On your way back home, you see a homeless man asking for money. He looks at you and asks if you can give him some coins. What do you do? You give him some money / You continue your way back home

Story 2

It's Friday afternoon and you're working hard to finish your essay before tomorrow, since a friend is arriving to visit you for the weekend. However, your friend John calls you to invite you to the cinema this evening: he had a date with a girl and had bought tickets, but she just cancelled it. What do you do? You go to the cinema / You tell him you are busy

The next morning you go to the train station to pick up your friend. While you wait for her, you check your Facebook on the cell phone and see a post from your flatmate's friend: he's asking for volunteers to help taking care of disabled children in the school where he works. What do you do? You continue checking posts / You say you'd like to help

It seems the train has been delayed, so you decide to have a walk outside the station. Right outside the station you see a homeless man juggling to music. When he finishes, he asks you for money. What do you do? You go back to the station / You give him some money

Finally, the train arrives and you meet your friend. You need to take a bus to go back home and leave the luggage, and you know there is one leaving from the far side of the station in 5 minutes. What do you do? You run to the bus stop / You wait for the next one

Then, you go to a pub to have a drink while you decide what to do. Your friend takes a seat and you go to the bar to order. When you pay, you realise the barman has given you more change than he should have done. What do you do? You tell him the change is wrong / You don't say anything

Finally, you decide to visit a museum. Although the entrance is free, there is a collection box to donate something to maintain the museum. What do you do? You donate something / You don't donate

3.11.11. Items for predictions

fraud when buying on the internet
card fraud
household accident
mouse/rat in house
more than £30000 debts
miss a flight
death before 80
witness a traumatising accident
domestic burglary
bone fracture
depression
heart failure
obesity
diabetes (type 2)
victim of violence by stranger
disease of spinal cord
serious hearing problems
infertility
dementia
drug abuse
being convicted of crime
house vandalised
gluten intolerance
appendicitis
age related blindness
death before 60
alcoholism
Parkinson's disease
back pain
being fired
eye cataract (clouding lens of the eye)
skin burn
hospital stay longer than three weeks
victim of bullying at work (nonphysical)
theft from person
sexual dysfunction
hepatitis A or B
severe teeth problems when old
cancer (colon/lung/prostate/breast/skin)
abnormal heart rhythm
victim of violence by acquaintance
herpes
migraine
having a stroke
victim of violence at home
severe insomnia
death before 70
severe injury accident (traffic or house)
autoimmune disease
victim of mugging
asthma
blood clot in vein
ulcer
kidney stones
Alzheimer's disease
anxiety disorder
limb amputation
epilepsy
liver disease
death by infection

Chapter 4. Effects of being watched on eye gaze and facial displays of typical and autistic individuals

I would like to thank Dr Jamie Ward for his support in implementing the studies reported in this chapter.

4.1. Abstract

Communication with others relies on coordinated exchanges of social signals, such as eye gaze and facial displays. However, this can only happen when partners are able to see each other and eye gaze and facial displays are used as a social signal. Although previous studies report that autistic individuals have difficulties in planning eye gaze and producing facial displays, evidence from real-life dyadic tasks is scarce and mixed. Across two studies, this chapter investigated how eye gaze and facial displays of typical and high-functioning autistic individuals are modulated by the belief in being seen and true direct gaze during a structured Q&A task with a confederate. In each experiment participants were recorded with an eye-tracking and video-camera system while they completed the Q&A task under three social contexts: pre-recorded video, video-call and face-to-face. We found that typical participants gazed less to the confederate and produced more facial displays when they were being watched and when they were speaking. Contrary to our hypotheses, eye gaze and facial motion patterns in the autistic participants were overall similar to the typical group. This suggests that high-functioning autistic participants are able to use eye gaze and facial displays as social signals. Future studies will need to investigate to what extent this reflects spontaneous behaviour or the use of compensation strategies.

4.2. Introduction

Communication with other people is based on complex exchanges of social signals, which are mediated by eye gaze, facial expressions, speech or gestures. This is possible because both partners are able to see each other and, consequently, eye gaze acquires a dual function: the eyes can perceive information from the environment, as well as signal information back to the partner (Argyle & Cook, 1976; Gobel et al., 2015; Risko et al., 2016). Because our eyes share these two functions, eye gaze can convey a wide range of meanings depending on its direction and duration, such as attentiveness to a target (Frischen et al., 2007; Kuhn et al., 2009), emotions and feelings (Baron-Cohen et al., 1997), or desire to communicate (Ho et al., 2015), among others. In line with this, Kendon (1967) originally suggested that rapid and subtle changes in gaze direction and duration result in three main social functions of gaze: monitoring (to gather information from the partner), expressive (to modulate the intensity or arousal in the interaction), and regulatory (to regulate turn-taking during conversation). Moreover, the social functions of gaze imply that, to convey meaningful messages, eye gaze needs to be spatially and temporally coordinated with other social signals (Cañigueral & Hamilton, 2019).

Previous studies suggest that autistic individuals have difficulties in exchanging social signals, particularly via eye gaze, but evidence is scarce and mixed (Falck-Ytter & Von Hofsten, 2011). A reason for this could be that traditional experimental designs in cognitive research have largely ignored the dual function of gaze (Gobel et al., 2015; Von dem Hagen & Bright, 2017). In typical lab studies, participants complete computer-based tasks where they “interact” with pictures or videos of another person (Risko et al., 2012), but they are aware that the pictures and videos cannot see them back: communication happens only one-way (from the picture or video to the participant) and the signalling function of gaze is completely lost. Although this approach allows good experimental control, it is not interactive (Risko et al., 2012, 2016) and might recruit cognitive mechanisms that are different from those recruited during face-to-face interactions (Redcay & Schilbach, 2019; Schilbach et al., 2013). Thus, examining gaze patterns of autistic people in *live* interactions, where they can use eye gaze to perceive and signal information (in coordination with other social signals), could contribute to further understand which cognitive mechanisms underlie their social difficulties. Across two studies, this chapter investigated how gaze behaviour of typical and autistic individuals is modulated by the belief in being seen and true direct gaze during a structured conversation.

4.2.1. The perceiving function of eye gaze

Traditionally, research studying gaze behaviour has focused on how we use our eyes to perceive information from pictures and videos. Early research on visual attention introduced the concept of saliency maps to describe how we sample information from a visual scene. For every location in the scene, saliency maps encode its saliency by combining information from various visual features (e.g. intensity, colour, orientation, motion) (Itti & Koch, 2001; Itti et al., 1998; Koch & Ullman, 1985). Crucially, only the location that is most salient will be further processed in downstream visual areas, guiding the next eye movement to that specific location (Itti & Koch, 2001; Kastner & Ungerleider, 2000; Koch & Ullman, 1985). Saliency maps encode both static and dynamic features of the visual scene (bottom-up bias; Itti & Koch, 2001; Jeong, Ban, & Lee, 2008; Koch & Ullman, 1985; Milanese, Gil, & Pun, 1995), but they can also be modelled by affective features, which are associated with preference or dislike for the visual stimuli, or with the goal of the task at hand (top-down bias; Itti et al., 1998; Jeong et al., 2008; Olshausen, Anderson, & Van Essen, 1993; Tsotsos et al., 1995; Veale, Hafed, & Yoshida, 2017). By integrating low-level (static and dynamic) and affective features, saliency maps allow us to actively plan our eye movements to maximise the information we extract from the world (Cañigueral & Hamilton, 2019; Yang et al., 2016).

Top-down modulation of saliency maps is particularly important for social scenes, where visual attention is biased towards faces and eyes of other people (Bindemann, Burton, & Jenkins, 2005; Birmingham et al., 2009). Given that the eyes are small and have low saliency (Birmingham et al., 2009), low-level features are not enough to account for gaze behaviour in social scenes (Birmingham et al., 2009; Nasiopoulos et al., 2015). For instance, fixations during free-viewing of naturalistic social scenes are better predicted by social and low-level salient features, than by low-level features alone (End & Gamer, 2017; Rubo & Gamer, 2018). Because the face and the eyes are a rich source of social information (Crivelli & Fridlund, 2018; Hamilton, 2016), this preferential bias to attend to faces likely results from the need to maximise information sampling about others during social interactions (Cañigueral & Hamilton, 2019; Yang et al., 2016). In line with this, Kendon (1967) proposed that during conversation our eyes have the crucial function of monitoring attentional states and facial expressions of the partner, to ensure mutual understanding and approval (Efran, 1968; Efran & Broughton, 1966; Kleinke, 1986).

4.2.2. The signalling function of eye gaze

Studies using pictures and videos provide a great deal of insight into gaze behaviour in terms of perceiving information from the world, but are limited to understand how we use our eyes to signal information to others. In line with the dual function of gaze (Argyle & Cook, 1976; Gobel et al., 2015; Risko et al., 2016), recent research has used more ecologically valid designs, like face-to-face interactions. It has been proposed that in such live settings "one cannot not communicate" (Watzlawick et al., 1967), meaning that both presence and absence of social behaviour directed to the other will be sending a signal (e.g. gazing to the other means "I am interested in starting an interaction", but not gazing to the other indicates "I am not interested in doing so") (Foulsham et al., 2011). Thus, studying gaze patterns in live interactions is key to examine how we plan our eye movements to maximise the information we sample, but also optimise the information we signal to others (Cañigueral & Hamilton, 2019).

Recent studies suggest that there is little relationship between gaze patterns in computer-based tasks and gaze patterns in the real world (Foulsham & Kingstone, 2017; Hayward et al., 2017). For instance, participants sitting in a waiting room gaze less to a live confederate also waiting in the room, than to the same confederate in a video-clip (Laidlaw et al., 2011). Participants may avert gaze from the real confederate to signal no interest in starting an interaction with a stranger (i.e. social norm of civil inattention; Foulsham et al., 2011; Goffman, 1963), or to reduce arousal associated with eye contact in live interactions (i.e. expressive function of gaze described by Kendon; Argyle & Dean, 1965; Kendon, 1967; Pönkänen, Peltola, & Hietanen, 2011). This suggests that in non-communicative situations the signalling function of gaze (e.g. to show disinterest or reduce arousal) overrides our preferential bias to attend to faces.

However, in communicative contexts where participants are required to actively engage with the confederate (e.g. structured conversations), findings are mixed: in Chapter 2 we found that participants direct *less* gaze to the eyes of the confederate in a live video-call than in a pre-recorded video-clip, while another study showed the opposite pattern (Mansour & Kuhn, 2019). A reason for these inconsistent findings could be that gaze behaviour was averaged across the whole task, which might overlook an important feature of gaze during communicative exchanges: gaze patterns are *dynamic*, that is, they change over time as they are coordinated with other social signals, both within and across interacting partners.

4.2.3. Eye gaze during conversation

During live communicative exchanges, such as conversation, eye gaze needs to be integrated and coordinated with other social signals. An essential signal that we use during conversation is speech, which defines two alternating roles between partners involved in the conversation: the speaker and the listener. In a seminal study, Kendon (1967) found that transitions between speaker and listener states (i.e. turn-taking) are modulated by eye gaze, suggesting that our eyes have a regulatory function.

In line with Kendon's original findings (1967), recent studies have shown that gaze behaviour is asymmetrical between speakers and listeners.

Speakers tend to avert their gaze when they begin to talk and when they hesitate (to indicate that they are going to say something), but direct their gaze to the listener when they are finishing an utterance (probably to indicate that the listener can take the turn) (Cummins, 2012; Duncan & Fiske, 1977; Hessels, Holleman, Kingstone, Hooge, & Kemner, 2019; Ho et al., 2015; Kendon, 1967; Sandgren et al., 2012). Moreover, they constantly shift their gaze toward and away from listeners while speaking (Kendon, 1967). These brief periods of mutual eye gaze, which usually elicit some form of visual or auditory feedback from the listener (i.e. back-channelling, like nodding or saying “mhm”; Bavelas, Coates, & Johnson, 2002), allow speakers to monitor whether listeners are understanding and attending to what they are saying. On the other hand, listeners gaze at speakers most of the time (Kendon, 1967), and make more gaze shifts to the speakers (as well as gestures and head shifts) when they want to take the turn to speak (Harrigan, 1985; Ho et al., 2015).

Altogether, these findings illustrate how in live communicative interactions we plan our eye movements in relation to other social signals that we send to our partner and that our partner sends to us, thus combining the signalling and perceiving functions of gaze. Studying the presence and direction of temporal dependencies between social signals can give much insight into the cognitive mechanisms that modulate gaze planning in live communicative exchanges, but also how they are compromised in disorders of social interactions.

4.2.4. Eye gaze in autism

Autism is a neurodevelopmental condition characterized by difficulties in interpersonal interaction and communication, and the presence of restricted and repetitive patterns of behaviour (*Diagnostic and Statistical Manual of Mental Disorders 5th Ed.*, 2013). A hallmark of autism is the presence of abnormal gaze behaviour in infants, and this is used as a diagnostic criterion from early infancy (Zwaigenbaum et al., 2005). However, the evidence is mixed for autistic adults: while some studies find that autistic adults avoid making eye contact, others show that they have typical gaze patterns (see Falck-Ytter & Von Hofsten, 2011 for a review). A reason for these inconsistencies could be that most of past research has used pictures and videos as stimuli, where eye gaze exclusively has a perceiving function (Chevallier et al., 2015; Drysdale et al., 2018; Von dem Hagen & Bright, 2017). However, to fully understand the cognitive mechanisms underlying social difficulties in autism it is necessary to study gaze behaviour in *live* interactions, where gaze patterns result from the interplay of its perceiving and signalling functions.

Studies looking at gaze behaviour of autistic people during live interactions are scarce. To our knowledge, no study has systematically compared gaze patterns of clinically-diagnosed autistic individuals in live versus pre-recorded interactions, so it is unknown to what extent they plan eye movements to signal information to others. Nonetheless, an attempt has been made by relating gaze behaviour to autistic traits. In a recent study (Von dem Hagen & Bright, 2017 Experiment 1), participants were shown videos of a confederate and they believed that the videos were either a pre-recorded or live video-feed. Results showed that participants with low autistic traits directed less gaze to the live video-feed than to the pre-recorded video-clips, but this difference was absent in participants with high autistic traits. This suggests that autistic individuals might not use eye gaze as a signal, in this case to indicate disinterest in interacting with a stranger (Foulsham et al., 2011; Goffman, 1963) or to reduce arousal associated with eye contact (Argyle & Dean, 1965; Kendon, 1967; Pönkänen et al., 2011).

A core question is whether autistic people coordinate eye gaze with other social signals (e.g. speech) during live communicative exchanges. Only one study has looked at gaze patterns of clinically-diagnosed autistic people during conversation (Freeth & Bugembe, 2018), although two studies have compared between individuals with high versus low autistic traits (Vabalas & Freeth, 2016; Von dem Hagen & Bright, 2017 Experiment 2). Using Q&A tasks over online video-feed or face-to-face interactions, these studies have reported that eye gaze of both groups follows similar patterns when alternating between speaker and listener roles. However, von dem Hagen & Bright (Von dem Hagen & Bright, 2017 Experiment 2) also found that participants with high autistic traits spent less time looking at the live confederate than participants with low autistic traits (regardless of speaker or listener state). Similarly, Hessels and colleagues (Hessels, Holleman, Cornelissen, Hooge, & Kemner, 2018) found that high autistic traits correlate with less gaze directed to the eyes of the partner as well as less mutual eye contact. Thus, it could be that autistic participants find it hard to keep track of the spatio-temporal dynamics of live social interactions (see also Bolis, Balsters, Wenderoth, Becchio, & Schilbach, 2018; Cañigueral & Hamilton, 2019): this might impose higher cognitive demands, which in turn reduces gaze directed to faces.

As we have previously suggested, these inconsistent findings could result from averaging patterns of eye gaze across the whole task, which might neglect differences embedded in more fine-grained dynamics of gaze behaviour along time. For instance, previous studies using non-interactive stimuli found that autistic individuals do not use eye contact to coordinate subsequent social behaviours, such as gaze following (Böckler, Timmermans, Sebanz, Vogeley, & Schilbach, 2014), generation and mimicry of actions (Forbes, Wang, & Hamilton, 2017; Schilbach, Eickhoff, Cieslik, Kuzmanovic, & Vogeley, 2012), or mimicry of facial expressions (Neufeld, Ioannou, Korb, Schilbach, & Chakrabarti, 2016). Looking at how gaze patterns of typical and autistic people develop over time and in relation to other social signals could yield further insight into which cognitive components of gaze planning are disrupted in autism.

4.2.5. The present study

This chapter aimed to investigate how eye gaze and facial motion patterns are modulated by the belief in being watched and the potential for true direct gaze in typical and autistic individuals. Across two studies we tested a sample of typical participants (Experiment 1: pilot), and a sample of matched typical and autistic participants (Experiment 2). In each experiment, participants engaged in a spoken Q&A task with a confederate (professional actress or actor) in three different social contexts: Video (pre-recorded video-clips of the confederate), VideoCall (live video-call with the confederate), and Real (live face-to-face interaction with the confederate). These social contexts differed in the participants' belief in being watched and the potential of true direct gaze, creating gradually increasing levels of ecological validity (Figure 4-1a). In the Video condition participants knew the confederate could not watch them, and there was no true direct gaze. This means that gaze of participants only had a perceiving function. In the VideoCall condition participants believed the confederate could watch them but there was no true direct gaze, since in video-calls there is a mismatch between true gaze direction and perceived gaze direction. This means that gaze had a perceiving function, and that the signalling function was somewhat limited (i.e. exchange of signals is not fully coordinated). Finally, in the Real condition participants believed the confederate could watch them and there was true direct gaze: eye gaze had both perceiving and (full) signalling functions.

Across all three social contexts, we recorded eye gaze of participants with wearable eye-tracking technology and measured the amount of gaze directed to the eye and mouth region of the confederate. Following traditional analyses of gaze behaviour, we first looked at gaze patterns after aggregating the data across the whole task for each condition. However, to study more detailed dynamics of eye gaze in relation to speech, we then analysed differences between conditions along the trial time-course. During the task, we also tracked the face of participants with a video-camera. Previous studies have found that participants make and mimic more facial displays when they are being watched (Chovil, 1991b; Fridlund, 1991; J. K. Hietanen, Kylliäinen, et al., 2018), suggesting that we use facial displays not only to express emotions but also as a tool for communication (Crivelli & Fridlund, 2018). For instance, we use facial displays to add emphasis to what we are saying or to convey ideas that are difficult to express only with words (Chovil, 1991a). However, a recent meta-analysis found that autistic participants are less likely to spontaneously produce and mimic facial displays (Trevisan, Hoskyn, & Birmingham, 2018). Thus, in a complementary analysis we aimed to look at how the belief in being watched and potential for true direct gaze modulates the amount of facial displays during conversation.

In the following sections we present our hypotheses, methodology and findings for Experiment 1 (pilot with typical participants) and Experiment 2 (comparison between typical and autistic participants), respectively.

4.3. Experiment 1: pilot study with typical participants

4.3.1. Hypotheses

Experiment 1 investigated eye gaze and facial motion patterns of typical participants while they completed a Q&A task in three social contexts: Video, VideoCall and Real. Based on the findings from Chapter 2 and previous studies (Laidlaw et al., 2011), for the aggregated analysis of eye gaze we expected that participants would direct less gaze towards the confederate in the VideoCall and Real conditions (where gaze has a perceiving and signalling function) compared to the Video condition (where gaze can only perceive information). We predicted no differences between VideoCall and Real conditions: these two conditions differ on the potential for true direct gaze along the trial time-course, but effects of this subtle manipulation are probably hard to capture using aggregated measures.

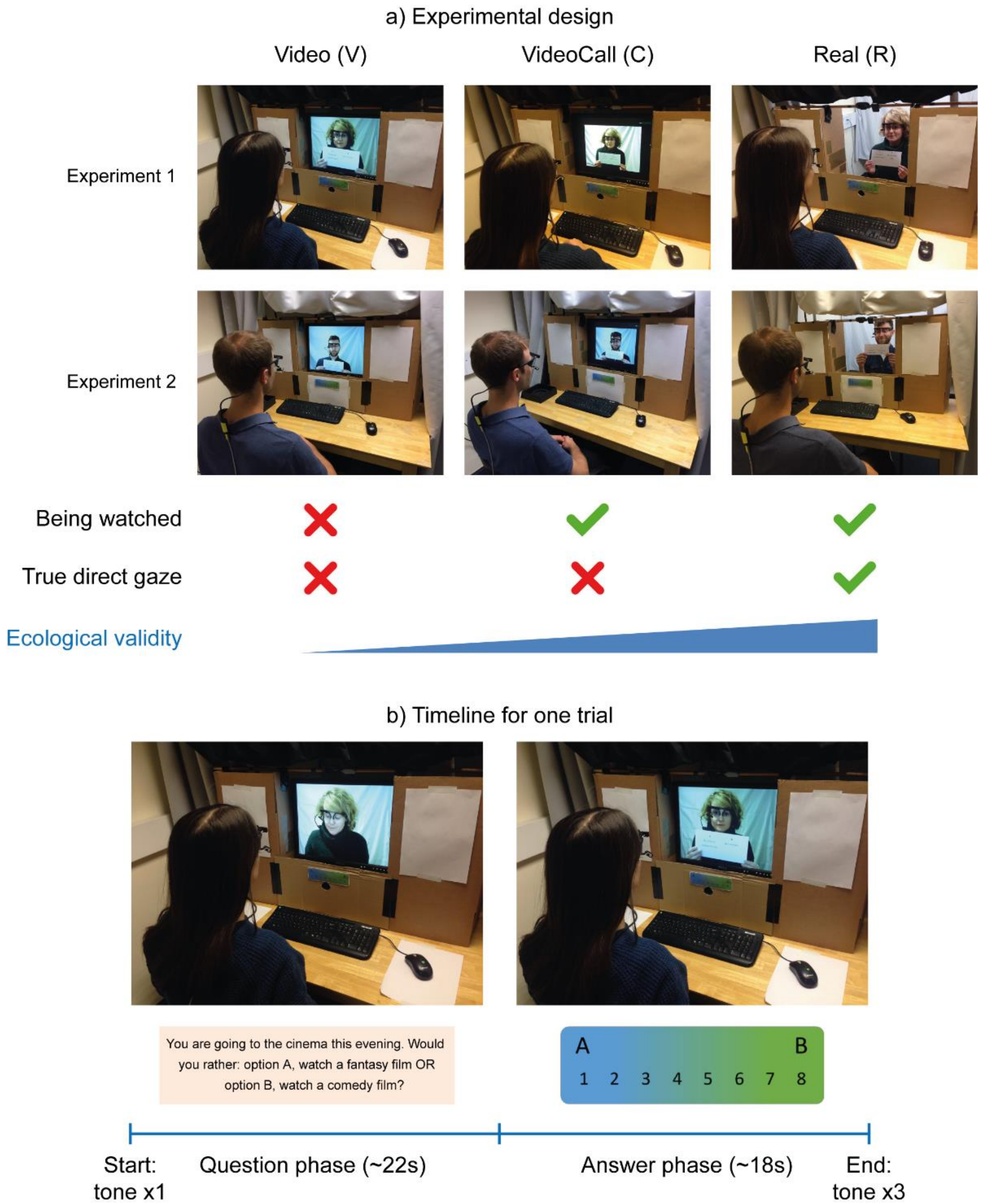

Figure 4-1. Study design.
a) Experimental design and sample pictures of conditions, for both Experiment 1 and 2. b) Timeline for one trial in the Video condition.

For the time-course analysis of eye gaze, we looked at differences between conditions in 5 different time-windows along the trial time-course: start of question, end of question, turn-taking, start of answer, and end of answer. In line with previous evidence (Ho et al., 2015; Kendon, 1967), we predicted that participants would direct more gaze to the confederate during the question time-windows (i.e. when they were listening) than during the answer time-windows (i.e. when they were speaking). We expected this pattern would be true particularly for the VideoCall and Real conditions, where gaze acquires a signalling function and eye movements are planned to regulate turn-taking. Moreover, we expected that differences between Real and VideoCall (or Video) conditions would be greater at moments where gaze is planned, not only to monitor information about the other, but also to signal information about who is taking the turn. Thus, based on previous studies, we predicted that participants would gaze more to the confederate in the Real condition at the start of the Question (to signal interest in what the confederate was saying; Argyle & Cook, 1976; Kendon, 1967), during Turn-taking (to signal that they are taking the turn; Ho et al., 2015; Kendon, 1967), and at the end of the Answer (to signal that they were ending the answer and to monitor what the confederate thinks about their answer; Efran, 1968; Efran & Broughton, 1966; Ho et al., 2015; Kendon, 1967; Kleinke, 1986).

Finally, if participants use facial displays as a tool for communication (Crivelli & Fridlund, 2018), we predicted they would generally move their face more in the VideoCall and Real conditions compared to the Video condition. Moreover, since we use facial displays to add meaning to speech (Chovil, 1991a), we expected that along the trial time-course participants would move their face more during the answer time-windows (i.e. when they were speaking) than during the question time-windows (i.e. when they were listening). A potential confound in this analysis is that the face-tracking algorithm may pick up facial motion related to moving the mouth when speaking; this limitation was addressed in Experiment 2.

4.3.2. Materials and Methods

4.3.2.1. Participants and confederate

Thirty healthy adult participants participated in the study (25 females, 5 males; mean age: 22.93±2.78). Two participants were excluded from the analyses due to poor signal quality in the eye-tracking data, so the final sample consisted of a group of 28 adults (23 females, 5 males; mean age: 22.96±2.87). The confederate was a professional actress (playing age: 18-28) hired for the full duration of the study, to ensure a consistent performance between trials and participants. Importantly, she was unaware of the aims and hypotheses of the study. Participants were told the confederate was a student helping with the study. All participants and the confederate provided written informed consent and were compensated for their participation in the study. The study was granted ethical approval by the local Research Ethics Committee, and was in accordance with the Declaration of Helsinki.

4.3.2.2. Task

To test how eye gaze patterns are modulated during conversation, we designed a question and answer (Q&A) task where participants engaged in a structured conversation with a confederate. This Q&A task resembled the “Would you rather…” game: participants were given two options about personal preferences, and they had to choose one of the options. We created 3 sets of questions (one for each experimental condition: Video, VideoCall and Real). Each set comprised 12 questions asking about personal preferences in either a daily situation (e.g. “You are going to the cinema this evening. Would you rather: option A, watch a fantasy film, or option B, watch a comedy film?”) or prosocial situations (e.g. “You have some spare mornings this year. Would you rather: option A, work as an assistant in a company, or Option B, volunteer in a nursing home?”). These questions were part of a larger pool of questions that we created and submitted to 2 rounds of piloting through an online form (30 adults in each pilot). This allowed us to refine the questions in each set until the 3 sets were matched on the prosociality scores given to the questions describing prosocial situations. Moreover, the 3 sets were matched for number of questions describing daily or prosocial situations, involving a monetary or temporal cost, and describing fictional or real situations. Note that for the analyses we pooled all types of questions together. See section *4.7.1. List of questions in Experiment 1* for the full list of questions used in Experiment 1.

For each trial, participants heard a single tone that indicated the start of the Question phase. The confederate read a question from a card (one card for each question), which had the full question written on one side, and the two options written on the other side (under the labels Option A and Option B). The confederate looked down to the card when reading the question, but briefly gazed to the participants’ face when saying “Option A” and “Option B” (to capture the participants’ attention to the options). After reading the question, the confederate gazed to the participant and held up the card, so that the side with the two options was now visible for participants. This cued the start of the Answer phase, where participants chose one of the options (A or B) and indicated on a scale from 1 to 8 how much they preferred that option over the other (1 = strongly prefer A; 8 = strongly prefer B). Participants spoke out their choices and were free to add any further explanation about their choice until they heard three consecutive tones, which indicated the end of the Answer phase and of the trial. During the Answer phase the confederate gazed to the participants' face and displayed a polite smile. The Question phase was around 22 seconds long, and the Answer phase was 18 seconds long, so each trial had a duration of around 40 seconds. There was a brief rest period of 5 seconds between trials. See Figure 4-1b for the timeline of a sample trial during the Video condition.

4.3.2.3. Experimental conditions and stimuli

Participants completed the task under three experimental conditions (Video, VideoCall and Real). These conditions differed in the belief in being watched and the potential for true direct gaze, thus creating gradually increasing levels of ecological validity in each condition (see Figure 4-1a).

For the Video (V) condition, participants observed pre-recorded videos of the confederate on a monitor (at distance of 60 cm) while they were alone in the testing room. Thus, participants knew the confederate could not watch them and there was no potential for true direct gaze, resulting in a low ecologically valid interaction where gaze only has a perceiving function. During the filming session, the confederate went through the full list of questions in Set 1, and was recorded with a webcam on top of a monitor. This way the confederate's appearance, size and perspective matched the VideoCall and Real conditions.

For the VideoCall (C) condition, participants were alone in the room and interacted with the confederate (in the room next door) through a freely-available, video-call software called Zoom. The monitor was placed at a distance of 60 cm. Here, participants believed the confederate could watch them but there was no potential for true direct gaze, since in video-calls there is a mismatch between true gaze direction and perceived gaze direction: when the confederate gazed at the participants' eyes on the monitor, participants perceived her gaze was slightly averted; similarly, when the confederate gazed at the webcam, participants perceived she was making eye contact. This resulted in a moderate ecologically valid interaction, where gaze has perceiving and (somewhat limited) signalling functions.

For the Real (R) condition, participants and confederate were in the same room, sitting across a table and facing each other at a distance of 100 cm (the experimenter left the room during the task). In this condition, participants believed the confederate could watch them and there was potential for true direct gaze, resulting in a high ecologically valid interaction where gaze has perceiving and (full) signalling functions.

Across all conditions, the confederate was wearing a wearable eye-tracker and appeared in front of a neutral plain background. Her eye gaze and facial expression patterns were consistent across conditions and trials. For each question, the confederate read the question from the card, but directed her gaze to the participants' face (webcam in the Video and VideoCall conditions) when saying "Option A" and "Option B" (to capture the participants' attention to the options). Then, the confederate held up the card so that the side with the two options was visible for participants. While participants answered, the confederate gazed to the participants' face and displayed a polite smile. She was instructed not to react to the choices of participants.

Each experimental condition was associated with same set of questions for all participants (Set 1 - Video; Set 2 - VideoCall; Set 3 - Real), but the questions were matched across sets (see section *4.3.2.2. Task* for an explanation on how questions were matched). We counterbalanced the order of the experimental conditions, creating 6 different counterbalancing conditions: *V-C-R, V-R-C, C-V-R, C-R-V, R-V-C, R-C-V.* Each participant was allocated to one counterbalancing condition and completed the task under each of the three experimental conditions. The overall duration of the study was around 45 minutes.

4.3.2.4. Post-test questionnaire and debriefing

After completing the task under the three conditions, all participants completed a post-test questionnaire with two sections. In the first section, participants had to indicate on a scale from 0 (disagree) to 8 (agree) to what extent they agreed with some statements. These statements asked about how *natural* and *reciprocal* the interaction with the confederate was in each condition (e.g. “I think the interaction in the Video was very natural”). In the second section, participants were asked which interaction they liked the most and the least (and why), as well as a question to check that they did not realise the real purpose of the experiment. See section *4.7.2. Post-test questionnaire* for the full post-test questionnaire. After the post-test questionnaire, the experimenter debriefed participants about the real purpose of the study.

4.3.2.5. Experimental set-up

Participants sat on one side of a table in a testing room with dim fluorescent light. A cardboard occluder was placed on the table to block the background on the other side of the table, except for a 14” squared window in the centre (see Figure 4-1). During the Video and VideoCall conditions a 14” monitor was fitted to the window in the occluder. During the Real condition the confederate sat on the other side of the table and only her face and upper half of the body was visible to participants through the window. The use of the occluder with the window ensured that the confederate had similar appearance across all three conditions (see Figure 4-1a).

The room was equipped with a dual wearable eye-tracking system and two webcams arranged to record data from the face of the participants and confederate. The eye-tracker and webcam for the participant was connected to a PC in the testing room and was used for all three conditions. The eye-tracker and webcam for the confederate was connected to a laptop, so that it could be moved to the room next door for the VideoCall condition. Data from the confederate was recorded for the VideoCall and Real conditions only. Unfortunately these recordings had poor signal quality and were not used for the analyses.

4.3.2.6. Eye gaze and facial motion data: acquisition and processing

Two wearable eye-trackers (Pupil Core monocular, Pupil Labs, Germany) were used to record eye movements of participants and confederate. The Pupil Core system uses a head-mounted “world” camera that records the environment, and a head-mounted “pupil” camera that tracks the right pupil movements at a rate of 120 Hz, which were down-sampled to 30 Hz to match the ‘world’ camera video frame rate. Compared to table-based eye-trackers, which require participants to sit immobile in front of a monitor, wearable eye-trackers allow researchers to record eye movements of participants while they move freely in more ecologically valid paradigms (Schilbach et al., 2013). In the Video and VideoCall conditions, participants sat approximately 60 cm from a 14” monitor and went through a 9-point screen-based calibration routine at the start of each condition (this took between 1 and 2 minutes). The same calibration routine was used for the confederate in the

VideoCall condition. For the Real condition, participants sat approximately 100 cm from the confederate. Participants and confederate went through a 6-point manual calibration routine at the start of this condition (between 1 and 2 minutes).

After data acquisition, the videos from the participants' "world" camera were further processed with OpenFace (Baltrusaitis et al., 2016) to detect facial landmark coordinates on the face of the confederate for each frame of the video. These coordinates were used to create an ellipse around the confederate's face, which was scaled to the size and orientation of the face by using the distance between both eyes as a reference. This system allowed us to control for the participants' and confederate's head movement during the task (e.g. moving toward or away from the confederate, or tilting the head), and ensured consistency across time-points (i.e. frames), trials and conditions when mapping the participants' gaze on the regions of interest. The regions of interest (ROIs) were defined by dividing the ellipse in two halves: Eyes region (upper half) and Mouth region (lower half). We then detected whether the gaze of participants fell into each ROI for each time-point in a trial.

To track facial motion (i.e. facial displays), the webcam video recordings (Logitech webcam; recording rate of 20 Hz) were processed with OpenFace (Baltrusaitis et al., 2016). The OpenFace algorithm uses the Facial Action Coding System (FACS; Ekman & Friesen, 1976) to taxonomise movements of facial muscles and deconstruct facial displays in specific Action Units (AU). OpenFace can recognise a subset of 18 facial AUs (including facial muscles in areas near the eyes, nose, cheeks, mouth and chin), and gives information about the presence or absence of each of these facial AUs for each frame of the video recording. We then summed the number of facial AUs for each time-point in a trial.

See Figure 4-2 for a diagram with an overview of the pipeline for data acquisition, processing and analyses.

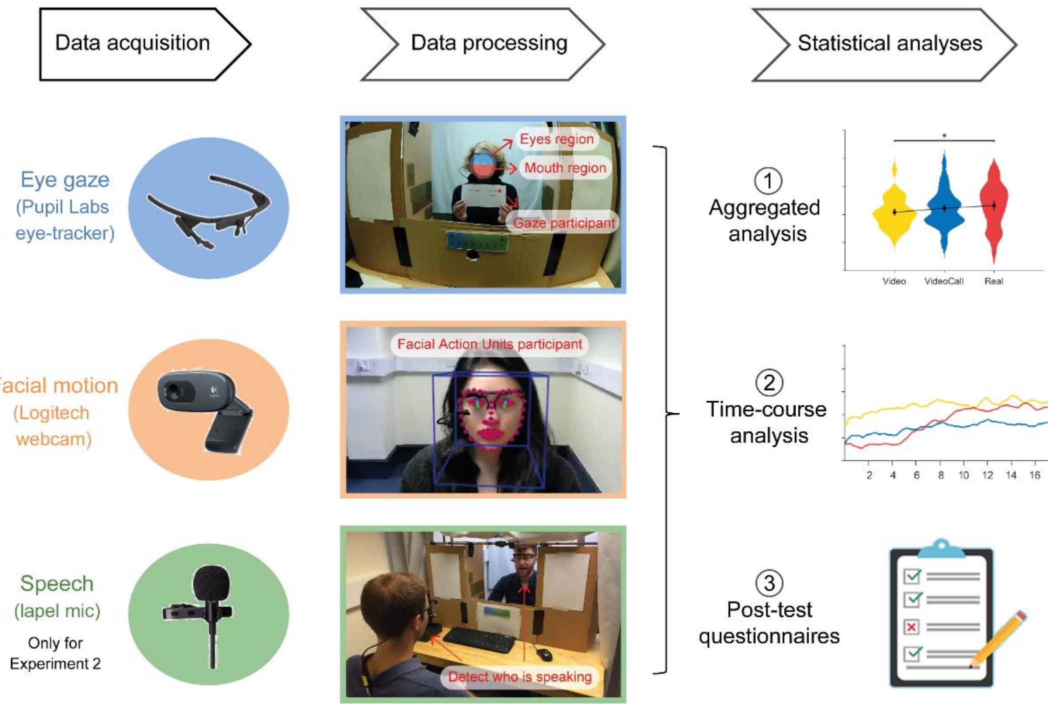

Figure 4-2. Overview of the pipeline for data acquisition, processing and analyses.

4.3.2.7. Statistical analyses

To check whether our experimental manipulation modulated how participants perceived the interaction with the confederate, a 1-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor was performed for each of the traits rated in the post-test questionnaire: naturalness and reciprocity. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed.

For eye gaze and facial motion data, we performed two types of analyses: aggregated and time-course. Aggregated analyses are useful to investigate general patterns of behaviour across different conditions, and use aggregated data across entire recording sessions (see Figure 4-2). For the eye gaze analysis, we computed the mean proportion of looking time for each ROI (Eyes and Mouth) and Condition, across all time-points and trials. Note that proportion of looking time refers to the amount of time that participants spent looking at each ROI, relative to the total duration of the trial. For the facial motion analysis, we computed the mean number of active facial AUs for each Condition, across all time-points and trials. For each measure (proportion looking time to Eyes, proportion looking time to Mouth, and number facial AUs), we performed a 1-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed.

Although aggregated analyses yield important insight into patterns of behaviour, time-course analyses offer the possibility to study more fine-grained dynamics of behaviour along time, which are otherwise lost in aggregated analyses (see Figure 4-2). Here, our aim was to investigate how eye gaze and facial motion patterns vary throughout the time-course of the trial in relation to speech. For this, we distinguished between 5 different time-windows in the trial: start of the question/interaction (0-10 s), end of the question (10-20 s), turn-taking (20-24 s), start of the answer (24-32 s), and end of the answer/interaction (32-40 s). Note that the time-window for turn-taking was 4 seconds, which is a rather long duration for this type of event. We chose this longer time-window because, since we did not have an accurate time measurement for the end of each question in the VideoCall and Real conditions (which slightly varied across participants), we used the time values from a pre-recorded version of these questions (with the same confederate). This means that, although the time-course for each trial was locked to the end of the Question phase according to these time values (i.e. around 22 s), for some trials this event might have happened slightly earlier or later than the values used. Thus, we chose a time-window at 22±2 s to account for this variability.

For the eye gaze analysis, we computed the mean proportion of gaze for each ROI and time-point, across trials in the same Condition. Thus, we obtained two time-courses (gaze to Eyes and gaze to Mouth) for each participant and Condition, with the mean proportion of gaze to each ROI along the trial duration. These time-courses were smoothed using a moving average filter of 1 second. For the facial motion analysis, we computed the mean number of facial AUs for each time-point, across trials in the same Condition: we obtained one time-course for each participant and Condition, with the mean number of facial AUs along the trial duration. For each measure (proportion gaze to Eyes, proportion gaze to Mouth, and number facial AUs), we computed the means for each time-window. A 2-way repeated measures ANOVA with Condition (Video, VideoCall, Real) and Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) as within-subject factors was performed for each measure. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed.

Note that, although we used the time-window data for statistical analyses, the full time-course data was used for plots.

4.3.3. Results

4.3.3.1. Manipulation check: post-test questionnaire ratings

In the post-test questionnaire, participants rated the confederate in each condition on two traits: naturalness and reciprocity. A 1-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor was performed for each of the traits. See Table 4-1 for descriptives (mean and SD) on post-test questionnaire ratings. For naturalness, results showed that there was a main effect of Condition, $F(2,54) = 5.037$, $p = .017$, $n_p^2 = .157$: the confederate was perceived as more natural in the VideoCall compared to the Video condition, $t(27) = 3.02$, $p = .016$, $d_z = .570$, but there was no difference between Video and Real conditions, $t(27) = 2.37$, $p > .05$, $d_z = .449$, and between VideoCall and Real conditions, $t(27) = .449$, $p > .05$, $d_z = .084$ (Figure 4-3a). For reciprocity, results showed that there was a main effect of Condition, $F(2,54) = 14.2$, $p < .001$, $n_p^2 = .345$: the confederate was perceived as more reciprocal in the VideoCall compared to the Video condition, $t(27) = 3.10$, $p = .013$, $d_z = .586$; more reciprocal in the Real compared to the Video condition, $t(27) = 4.16$, $p < .001$, $d_z = .787$; and more reciprocal in the Real compared to the VideoCall condition, $t(27) = 3.52$, $p = .005$, $d_z = .665$ (Figure 4-3a).

Table 4-1. Descriptives for post-test questionnaire ratings in Experiment 1

Condition	Natural	Reciprocal
Video	*M* = 5.04 *SD* = 2.01	*M* = 4.04 *SD* = 2.43
VideoCall	*M* = 5.71 *SD* = 1.80	*M* = 4.89 *SD* = 2.35
Real	*M* = 5.82 *SD* = 2.07	*M* = 5.57 *SD* = 2.47

4.3.3.2. Aggregated analyses

To investigate general patterns of eye gaze and facial motion across the three conditions, we aggregated the data across all time-points and trials for each Condition. Using the proportion of looking time to Eyes and Mouth region as measures for eye gaze, and the number of facial AUs as a measure for facial motion, we fitted a 1-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor. See Table 4-2 for descriptives (mean and SD) on these measures.

Table 4-2. Descriptives for aggregated analyses in Experiment 1

Condition	Prop. looking time to Eyes region[a]	Prop. looking time to Mouth region	Number facial AUs
Video	*M* = .123 (.116) *SD* = .109 (.105)	*M* = .160 *SD* = .096	*M* = 4.16 *SD* = 1.09
VideoCall	*M* = .070 (.053) *SD* = .107 (.061)	*M* = .095 *SD* = .065	*M* = 4.43 *SD* = 1.32
Real	*M* = .047 (.046) *SD* = .049 (.050)	*M* = .118 *SD* = .093	*M* = 4.62 *SD* = 1.56

[a]Values after removal of the outlier are in brackets.

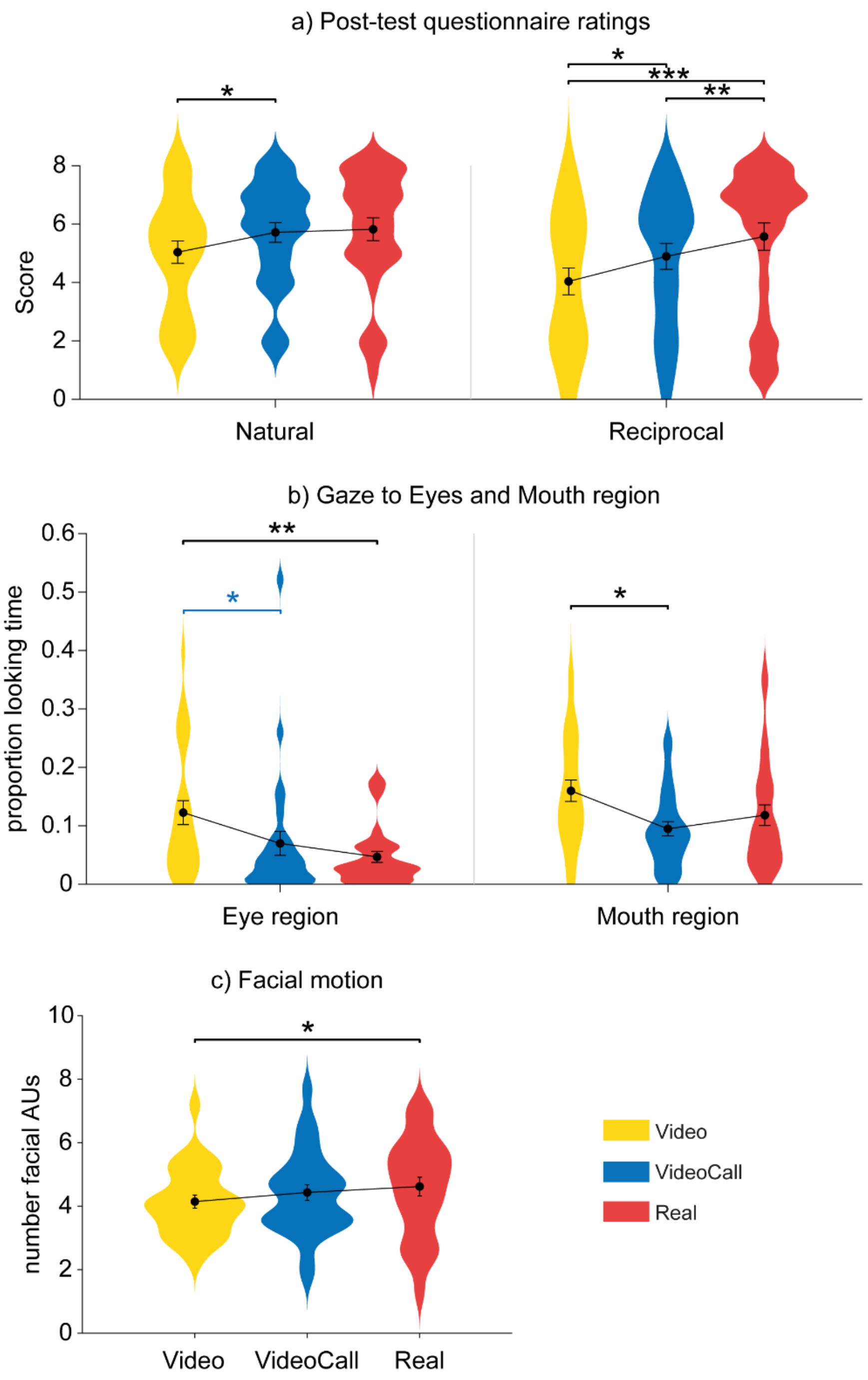

Figure 4-3. Results for ratings and aggregated analyses in Experiment 1.
a) Post-test questionnaire ratings. b) Proportion of looking time to Eyes and Mouth region for each Condition. c) Number of facial AUs for each Condition. Mean (filled circle), SE (error bars), and frequency of values (width of distribution). Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***). Blue asterisks signify difference between Video and VideoCall after removing the outlier.

For eye gaze directed to the Eyes region, there was a main effect of Condition, $F(2,54) = 7.003$, $p = .002$, $\eta_p^2 = .206$. Post-hoc pairwise comparisons showed that participants looked less to the Eyes region of the confederate in the Real compared to the Video condition, $t(27) = 3.62$, $p = .004$, $d_z = .684$, but there was no difference between Video and VideoCall conditions, $t(27) = 2.52$, $p > .05$, $d_z = .477$, and between VideoCall and Real conditions, $t(27) = 1.15$, $p > .05$, $d_z = .217$ (Figure 4-3b). However, since we detected an outlier in the VideoCall condition, we repeated the analysis after removal of this outlier for all conditions. Results showed that there was a main effect of Condition, $F(2,52) = 9.113$, $p = .002$, $n_p^2 = .260$. Post-hoc pairwise comparisons showed that participants looked less to the Eyes region of the confederate in the Real compared to the Video condition, $t(26) = 3.45$, $p = .009$, $d_z = .664$, and in the VideoCall compared to the Video condition, $t(26) = 3.15$, $p = .011$, $d_z = .606$ (see blue asterisk in Figure 4-3b). There was no difference between VideoCall and Real conditions, $t(26) = .583$, $p > .05$, $d_z = .112$.

For eye gaze directed to the Mouth region, there was a main effect of Condition, $F(2,54) = 4.01$, $p = .024$, $n_p^2 = .129$: participants looked less to the Mouth region of the confederate in the VideoCall compared to the Video condition, $t(27) = 3.09$, $p = .013$, $d_z = .585$, but there was no difference between Video and Real conditions, $t(27) = 1.5$, $p > .05$, $d_z = .294$, and between VideoCall and Real conditions, $t(27) = 1.04$, $p > .05$, $d_z = .197$ (Figure 4-3b).

For facial motion, there was a main effect of Condition, $F(2,54) = 4.33$, $p = .018$, $n_p^2 = .138$: participants moved their face more in the Real compared to the Video condition, $t(27) = 2.91$, $p = .022$, $d_z = .551$, but there was no difference between Video and VideoCall conditions, $t(27) = 2.06$, $p > .05$, $d_z = .389$, and between VideoCall and Real conditions, $t(27) = 1.03$, $p > .05$, $d_z = .194$ (Figure 4-3c).

4.3.3.3. Time-course analyses

Using time-course analyses, we aimed to study more detailed dynamics of eye gaze and facial motion along the trial, which cannot be captured by aggregated analyses. For each measure (proportion gaze to Eyes, proportion gaze to Mouth, number of facial AUs), we computed the mean along the time-course, across trials in the same Condition. We distinguished between 5 different time-windows in the trial, and performed a 2-way repeated measures ANOVA with Condition (Video, VideoCall, Real) and Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) as within-subject factors. Only significant main effects and interactions are reported in the text; see Table 4-3 for descriptives (mean and SD), and section *4.7.3. Tables with full results from time-course analyses* (Table 4-9) for full results and post-hoc tests.

For eye gaze directed to the Eyes region of the confederate, there was a main effect of Condition, $F(2,54) = 6.82$, $p = .002$, $n_p^2 = .202$, and a main effect of Time-window, $F(4,108) = 21.9$, $p < .001$, $n_p^2 = .447$: participants generally looked more to the eyes of the confederate in the Video than in the Real condition (after removing the outlier, only more gaze in the Video than in the VideoCall condition), and during the Question phase than during Turn-taking and Answer phase. There was also an interaction effect between Condition and Time-window, $F(8,216) = 4.81$, $p = .002$, $n_p^2 = .151$. At the start of the Question phase participants looked less to the Eyes region in the VideoCall and Real conditions (compared to the Video), and a similar pattern was found at the end of the Question phase and at Turn-taking for the Real condition (but only for the VideoCall condition after removing the outlier). At the end of the Answer phase participants increased gaze directed to the eyes in the Video condition (compared to VideoCall and Real), as well as in the VideoCall condition compared to the Real condition (see Figure 4-4a).

Table 4-3. Descriptives for time-course analyses in Experiment 1

Condition	Time-window	Prop. gaze to Eye region[a]	Prop. gaze to Mouth region	Number facial AUs
Video	Start Question	*M* = .189 (.182) *SD* = .148 (.141)	*M* = .221 *SD* = .140	*M* = 3.39 *SD* = 1.13
	End Question	*M* = .160 (.152) *SD* = .150 (.150)	*M* = .258 *SD* = .177	*M* = 3.12 *SD* = 1.12
	Turn-taking	*M* = .075 (.072) *SD* = .121 (.121)	*M* = .151 *SD* = .126	*M* = 3.42 *SD* = 1.18
	Start Answer	*M* = .037 (.031) *SD* = .055 (.040)	*M* = .031 *SD* = .038	*M* = 5.78 *SD* = 1.27
	End Answer	*M* = .103 (.093) *SD* = .132 (.116)	*M* = .090 *SD* = .085	*M* = 5.13 *SD* = 1.38
VideoCall	Start Question	*M* = .095 (.085) *SD* = .110 (.074)	*M* = .128 *SD* = .085	*M* = 3.63 *SD* = 1.47
	End Question	*M* = .102 (.084) *SD* = .152 (.099)	*M* = .128 *SD* = .098	*M* = 3.24 *SD* = 1.47
	Turn-taking	*M* = .029 (.017) *SD* = .071 (.021)	*M* = .071 *SD* = .075	*M* = 4.10 *SD* = 1.54
	Start Answer	*M* = .039 (.024) *SD* = .108 (.077)	*M* = .022 *SD* = .039	*M* = 6.23 *SD* = 1.36
	End Answer	*M* = .053 (.041) *SD* = .099 (.063)	*M* = .080 *SD* = .069	*M* = 5.33 *SD* = 1.53
Real	Start Question	*M* = .054 (.053) *SD* = .060 (.060)	*M* = .114 *SD* = .087	*M* = 3.97 *SD* = 1.64
	End Question	*M* = .087 (.086) *SD* = .108 (.109)	*M* = .233 *SD* = .186	*M* = 3.46 *SD* = 1.60
	Turn-taking	*M* = .024 (.023) *SD* = .033 (.034)	*M* = .128 *SD* = .151	*M* = 4.01 *SD* = 1.62
	Start Answer	*M* = .021 (.021) *SD* = .050 (.050)	*M* = .043 *SD* = .091	*M* = 6.13 *SD* = 1.79
	End Answer	*M* = .023 (.019) *SD* = .054 (.051)	*M* = .042 *SD* = .064	*M* = 5.71 *SD* = 1.92

[a]Values after removal of the outlier are in brackets.

For eye gaze directed to the Mouth region of the confederate, there was a main effect of Condition, $F(2,54) = 4.17$, $p = .021$, $n_p^2 = .134$, and a main effect of Time-window, $F(4,108) = 44.2$, $p < .001$, $n_p^2 = .621$: participants generally looked more to the mouth of the confederate in the Video than in the VideoCall condition, and during the Question phase than during Turn-taking and Answer phase. There was also an interaction effect between Condition and Time-window, $F(8,216) = 3.52$, $p = .012$, $n_p^2 = .115$. At the start of the Question phase participants looked less to the Mouth region in the VideoCall and Real conditions (compared to the Video), and a similar pattern was found at the end of the Question phase and at Turn-taking for the VideoCall condition. At the end of the Answer phase participants increased gaze directed to the eyes in the Video condition (compared to VideoCall and Real) (see Figure 4-4b).

For facial motion, there was a main effect of Condition, $F(2,54) = 4.63$, $p = .014$, $n_p^2 = .146$, and a main effect of Time-window, $F(4,108) = 110.2$, $p < .001$, $n_p^2 = .803$: participants generally moved their face more in the Real than the Video condition, and during the Answer phase than the Question phase and Turn-taking. There was no interaction effect between Condition and Time-window, $F(8,216) = 2.60$, $p > .05$, $n_p^2 = .088$ (Figure 4-4c).

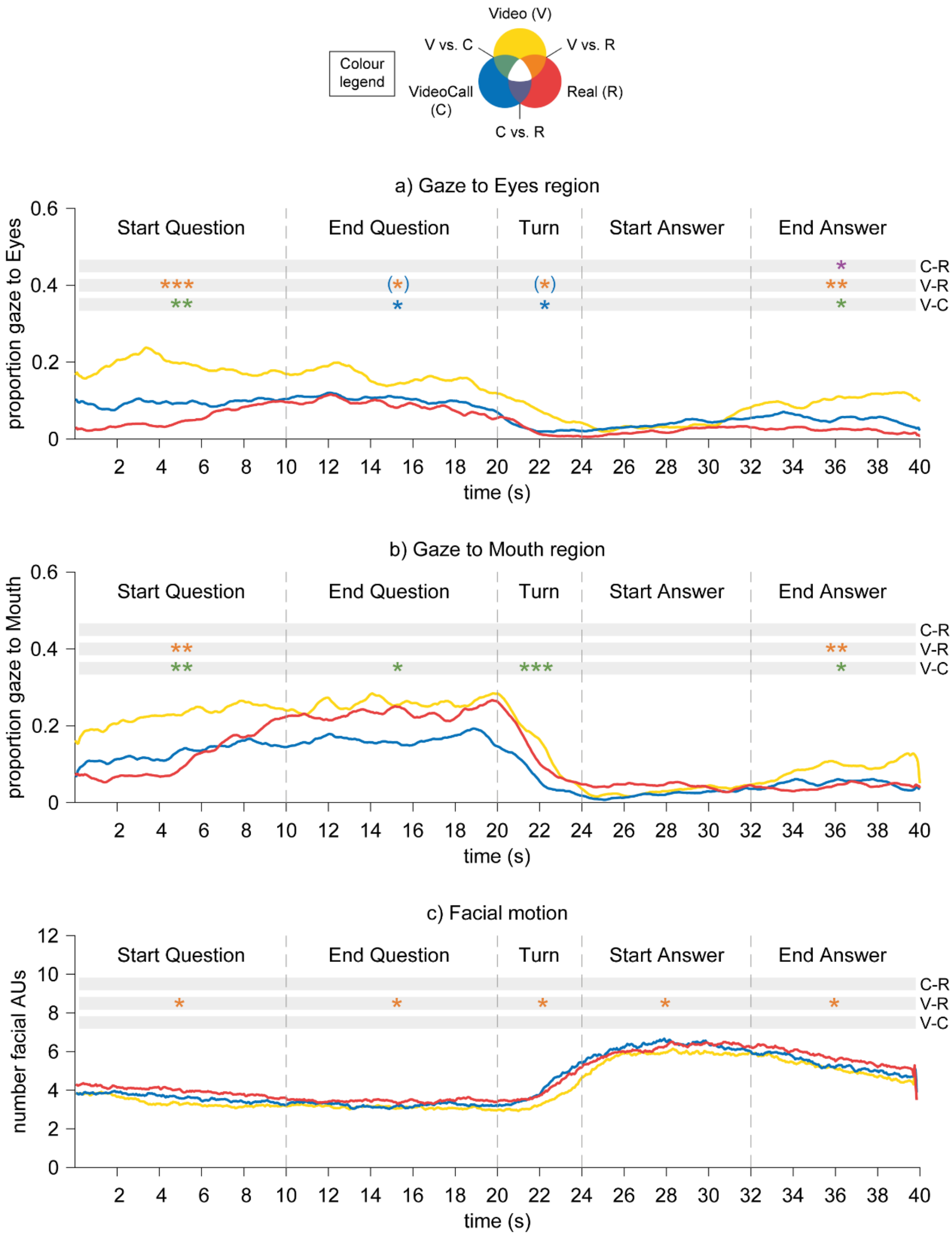

Figure 4-4. Results for time-course analyses in Experiment 1.
a) Time-course for proportion of eye gaze directed to Eyes region. b) Time-course for proportion of eye gaze directed to Mouth region. c) Time-course for number of facial AUs. Asterisks signify difference at $p < .05$ (*), $p < .01$ (**) and $p < .001$ (***). Blue asterisks signify difference between Video and VideoCall after removing the outlier, and blue brackets indicate null difference between Video and Real after removing the outlier.

4.3.4. Interim discussion

Experiment 1 aimed to investigate how gaze patterns and facial displays are modulated by the belief in being watched and the potential for true direct gaze in typical individuals. Importantly, post-test questionnaire ratings showed our manipulation across the three conditions was successful: participants perceived the confederate was most reciprocal in the Real condition, and least reciprocal in the Video condition. Note that participants perceived the confederate was more natural in the VideoCall than Video condition, although there were no differences with the Real condition: these inconsistent ratings could be because the task was a structured Q&A interaction, which already lacked the continuity of natural conversation.

Our results show that participants looked less to the eyes of the confederate in the Real and VideoCall conditions compared to the Video condition. Similarly, participants looked less to the mouth of the confederate in the VideoCall compared to the Video condition, although there were no differences between Real and Video conditions. This is in line with the findings in Chapter 2 and previous studies indicating that gaze patterns are modulated by the belief in being watched: participants gaze less to a live partner compared to a video-clip of the same partner, because in a live interaction eye gaze has a dual function of both perceiving and signalling information (Gobel et al., 2015; Laidlaw et al., 2011).

A core question is how participants use eye gaze in relation to other social signals (i.e. speech) during live communicative exchanges. This can give further insight into how we plan eye movements to maximise the information we gather from others and optimise the information we send to others. To study detailed dynamics of eye gaze, we looked at differences between conditions in 5 different time-windows along the trial time-course: start of the question, end of the question, turn-taking, start of the answer, and end of the answer. In line with previous studies (Hessels et al., 2019; Ho et al., 2015; Kendon, 1967), we found that participants generally looked more to the eyes and mouth of the confederate during the Question phases than during the Answer phases. However, we found that this pattern was also true for the Video condition, where participants were aware they were not in a live conversation, and so there was no need to regulate turn-taking. This opens up an interesting question for future research: do we look away from faces when speaking to signal we want to keep the turn, as suggested by the regulatory function of gaze (Kendon, 1967), or rather because looking at faces is cognitively demanding and might otherwise interfere with speaking (Beattie, 1981; Glenberg, Schroeder, & Robertson, 1998; Kendon, 1967; Markson & Paterson, 2009)? The fact that we find the same modulation across all three conditions indicates that the latter might be the case.

As expected, differences between the Real condition and the VideoCall or Video conditions happened either at the start of the interaction (start Question) or at the end of the interaction (end Answer). Based on previous studies, we predicted that participants would look more to the Real confederate at the start of the Question to signal interest in what she was saying (Argyle & Cook, 1976; Kendon, 1967), and at the end of the Answer to signal that they were ending the answer (Ho et al., 2015; Kendon, 1967) or to monitor facial displays of the confederate (Efran, 1968; Efran & Broughton, 1966; Kendon, 1967; Kleinke, 1986). However, at these time-windows participants looked *less* to the eyes and mouth of the confederate in the Real condition. This suggests that participants were averting gaze to reduce the intensity of the interaction or arousal associated with live eye contact with a stranger (Argyle & Dean, 1965; Kendon, 1967; Pönkänen et al., 2011). Note that we did not find any differences during Turn-taking. As we discuss below, this could be because triggers for turn-taking in the Real and VideoCall conditions (where the speech speed of the confederate slightly varied among questions and participants) were not as accurate as in the Video condition (which uses pre-recorded videos).

Comparison between the VideoCall and Video conditions showed that there was a similar pattern of results: participants looked less to the eyes and mouth of the confederate in the VideoCall condition, both at the start and end of the interaction. The similar patterns between Real and VideoCall conditions indicates that our manipulation of true direct gaze did not have strong effects on gaze planning. However, in the VideoCall condition participants also looked less to the confederate during the end of the Question phase and Turn-taking. Unfortunately, as mentioned earlier, our interpretation of these findings is constrained by the fact that triggers for turn-taking in the VideoCall condition were not as accurate as in the Video condition.

Finally, we also looked at patterns of facial motion. Results showed that participants moved their face more in the Real than in the Video condition (although there were no differences between VideoCall and Video conditions). This is in line with previous studies showing that participants make more facial displays when being watched, which suggests that we use facial displays as a social signal (Chovil, 1991b; Crivelli & Fridlund, 2018; Fridlund, 1991; J. K.

Hietanen, Kylliäinen, et al., 2018). When looking at the time-course of facial motion along the trial we found that, as expected, participants moved their face more during the Answer phase than during the Question phase. Although we hypothesised that participants would do this to help communicate their spoken answers in the Real and VideoCall conditions (Chovil, 1991a), we found that this pattern was also true for the Video condition. This could be because the face-tracking algorithm was also picking up facial motion related to moving the mouth for speech production. We discuss this limitation below.

There were two main limitations to Experiment 1. First, facial motion effects might be confounded with effects related to speech production, since moving the mouth to speak is likely to be detected as facial motion. Second, the triggers for turn-taking were not as accurate in the VideoCall and Real conditions as in the Video condition, since the speech speed of the confederate slightly varied among questions and participants. To address these limitations, in Experiment 2 we recorded the voice of participants and confederate with two lapel microphones. The participants' microphone allowed us to detect when participants were speaking and account for this in the facial motion analysis. The confederate's microphone was used as a trigger system, where the confederate was instructed to tap on the microphone at the end of each question: this allowed us to automatically detect a peak in the audio signal that accurately corresponded to the time of turn-taking.

Building on our findings from Experiment 1, in Experiment 2 we tested a matched sample of typical and autistic participants. Previous studies suggest that autistic individuals have difficulties in appropriately using eye gaze during social interactions, but evidence is mixed (Falck-Ytter & Von Hofsten, 2011).

Thus, in Experiment 2 we examined differences between typical and autistic patterns of eye gaze and facial displays in a communicative situation.

4.4. Experiment 2: typical and autistic participants

4.4.1. Hypotheses

Experiment 2 investigated eye gaze and facial motion patterns of typical and autistic participants while they completed a Q&A task in three social contexts: Video, VideoCall and Real. Based on our findings in Experiment 1, for the aggregated analysis of eye gaze we expected that typical participants would direct less gaze towards the confederate in the VideoCall and Real conditions compared to the Video condition. However, if autistic individuals do not plan gaze behaviour to send signals (Von dem Hagen & Bright, 2017 Experiment 1), we should not find differences between conditions for the autistic group. We also expected that the proportion of gaze directed to the confederate would be lower in the autistic compared to the typical group for all conditions (Von dem Hagen & Bright, 2017 Experiment 2).

Similar to Experiment 1, for the time-course analysis of eye gaze we looked at differences between conditions in 5 different time-windows along the trial time-course: start of question, end of question, turn-taking, start of answer, and end of answer. In line with previous studies (Freeth & Bugembe, 2018; Ho et al., 2015; Kendon, 1967; Vabalas & Freeth, 2016; Von dem Hagen & Bright, 2017 Experiment 2), we predicted that both typical and autistic participants would direct more gaze to the confederate during the question time-windows (i.e. when they were listening) than during the answer time-windows (i.e. when they were speaking). Building on our findings in Experiment 1 we also predicted that, if cognitive demands associated with perceiving faces modulate gaze planning while speaking, these effects would be true for all three conditions. If they were strictly related to regulation of turn-taking, they would only be true for the VideoCall and Real conditions.

When looking at differences between conditions along the trial time-course, we expected to replicate our findings in Experiment 1, that is, typical participants would gaze less to the confederate at the start and end of the VideoCall and Real interactions to reduce arousal (Argyle & Dean, 1965; Kendon, 1967; Pönkänen et al., 2011). Because in Experiment 2 we had more accurate triggers for turn-taking, we expected that this modulation would also be true for the turn-taking time-window. Moreover, if autistic participants do not plan eye movements to signal information, their gaze behaviour would show no differences between conditions along the trial time-course.

Regarding the amount of facial displays, for the typical group we expected to replicate our findings in Experiment 1: they would move their face more in the Real than in the Video condition (Chovil, 1991b; Fridlund, 1991; J. K. Hietanen, Kylliäinen, et al., 2018), and in the Answer phases compared to the Question phases (Chovil, 1991a). Note that, because we recorded speech of participants, we could now control for facial motion effects related to speech production. Finally, a recent meta-analysis found that autistic participants are less likely to spontaneously produce and mimic facial displays (Trevisan et al., 2018). Thus, we expected that autistic participants would show no differences in facial motion between conditions or time-windows, and that they would make less facial displays than the typical group.

4.4.2. Materials and Methods

4.4.2.1. Participants

A group of 26 typical adults and a group of 26 autistic adults participated in this study. Both groups were matched on age, gender, handedness and Intelligence Quotient (IQ; Wechsler Adult Intelligence Scale, WAIS-III UK, Wechsler, 1999b, 1999a), but differed on the Autism Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) (see Table 4-4). Note that the autistic group was high functioning, which means that their IQ is higher than 80: since both groups were matched, the typical group also had high IQ on average. All participants were recruited using an autism database at the author's institution. Recruitment of autistic participants was based on diagnosis from an independent clinician. Routine diagnostic procedures include the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) and the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Lecouteur, 1994), among others. Autistic participants included in the analyses were diagnosed as either Asperger's Syndrome (21) or Autism Spectrum Disorder (5). They were also tested on module 4 of the ADOS by a trained researcher: 10 participants met the ADOS classification for Autism; 10 for Autism Spectrum; 6 did not meet the classification for any of them, but all 6 participants had a clear diagnosis from an independent clinician.

The confederate was a professional actor (playing age: 23-29) hired for the full duration of the study, to ensure a consistent performance between trials and participants. Participants were told the confederate was a student helping with the study. Importantly, he was unaware of the aims and hypotheses of the study. All participants and the confederate provided written informed consent and were compensated for their participation in the study. The study was granted ethical approval by the local Research Ethics Committee, and was in accordance with the Declaration of Helsinki.

Table 4-4. Comparison of the typical and autistic groups included in Experiment 2

	Typical (N=26)		Autistic (N=26)		*t*-test
	Mean (*SD*)	Range	Mean (*SD*)	Range	*p*-value
Age	32.8 (10.9)	20-62	34.9 (7.71)	22-54	0.42
Gender	6 F, 20 M	-	5 F, 21 M	-	-
Handedness	2 L, 24 R	-	3 L, 23 R	-	-
IQ: full-scale	117.3 (12.0)	99-143	114.2 (11.5)	86-136	0.25
IQ: verbal	118.7 (11.7)	96-139	115.5 (10.2)	91-135	0.26
IQ: performance	112.2 (12.6)	91-140	109.9 (14.4)	80-136	0.40
AQ	13.5 (6.15)	4-28	33.1 (8.92)	10-48	<.001 ***
ADOS: total	-	-	8.64 (3.45)	2-17	-
ADOS: communication	-	-	3.32 (2.39)	0-9	-
ADOS: social interaction	-	-	5.72 (2.44)	1-11	-

F=female; M=male; L=left; R=right. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

4.4.2.2. Task

Participants completed the same task as in Experiment 1 (see Figure 4-1b). However, the 3 sets of questions comprised 10 items (instead of 12). See section *4.7.4. List of questions in Experiment 2* for the full list of questions used in Experiment 2.

4.4.2.3. Experimental conditions and stimuli

Participants completed the task under the same three conditions as in Experiment 1. All videos for the Video condition were recorded again with the new confederate, and the behaviour of the confederate during the task was the same one as in Experiment 2. Since in Experiment 1 there was no effect of order of conditions, in this experiment we only used 2 counterbalancing conditions: C-V-R and R-V-C. In these counterbalancing conditions, the Video condition is always in the second position and the order of VideoCall and Real conditions is swapped between first and third positions. This gives participants a “break” between the two live interactions, thus making the task less overwhelming for autistic participants. The overall duration of the task was around 45 minutes.

4.4.2.4. Post-test questionnaire and debriefing

After completing the task under the three conditions, all participants completed the same post-test questionnaire as in Experiment 1 (see section *4.7.2. Post-test questionnaire* for the full post-test questionnaire), and were debriefed about the real purpose of the study.

4.4.2.5. Experimental set-up

The experimental set-up was the same one as in Experiment 1 (see Figure 4-1a), except for two new additions. First, we wanted to record speech from participants and confederate (to control for facial motion effects due to speech production). Thus, a lapel microphone was attached to the participants’ shirt (close to their mouth), and another lapel microphone was placed on the table, near the confederate. These two lapel microphones recorded the sound in the environment in stereo. Second, we wanted to have more accurate triggers for turn-taking (i.e. end of question), since the speech speed of the confederate slightly varied among questions in the VideoCall and Real conditions. For this, we designed an audio trigger system using the lapel microphone located on the table near the confederate: the confederate was instructed to tap on the microphone at the end of each Question phase, thus generating a peak in the audio signal at the time of turn-taking. We then processed the audio signal and automatically detected the time-point where the audio signal peaked (i.e. time of turn-taking).

4.4.2.6. Eye gaze, facial motion and speech data: acquisition and processing

The acquisition and processing of eye gaze and facial motion data was the same as in Experiment 1. In Experiment 2 we also recorded the speech of participants and confederate with two lapel microphones. This audio signal was further processed with a homemade program that detected who (participant or confederate) was speaking for each time-point in a trial (see Figure 4-2), and we computed the proportion of participant's speech across trials for each time-point.

4.4.2.7. Statistical analyses

We first checked whether our experimental manipulation modulated how participants perceived the interaction with the confederate, and whether there were any differences between the typical and autistic group. For each trait in the post-test questionnaire (naturalness and reciprocity) we run a 2-way repeated measures ANOVA with mean rating as dependent variable, Condition (Video, VideoCall, Real) as within-subject factor and Group (Typical, Autism) as between-subject factor. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed.

Similar to Experiment 1, we performed aggregated and time-course analyses of eye gaze, facial motion, and speech data (see Figure 4-2). For the aggregated analysis of eye gaze, we performed a 2-way repeated measures ANOVA with mean proportion of looking time to each ROI (Eyes and Mouth region) as dependent variable, Condition (Video, VideoCall, Real) as within-subject factor, and Group (Typical, Autism) as between-subject factor. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. For the aggregated analysis of facial motion, we fitted a multilevel ANOVA with mean number of facial AUs as dependent variable, Participant as random factor (random intercept), Speech as random factor (random slope), and Condition (Video, VideoCall, Real), Group (Typical, Autism) and Speech as fixed factors. This allowed us to control for facial motion effects related to speech production. This analysis included 1560 data-points (2 groups, 26 participants/group, 3 conditions, 10 trials/condition). Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. For the aggregated analysis of speech, we computed the mean proportion of speech for each Condition, across all time-points and trials. We then performed a 2-way repeated measures ANOVA with mean proportion of speech as dependent variable, Condition (Video, VideoCall, Real) as within-subject factor, and Group (Typical, Autism) as between-subject factor. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed.

To investigate how eye gaze, facial motion and speech patterns vary throughout the time-course of the trial, we distinguished between 5 different time-windows in the trial: start of the question/interaction (0-10 s), end of the question (10-22 s), turn-taking (22-24 s), start of the answer (24-32 s), and end of the answer/interaction (32-40 s). Note that the time-window for turn-taking was 2 seconds long (instead of 4 seconds in Experiment 1). We were able to use a more accurate time-window for turn-taking (starting at 22 s) because the time-course for each trial was locked to the end of the Question phase according to the time of turn-taking detected by the audio trigger system. Since 22 s was the time the question ended, we allowed 2 s after this time for turn-taking (i.e. from 22 to 24 s).

For each measure (proportion gaze to Eyes region, proportion gaze to Mouth region, number facial AUs and proportion of speech) we obtained one time-course dataset (along the trial duration) for each participant and Condition. For eye gaze and speech data, the time-courses were smoothed using a moving average filter of 1 second, and we computed the means for each time-window. A 3-way repeated measures ANOVA with Condition (Video, VideoCall, Real) and Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) as within-subject factors, and Group (Typical, Autism) as between-subject factor was performed for each measure. Where sphericity could not be assumed, corrected *p*-values using the Greenhouse-Geisser estimate were used. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. For facial motion data, we also computed the means for each time-window. To control for facial motion effects related to speech production, we then fitted a multilevel ANOVA with mean number of facial AUs as dependent variable, Participant as random factor (random intercept), Speech as random factor (random slope), and Condition (Video, VideoCall, Real), Group (Typical, Autism), Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) and Speech as fixed factors. This analysis included 7800 data-points (2 groups, 26 participants/group, 3 conditions, 10 trials/condition, 5 time-windows/trial). Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. Note that, although we used the time-window data for statistical analyses, the full time-course data was used for plots.

4.4.3. Results

4.4.3.1. Manipulation check: post-test questionnaire ratings

In the post-test questionnaire, both groups rated the confederate in each condition on two traits: naturalness and reciprocity. A 2-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor and Group (Typical, Autism) as between-subject factor was performed for each of the traits. See Table 4-5 for descriptives (mean and SD) on post-test questionnaire ratings. For both traits we found a main effect of Group (naturalness: $F(1,50) = 4.69$, $p = .035$, $n_p^2 = .086$; reciprocity: $F(1,50) = 4.03$, $p = .05$, $n_p^2 = .075$): the Autism group perceived the confederate as more natural and reciprocal than the Typical Group (Figure 4-5). For naturalness there was a main effect of Condition, $F(2,100) = 3.68$, $p = .04$, $n_p^2 = .069$, but there were no effects in the post-hoc pairwise comparisons (Video vs. VideoCall: $t(51) = 2.26$, $p > .05$, $d_z = .313$; Video vs. Real: $t(51) = 2.11$, $p > .05$, $d_z = .293$; VideoCall vs. Real: $t(51) = .814$, $p > .05$, $d_z = .113$) (Figure 4-5a). For reciprocity, there was a main effect of Condition, $F(2,100) = 37.8$, $p < .001$, $n_p^2 = .431$: the confederate was perceived as more reciprocal in the VideoCall compared to the Video condition, $t(51) = 5.64$, $p < .001$, $d_z = .782$; more reciprocal in the Real compared to the Video condition, $t(51) = 6.94$, $p < .001$, $d_z = .962$; and more reciprocal in the Real compared to the VideoCall condition, $t(51) = 3.93$, $p = .001$, $d_z = .544$ (Figure 4-5b). There was no interaction effect between Condition and Group for any of the traits (naturalness: $F(2,100) = 1.36$, $p > .05$, $\eta_p^2 = .027$; reciprocity: $F(2,100) = 1.06$, $p > .05$, $\eta_p^2 = .021$).

Table 4-5. Descriptives for post-test questionnaire ratings in Experiment 2

Condition	Natural		Reciprocal	
	Typical	Autism	Typical	Autism
Video	*M* = 3.96 *SD* = 1.95	*M* = 4.58 *SD* = 1.88	*M* = 2.81 *SD* = 2.06	*M* = 3.46 *SD* = 1.96
VideoCall	*M* = 4.11 *SD* = 1.88	*M* = 5.27 *SD* = 1.61	*M* = 3.85 *SD* = 2.01	*M* = 5.15 *SD* = 1.80
Real	*M* = 4.19 *SD* = 2.19	*M* = 5.50 *SD* = 2.06	*M* = 4.61 *SD* = 2.00	*M* = 5.50 *SD* = 1.84

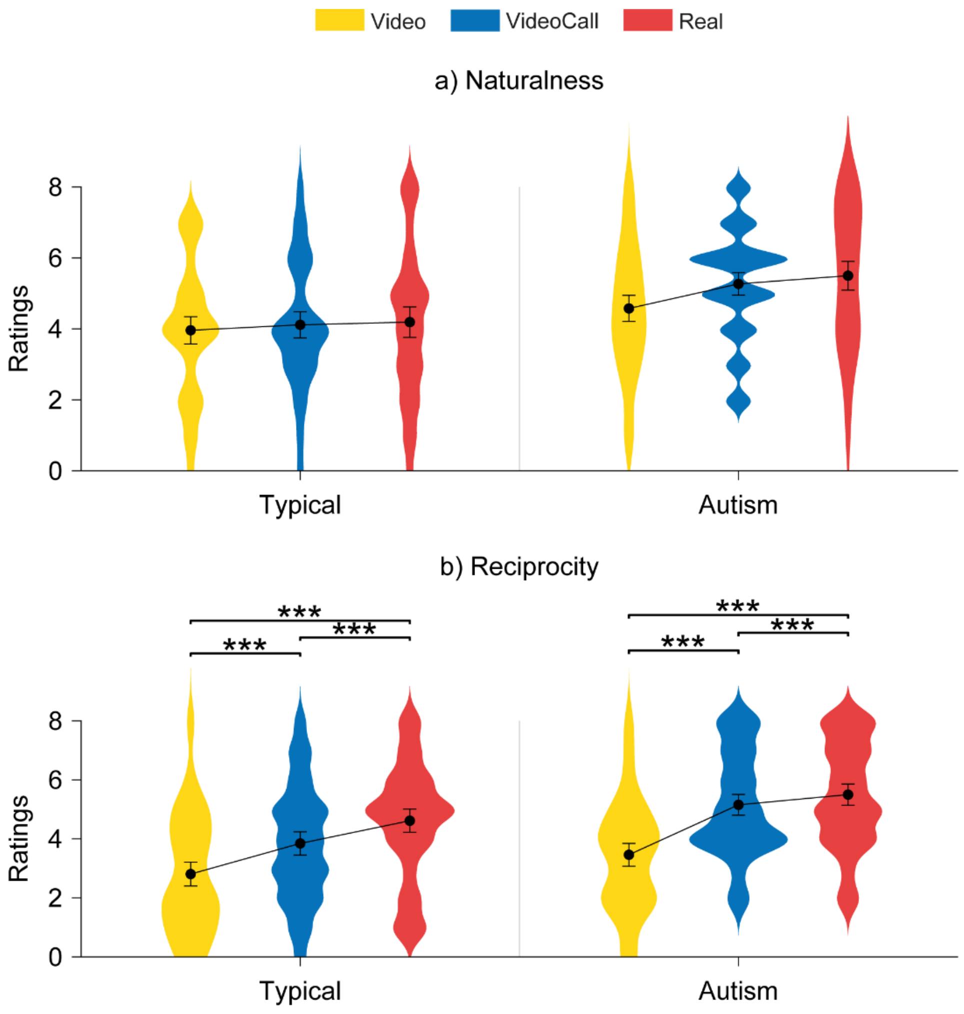

Figure 4-5. Results for post-test questionnaire ratings in Experiment 2.
a) Naturalness. b) Reciprocity. Mean (filled circle), SE (error bars), and frequency of values (width of distribution). Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

4.4.3.2. Aggregated analyses

To investigate general patterns of eye gaze, facial motion and speech across the three conditions, we aggregated the data across all time-points and trials for each Condition. See Table 4-6 for descriptives (mean and SD) on these measures.

For eye gaze measures (proportion of looking time to Eyes and Mouth region), we fitted a 2-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor and Group (Typical, Autism) as between-subject factor. For eye gaze directed to the Eyes region, there was a main effect of Condition, $F(2,100) = 9.98$, $p < .001$, $n_p^2 = .166$. Post-hoc pairwise comparisons showed that participants looked more to the Eyes region of the confederate in the Video condition compared to the VideoCall condition, $t(51) = 3.76$, $p = .001$, $d_z = .522$, and in the Video condition compared to the Real condition, $t(51) = 3.35$, $p = .006$, $d_z = .465$, but there were no differences between VideoCall and Real conditions, $t(51) = .583$, $p > .05$, $d_z = .081$ (Figure 4-6a). There was no main effect of Group, $F(1,50) = .083$, $p > .05$, $n_p^2 = .002$, nor interaction effect between Condition and Group $F(2,100) = 1.86$, $p > .05$, $n_p^2 = .036$.

For eye gaze directed to the Mouth region, there was a main effect of Condition, $F(2,100) = 3.81$, $p = .025$, $n_p^2 = .071$: participants tended to look less to the Mouth region of the confederate in the VideoCall compared to the Video condition, $t(51) = 2.41$, $p = .052$, $d_z = .334$, but there were no differences between Video and Real conditions, $t(51) = 2.13$, $p > .05$, $d_z = .295$, and between VideoCall and Real conditions, $t(51) = .600$, $p > .05$, $d_z = .083$ (Figure 4-6b). There was no main effect of Group, $F(1,50) = 2.42$, $p > .05$, $n_p^2 = .046$, nor interaction effect between Condition and Group, $F(2,100) = .057$, $p > .05$, $\eta_p^2 = .001$.

Table 4-6. Descriptives for aggregated analyses in Experiment 1

Condition	Group	Prop. looking time to Eyes region	Prop. looking time to Mouth region	Number facial AUs	Proportion of speech
Video	Typical	*M* = .127 *SD* = .139	*M* = .131 *SD* = .121	*M* = 4.34 *SD* = 1.37	*M* = .118 *SD* = .043
	Autism	*M* = .145 *SD* = .126	*M* = .101 *SD* = .100	*M* = 3.86 *SD* = .980	*M* = .120 *SD* = .050
VideoCall	Typical	*M* = .086 *SD* = .103	*M* = .090 *SD* = .086	*M* = 4.96 *SD* = 1.51	*M* = .118 *SD* = .046
	Autism	*M* = .059 *SD* = .066	*M* = .061 *SD* = .046	*M* = 4.29 *SD* = 1.22	*M* = .131 *SD* = .051
Real	Typical	*M* = .064 *SD* = .069	*M* = .095 *SD* = .093	*M* = 4.81 *SD* = 1.59	*M* = .117 *SD* = .051
	Autism	*M* = .094 *SD* = .113	*M* = .074 *SD* = .071	*M* = 4.27 *SD* = 1.35	*M* = .120 *SD* = .049

For facial motion, we fitted a multilevel ANOVA with number of facial AUs as dependent variable, Participant as random factor (random intercept), Speech as random factor (random slope), and Condition (Video, VideoCall, Real), Group (Typical, Autism), Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) and Speech as fixed factors. This allowed us to control for facial motion effects related to speech production. There was a main effect of Condition, $F(2,1512.0) = 12.54$, $p < .001$: participants moved their face more in the Real compared to the Video condition, $t(1516.2) = 3.44$, $p = .001$, $d_z = .039$, but there were no differences between VideoCall and Video condition, $t(1513.8) = 1.60$, $p > .05$, $d_z = .018$, or between VideoCall and Real condition, $t(1506.2) = 1.84$, $p > .05$, $d_z = .021$ (Figure 4-7a). There was no main effect of Group, $F(1,62.7) = 2.51$, $p > .05$, no main effect of Speech, $F(1,57.1) = 2.97$, $p > .05$, and no interaction effects between Condition and Group, $F(2,1512.0) = .468$, $p > .05$, between Condition and Speech, $F(2,1510.8) = 1.64$, $p > .05$, between Group and Speech, $F(1,57.1) = .104$, $p > .05$, and Condition, Group and Speech, $F(2,1510.8) = .762$, $p > .05$.

For the proportion of speech, we fitted a 2-way repeated measures ANOVA with Condition (Video, VideoCall, Real) as within-subject factor and Group (Typical, Autism) as between-subject factor. There was no main effect of Condition, $F(2,100) = 1.18$, $p > .05$, $n_p^2 = .023$, no main effect of Group, $F(1,50) = .206$, $p > .05$, $n_p^2 = .004$, and no interaction effect between Condition and Group, $F(2,100) = 1.04$, $p > .05$, $n_p^2 = .020$ (Figure 4-7b).

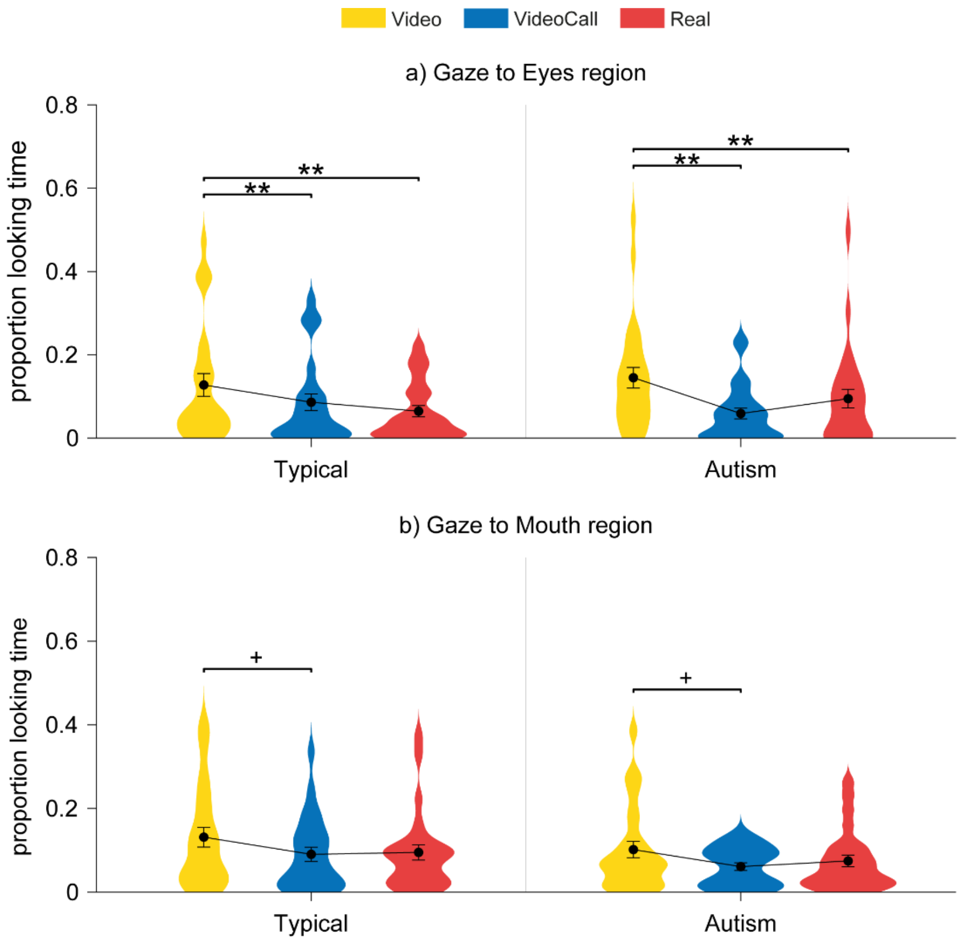

Figure 4-6. Results for aggregated analyses of eye gaze in Experiment 2. a) Proportion looking time to Eye region for each Condition and Group. b) Proportion looking time to Mouth region for each Condition and Group. Mean (filled circle), SE (error bars), and frequency of values (width of distribution). Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

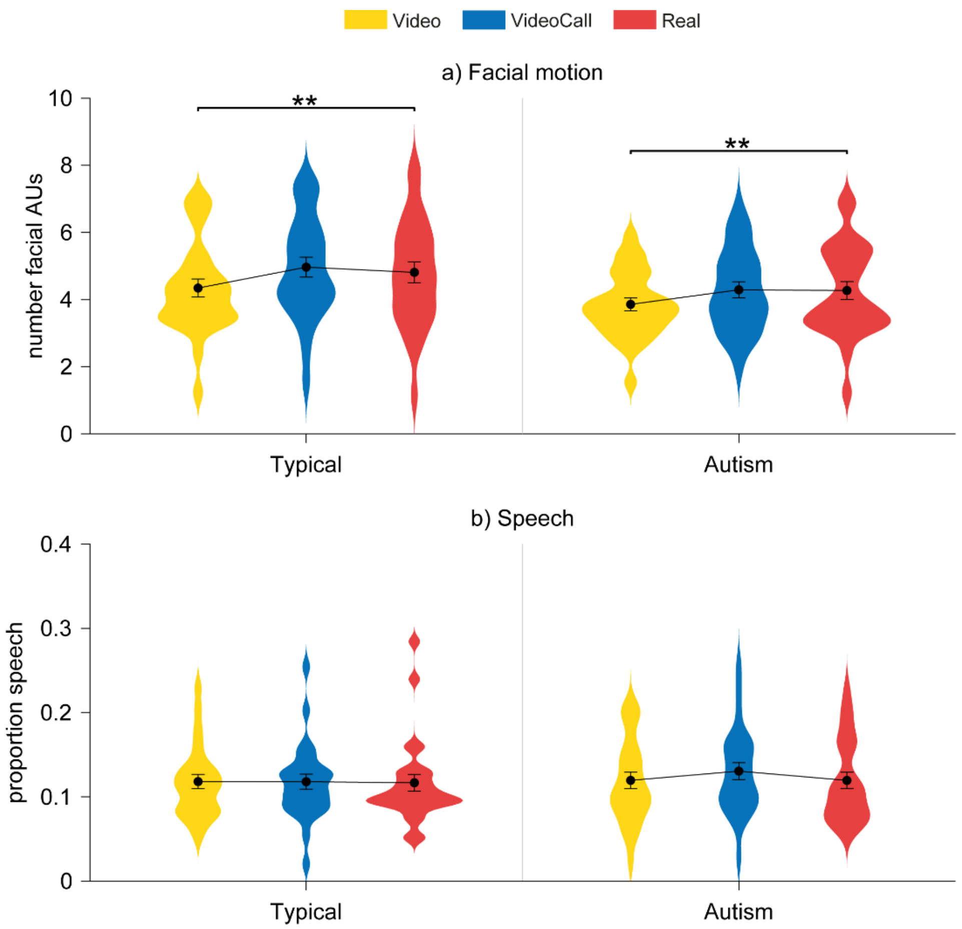

Figure 4-7. Results aggregated analyses facial motion and speech in Experiment 2. a) Number of facial AUs for each Condition and Group. b) Proportion of speech for each Condition and Group. Mean (filled circle), SE (error bars), and frequency of values (width of distribution). Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

4.4.3.3. Time-course analyses

As we did in Experiment 1, we used time-course analysis to study more detailed dynamics of eye gaze, facial motion and speech along 5 different time-windows in the trial. For eye gaze and speech measures (proportion gaze to Eyes, proportion gaze to Mouth and proportion of speech), we performed a 3-way repeated measures ANOVA with Condition (Video, VideoCall, Real) and Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) as within-subject factors, and Group (Typical, Autism) as between-subject factor. For facial motion (number of facial AUs), we fitted a multilevel ANOVA with Participant as random factor (random intercept), Speech as random factor (random slope), and Condition (Video, VideoCall, Real), Group (Typical, Autism), Time-window (Start Question, End Question, Turn-taking, Start Answer and End Answer) and Speech as fixed factors. Only significant main effects and interactions are reported in the text. See Table 4-7 for descriptives (mean and SD) of the Typical group, and Table 4-8 for descriptives (mean and SD) of the Autism group. See section *4.7.3. Tables with full results from time-course analyses* for full results and post-hoc tests for eye gaze and speech analysis (Table 4-10), and for facial motion analysis (Table 4-11).

For eye gaze directed to the Eyes region of the confederate, there was a main effect of Condition, $F(2,100) = 10.4$, $p < .001$, $n_p^2 = .172$, and a main effect of Time-window, $F(4,200) = 39.7$, $p < .001$, $n_p^2 = .443$: participants generally looked more to the eyes of the confederate in the Video than in the VideoCall and Real conditions, and during the Question phase than during Turn-taking and Answer phase. There was an interaction effect between Condition and Time-window, $F(8,400) = 5.55$, $p < .001$, $n_p^2 = .100$, and an interaction between Condition, Time-window and Group, $F(8,400) = 2.81$, $p = .028$, $n_p^2 = .053$. For the Typical group, at the start of the Question phase participants looked less to the Eyes region in the VideoCall and Real conditions (compared to the Video), and looked less at the end of the Answer phase in the VideoCall condition (see Figure 4-8a). For the Autism group, at the start of the Question phase participants looked less to the Eyes region in the VideoCall and Real conditions (compared to the Video), and looked less at Turn-taking (VideoCall and Real) and at the end of the Answer phase (VideoCall); at the end of the Question phase, autistic participants also looked more to the eyes in the Video and Real conditions than in the VideoCall condition (see Figure 4-8b). Moreover, between-group differences in the Real condition revealed that, at the start of the Question phase, the Typical group looked less to the Eyes region than the Autism group (see Figure 4-8c). No other main or interaction effects were significant.

Table 4-7. Descriptives for time-course analyses of Typical group in Experiment 2

Condition	Time-window	Prop. gaze to Eye region	Prop. gaze to Mouth region	Number facial AUs	Proportion speech
Video	Start Question	*M* = .145 *SD* = .142	*M* = .117 *SD* = .134	*M* = 3.39 *SD* = .990	*M* = .000 *SD* = .000
	End Question	*M* = .190 *SD* = .216	*M* = .208 *SD* = .203	*M* = 3.02 *SD* = .860	*M* = .000 *SD* = .000
	Turn-taking	*M* = .141 *SD* = .195	*M* = .228 *SD* = .237	*M* = 3.12 *SD* = .942	*M* = .067 *SD* = .116
	Start Answer	*M* = .045 *SD* = .066	*M* = .067 *SD* = .088	*M* = 4.67 *SD* = 1.37	*M* = .267 *SD* = .105
	End Answer	*M* = .077 *SD* = .108	*M* = .052 *SD* = .066	*M* = 4.96 *SD* = 1.62	*M* = .341 *SD* = .168
VideoCall	Start Question	*M* = .081 *SD* = .128	*M* = .084 *SD* = .094	*M* = 3.80 *SD* = 1.19	*M* = .000 *SD* = .000
	End Question	*M* = .145 *SD* = .178	*M* = .153 *SD* = .150	*M* = 3.59 *SD* = 1.12	*M* = .000 *SD* = .000
	Turn-taking	*M* = .105 *SD* = .142	*M* = .112 *SD* = .150	*M* = 3.73 *SD* = 1.29	*M* = .016 *SD* = .022
	Start Answer	*M* = .031 *SD* = .064	*M* = .042 *SD* = .088	*M* = 5.23 *SD* = 1.61	*M* = .340 *SD* = .113
	End Answer	*M* = .045 *SD* = .065	*M* = .036 *SD* = .033	*M* = 5.08 *SD* = 1.64	*M* = .377 *SD* = .174
Real	Start Question	*M* = .019 *SD* = .039	*M* = .041 *SD* = .065	*M* = 3.73 *SD* = 1.46	*M* = .000 *SD* = .000
	End Question	*M* = .125 *SD* = .132	*M* = .199 *SD* = .225	*M* = 3.53 *SD* = 1.35	*M* = .002 *SD* = .004
	Turn-taking	*M* = .077 *SD* = .135	*M* = .131 *SD* = .161	*M* = 3.98 *SD* = 1.42	*M* = .039 *SD* = .071
	Start Answer	*M* = .039 *SD* = .110	*M* = .029 *SD* = .037	*M* = 5.07 *SD* = 1.55	*M* = .287 *SD* = .119
	End Answer	*M* = .041 *SD* = .068	*M* = .053 *SD* = .078	*M* = 5.14 *SD* = 1.82	*M* = .328 *SD* = .145

Table 4-8. Descriptives for time-course analyses of Autism group in Experiment 2

Condition	Time-window	Prop. gaze to Eye region	Prop. gaze to Mouth region	Number facial AUs	Proportion speech
Video	Start Question	*M* = .138 *SD* = .112	*M* = .107 *SD* = .109	*M* = 3.77 *SD* = .1.40	*M* = .000 *SD* = .000
	End Question	*M* = .223 *SD* = .197	*M* = .159 *SD* = .176	*M* = 3.41 *SD* = 1.44	*M* = .001 *SD* = .003
	Turn-taking	*M* = .222 *SD* = .209	*M* = .160 *SD* = .177	*M* = 3.62 *SD* = 1.61	*M* = .078 *SD* = .122
	Start Answer	*M* = .066 *SD* = .086	*M* = .044 *SD* = .055	*M* = 5.29 *SD* = 1.62	*M* = .304 *SD* = .128
	End Answer	*M* = .077 *SD* = .090	*M* = .040 *SD* = .045	*M* = 5.56 *SD* = 1.56	*M* = .361 *SD* = .133
VideoCall	Start Question	*M* = .064 *SD* = .066	*M* = .066 *SD* = .059	*M* = 4.39 *SD* = 1.63	*M* = .000 *SD* = .000
	End Question	*M* = .087 *SD* = .095	*M* = .096 *SD* = .085	*M* = 4.08 *SD* = 1.66	*M* = .000 *SD* = .000
	Turn-taking	*M* = .065 *SD* = .079	*M* = .076 *SD* = .094	*M* = 4.66 *SD* = 1.63	*M* = .007 *SD* = .013
	Start Answer	*M* = .030 *SD* = .065	*M* = .027 *SD* = .036	*M* = 5.88 *SD* = 1.62	*M* = .367 *SD* = .161
	End Answer	*M* = .034 *SD* = .068	*M* = .030 *SD* = .053	*M* = 6.04 *SD* = 1.59	*M* = .334 *SD* = .148
Real	Start Question	*M* = .054 *SD* = .061	*M* = .035 *SD* = .037	*M* = 4.30 *SD* = 1.72	*M* = .000 *SD* = .000
	End Question	*M* = .185 *SD* = .193	*M* = .150 *SD* = .157	*M* = 3.75 *SD* = 1.67	*M* = .001 *SD* = .002
	Turn-taking	*M* = .138 *SD* = .0195	*M* = .133 *SD* = .164	*M* = 4.63 *SD* = 1.76	*M* = .043 *SD* = .060
	Start Answer	*M* = .037 *SD* = .082	*M* = .027 *SD* = .036	*M* = 5.76 *SD* = 1.86	*M* = .353 *SD* = .145
	End Answer	*M* = .048 *SD* = .092	*M* = .033 *SD* = .041	*M* = 5.91 *SD* = 1.85	*M* = .310 *SD* = .156

For eye gaze directed to the Mouth region of the confederate, there was a main effect of Condition, $F(2,100) = 4.83$, $p = .01$, $n_p^2 = .088$, and a main effect of Time-window, $F(4,200) = 38.7$, $p < .001$, $n_p^2 = .437$: participants generally looked more to the mouth of the confederate in the Video than in the VideoCall condition, and during the Question phase than during Turn-taking and Answer phase. There was an interaction effect between Condition and Time-window, *F*(8,400) = 4.86, *p* = .002, n_p^2 = .089. For both groups, at the start of the Question phase participants looked less to the Mouth region in the Real condition (compared to VideoCall and Video), and looked less at Turn-taking and start of Answer phase in the VideoCall and Real conditions (compared to Video); at the end of the Question phase, participants also looked more to the mouth in the Video condition than in the VideoCall condition (see Figure 4-9a and 4-9b). No other main or interaction effects were significant .

For facial motion, there was a main effect of Condition, *F*(2,7657.5) = 59.0, *p* < .001, and a main effect of Time-window, *F*(4,7669.2) = 76.0, *p* < .001: participants generally moved their face more in the Real condition than in the Video condition, and during the Answer phase than during the Question phase and Turn-taking. There was also an interaction effect between Condition and Time-window, *F*(8,7653.5) = 1.99, *p* = .043. For both groups, participants moved their face more in the Real and VideoCall conditions than in the Video condition, throughout all phases of the trial (see Figure 4-10a and 4-10b). No other main or interaction effects were significant.

For proportion of speech, there was no main effect of Condition, *F*(2,100) = 1.02, *p* > .05, n_p^2 = .020, but a main effect of Time-window, *F*(4,200) = 250.2, *p* < .001, n_p^2 = .833: participants generally produced more speech during the Answer phase than during the Question phase and Turn-taking. There was an interaction effect between Condition and Time-window, *F*(8,400) = 9.99, *p* < .001, n_p^2 = .166. During Turn-taking, participants in both groups produced more speech in the Video and Real conditions than in the VideoCall condition. At the start of the Answer, participants produced more speech in the VideoCall and Real conditions than in the Video condition. At the end of the Answer, participants produced more speech in the Video and VideoCall conditions than in the Real condition (see Figure 4-11a and 4-11b). No other main or interaction effects were significant.

4.5. Discussion

This chapter aimed to investigate how typical and autistic gaze patterns are modulated by the belief in being watched and the potential for true direct gaze. Across two studies we tested a sample of typical participants (Experiment 1: pilot), and a sample of matched typical and autistic participants (Experiment 2) while they engaged in a spoken Q&A task with a trained confederate. Contrary to what we expected, both typical and autistic participants showed similar modulation of eye gaze and facial displays: they looked less to the confederate and produced more facial displays when they were being watched (VideoCall and Real conditions) and when they were speaking (Answer phases). However, we found that at the start of the Real interaction, autistic participants gazed more to the confederate's eyes than typical participants. These findings challenge previous studies reporting atypical gaze behaviour in autism.

4.5.1. Social signalling in typical individuals

Post-test questionnaire ratings showed that the manipulation across the three conditions was also successful for Experiment 2: participants perceived the confederate was most reciprocal in the Real condition, and least reciprocal in the Video condition. Moreover, there were no differences in how natural the confederate was perceived in each condition, probably because the task itself (structured Q&A task) was missing the continuity of natural conversations.

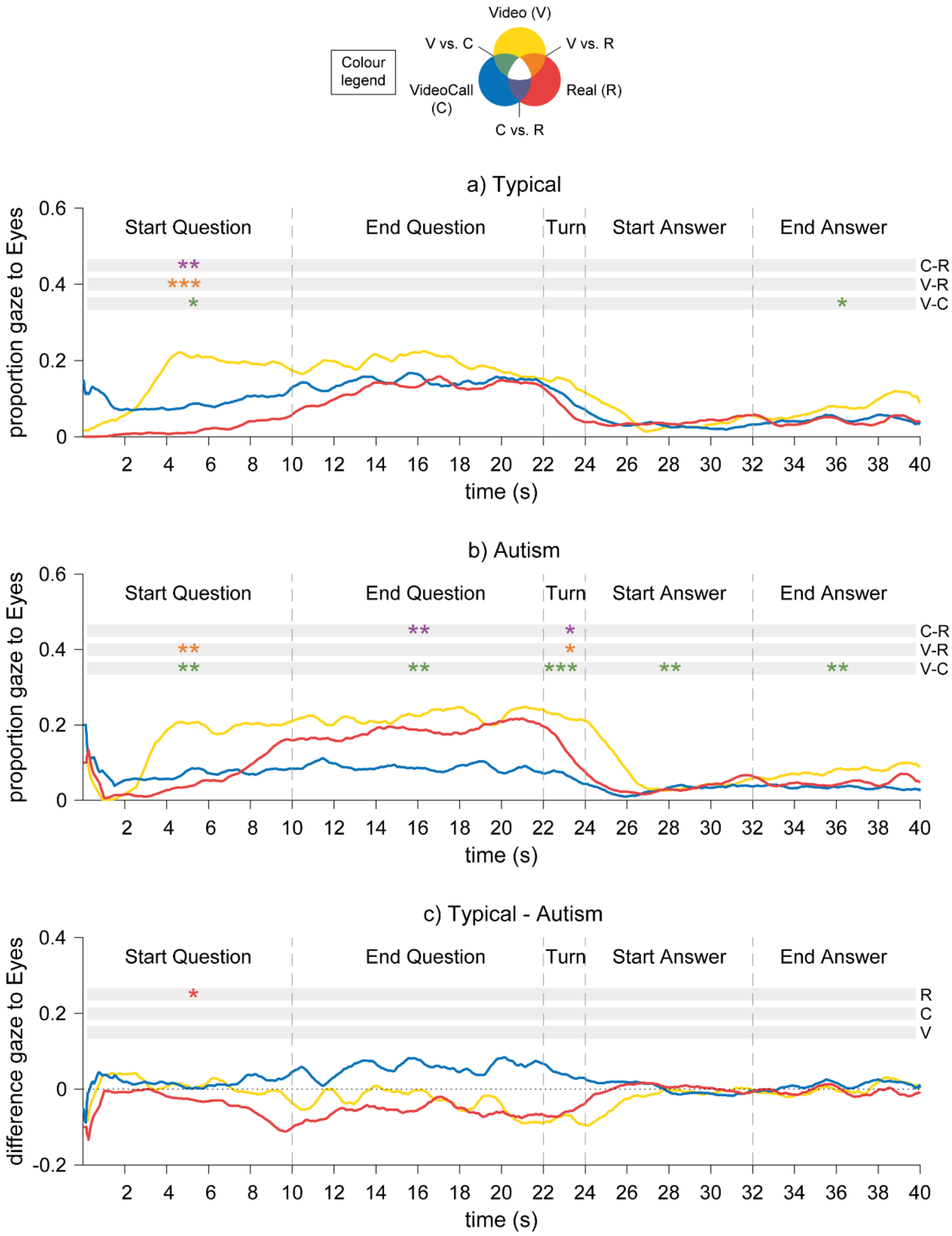

Figure 4-8. Results for time-course analyses of eye gaze directed to Eyes region in Experiment 2.
a) Typical group. b) Autism group. c) Difference between Typical and Autism groups: positive values indicate Typical > Autism, and negative values indicate Autism > Typical. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

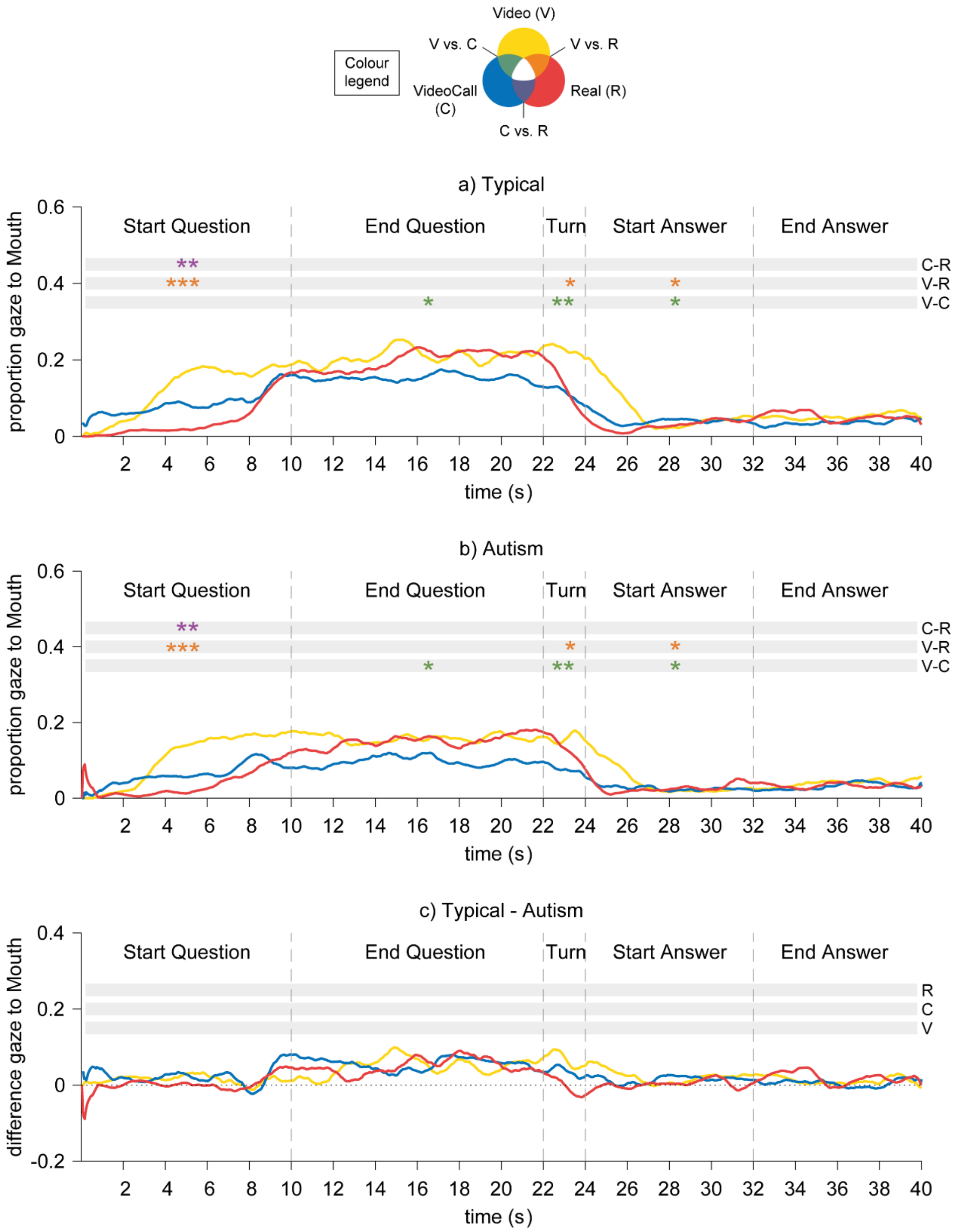

Figure 4-9. Results for time-course analyses of eye gaze directed to Mouth region in Experiment 2.
a) Typical group. b) Autism group. c) Difference between Typical and Autism groups: positive values indicate Typical > Autism, and negative values indicate Autism > Typical. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

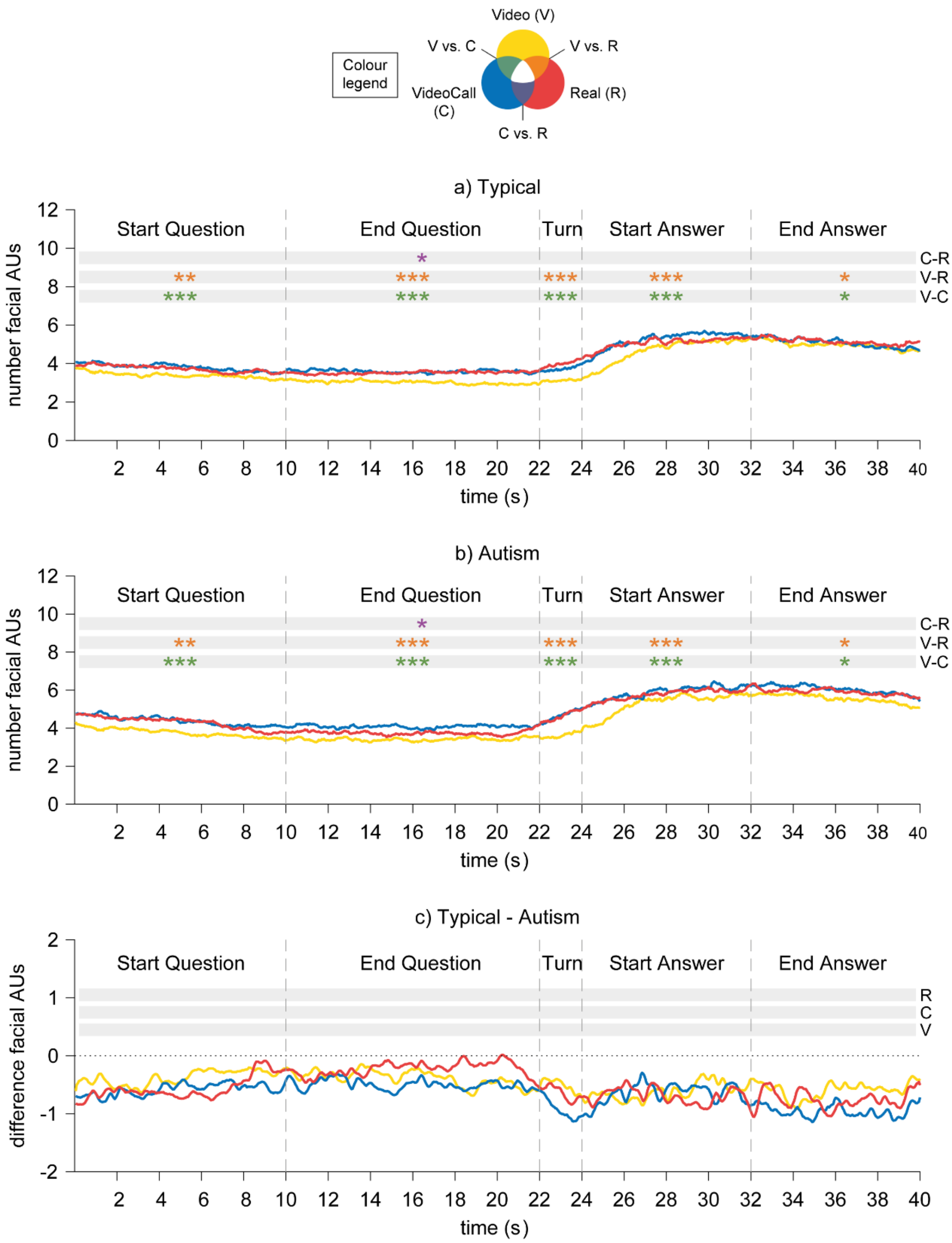

Figure 4-10. Results for time-course analyses of facial motion in Experiment 2. a) Typical group. b) Autism group. c) Difference between Typical and Autism groups: positive values indicate Typical > Autism, and negative values indicate Autism > Typical. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

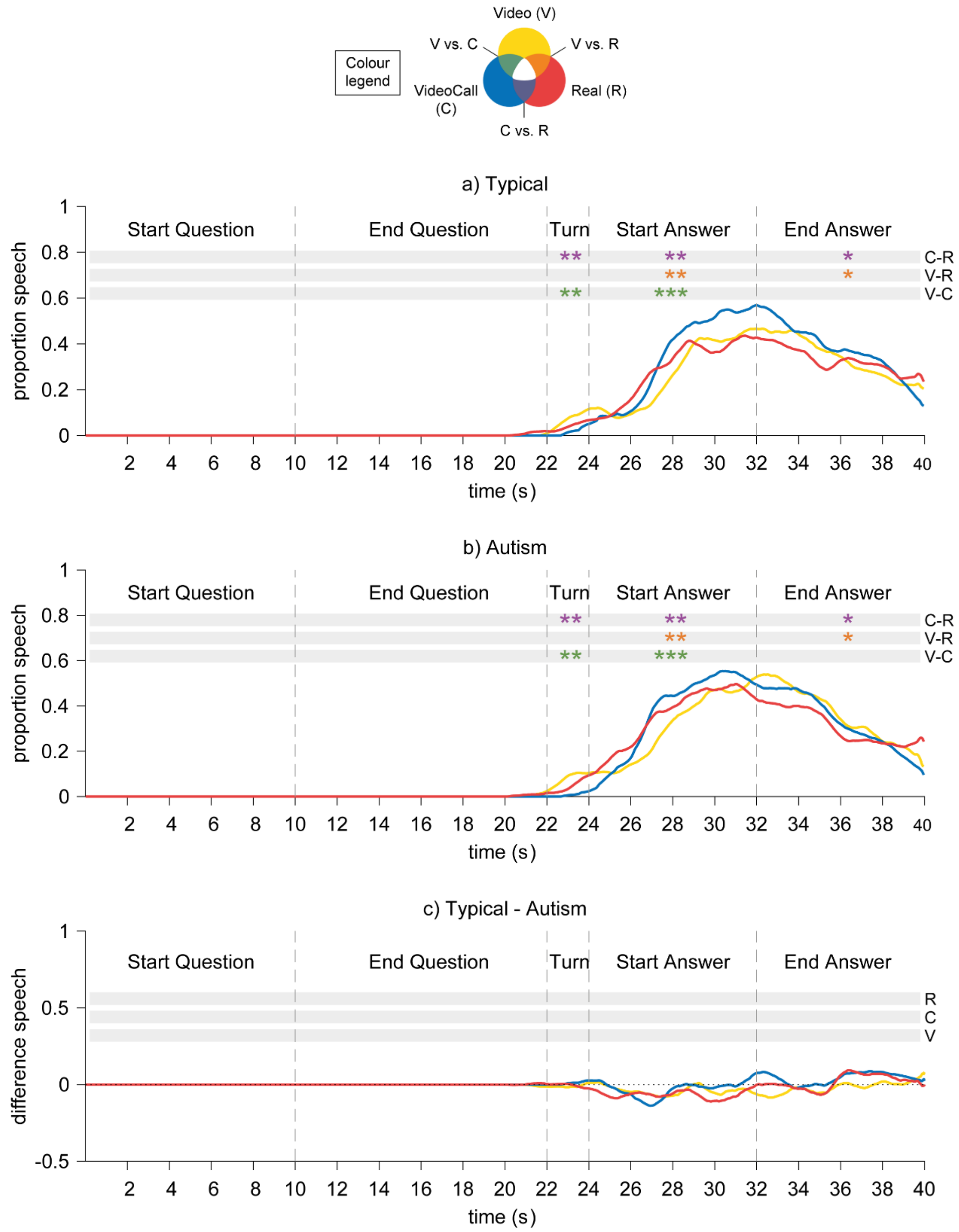

Figure 4-11. Results for time-course analyses of speech in Experiment 2.
a) Typical group. b) Autism group. c) Difference between Typical and Autism groups: positive values indicate Typical > Autism, and negative values indicate Autism > Typical. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

To investigate general patterns of eye gaze, we aggregated the data across the time-courses for each condition. Same as in Experiment 1, our results showed that participants looked less to the eyes of the confederate in the Real and VideoCall conditions compared to the Video condition. These findings are consistent with previous studies showing that participants gaze less to a live partner (who is watching them) than to a video-clip of the same partner (who is not watching them), either if they are actively interacting (as shown in Chapter 2) or not (Laidlaw et al., 2011). We also found that participants tended to look less to the mouth of the partner in the VideoCall than in the Video condition, although contrary to Experiment 1 this effect did not reach significance. Thus, the belief in being watched seems to mainly modulate eye gaze directed to the eyes of the confederate. It has been suggested that live interactions activate the dual function of gaze (Gobel et al., 2015; Risko et al., 2016): when being watched we need to plan eye movements to maximise the information we perceive from others, but also optimise the information we signal to others. Our findings suggest that eye gaze has stronger signalling function when directed to the eye region than when directed to the mouth region. Thus, in live interactions participants may decrease gaze-to-eyes and maintain gaze-to-mouth to maximise the information they perceive from the confederate while reducing the signalling component of gaze (e.g. to reduce intensity or arousal in the interaction; Argyle & Dean, 1965; Pönkänen et al., 2011).

To fully understand which cognitive mechanisms modulate gaze planning in live interactions, it is necessary to examine how eye gaze changes over time in relation to other signals, since this will modulate whether we need to optimise the perceiving or signalling function of gaze (Cañigueral & Hamilton, 2019). To do this, we looked at differences between conditions in 5 different time-windows along the trial time-course: start of the question, end of the question, turn-taking, start of the answer, and end of the answer. Consistent with Experiment 1, we found that participants looked more to the eyes and mouth of the confederate during the Question phase than during the Answer phase. This is consistent with previous studies investigating the regulatory function of gaze (Hessels et al., 2019; Ho et al., 2015; Kendon, 1967), which found that participants look more to the partner when listening than when speaking. However, this modulation was also true for the Video condition, where participants were aware that the confederate was pre-recorded and they were not in a live conversation. The fact that we find the same modulation across all three conditions (in both Experiment 1 and 2) indicates that averting gaze while speaking might be a consequence of, not only regulating turn-taking (Kendon, 1967), but also the fact that looking at faces is cognitively demanding (Beattie, 1981; Glenberg et al., 1998; Kendon, 1967; Markson & Paterson, 2009). Future studies will be needed to clarify this finding.

Our time-course analysis also showed that gaze-to-eyes patterns in the Video, VideoCall and Real conditions differed along the trial time-course. Similar to our findings in Experiment 1, participants looked less to the eyes of the confederate at the start or end of the Real and VideoCall interactions (i.e. start of Question phase and end of the Answer phase). Particularly at the start of the interaction, participants were slower to increase gaze-to-eyes in the live conditions (i.e. VideoCall and Real conditions), especially when there could be true direct gaze (i.e. Real condition). This is in line with the expressive function of gaze in face-to-face interactions (Kendon, 1967): participants may avert gaze to reduce arousal associated with eye contact in live (and particularly face-to-face) interactions (Argyle & Dean, 1965; Pönkänen et al., 2011). Note that, although in Experiment 2 we used more accurate triggers for turn-taking, again we did not find differences between conditions for this time-window. A reason for this could be that, since the task was very structured (i.e. confederate asks question, gazes at participant, and then participant answers), participants did not need to use gaze to regulate turn-taking in this context.

Similar to Experiment 1, we found that gaze-to-mouth patterns were also different between conditions along the trial time-course. At the start of the Question phase, participants looked less to the mouth of the confederate in the Real than in the VideoCall and Video conditions. This indicates that during the face-to-face interaction, where participants were being watched and there could be true direct gaze, they averted gaze to reduce arousal associated with face-to-face eye contact (Kendon, 1967; Pönkänen et al., 2011). At the end of the Question phase participants gazed more to the confederate's mouth in the Video than in the VideoCall condition, although there were no differences between Video and Real condition. This could be related to the fact that in the Video condition participants only had one chance to hear the question so they might have directed more gaze to the mouth for lipreading, whereas in the VideoCall (and Real) conditions they had the option to ask for brief clarifications (the confederate reported that this happened a few times). We also found that during Turn-taking and at the start of the Answer phase participants gazed less to the confederate's mouth in the VideoCall and Real conditions: this suggests that participants disengaged faster from the mouth of the live confederate than the pre-recorded confederate. Two different mechanisms could explain this finding. First, it could be that live faces are more cognitively demanding than pre-recorded faces, so participants avert gaze faster from live faces when they need to speak. However, it could also be that participants were using the regulatory function of gaze: when they knew the confederate could partly (VideoCall) or fully (Real) see the direction of their gaze, they averted gaze more quickly as they started to speak. Studying the role of cognitive load associated with live faces and live interactions can shed some light on this question.

To complement our gaze findings, we also looked at patterns of facial motion across the three conditions. A critical difference between Experiment 1 and 2 is that in the latter we also recorded speech, so we could control for facial motion related to production of speech (e.g. moving the mouth to speak). As in Experiment 1, participants moved their face more in the Real than in the Video condition, and we found that this effect was not related to speech production (a separate analysis further showed that speech production did not change across the three conditions). Time-course analysis further showed that participants moved their face more in the VideoCall and Real conditions than in the Video condition for all time-windows, and this effect was particularly marked during turn-taking. In line with previous studies, this indicates that participants made more facial displays when they were being watched by the confederate, since facial displays could be used as social signals (Chovil, 1991b; Crivelli & Fridlund, 2018; Fridlund, 1991; J. K. Hietanen, Kylliäinen, et al., 2018). A limitation to this finding is that we cannot rule out the possibility that higher amount of facial displays reflects an automatic affective reaction to the presence of others, for instance due to anxiety or nervousness related to being evaluated. Future studies could test whether changes in amount of facial displays are related to changes in arousal, as well as investigate whether the content of facial displays can provide further insight into their function (e.g. signalling or expressing anxiety). Moreover, participants moved their face more during the Answer phase than during the Question phase for all conditions: despite lower levels of facial motion in the Video compared to the Real and VideoCall conditions, the difference between Question and Answer phases was just as evident.

Overall, these findings indicate that eye gaze and facial displays are coordinated with speech (i.e. listening/speaking role) to send appropriate and meaningful signals to the confederate. Particularly for eye gaze, our findings suggest that in live interactions eye movements towards eyes and mouth of the confederate result from a trade-off between the information they can perceive or signal (e.g. averting gaze to reduce arousal at the start or end of the interaction). We also found that differences between conditions are especially pronounced at the start of the interaction (gaze-to-eyes and gaze-to-mouth) and turn-taking (gaze-to-mouth and facial displays), suggesting that effects of being watched are stronger at moments where social signals are needed to regulate the interaction. These findings show how analysing the dynamics of social behaviour over time can provide novel insight into which mechanisms modulate social signals during communication.

4.5.2. Social signalling in autistic individuals

For autistic participants, post-test questionnaire ratings showed that the manipulation was also successful: the confederate was perceived most reciprocal in the Real condition, and least reciprocal in the Video condition. Similar to the typical group, there were no differences in ratings of naturalness, likely because our Q&A task was too structured. Interestingly, autistic participants rated the confederate as generally more reciprocal and natural than the typical group. It could be that, since autistic participants have difficulties in accurately picking up subtleties of social interactions, they felt the interactions in our structured task were as natural and reciprocal as natural conversations.

Contrary to what we expected, general patterns of gaze-to-eyes and gaze-to-mouth in the aggregated analysis were the same between typical and autistic groups. To our knowledge, this is the first study to systematically compare eye gaze patterns of clinically-diagnosed autistic individuals in live versus pre-recorded interactions, and our findings suggest that gaze planning in autism is modulated by both its perceiving and signalling functions. In contrast with these findings, a previous study (Von dem Hagen & Bright, 2017 Experiment 1) found that participants with high autistic traits directed equal gaze to a live video-feed and a pre-recorded video. A key difference is that in Von dem Hagen & Bright's study participants with high autistic traits were not clinically-diagnosed. One possibility is that clinically-diagnosed individuals can better understand their difficulties and improve the management of their social behaviour. In turn, this may help them to develop compensation strategies, which imply that although there is improved behavioural presentation of symptoms, deficits persist at the cognitive and neurobiological level (Livingston & Happé, 2017). In the context of this study, it could be that participants learn to mimic general patterns of typical gaze behaviour (e.g. make eye contact; Del Bianco, Mazzoni, Bentenuto, & Venuti, 2018) despite atypical underlying neural activity associated with eye contact. Another possibility is that our results are confounded by alexithymia, a common comorbidity to autism. Alexithymia is a subclinical condition characterised by difficulties in identifying and describing emotions, and it has been related to emotional and empathy deficits traditionally associated to autism (Bird et al., 2010). Interestingly, it has been shown that autism symptom severity is negatively related to overall attention to faces, whereas the degree of alexithymia is negatively related to fixations to eyes (Bird, Press, & Richardson, 2011). Thus, it would be interesting to test if differences between typical and autistic individuals on gaze-to-eyes and gaze-to-mouth are better explained by alexithymia traits.

For the time-course analysis of gaze, we found that autistic participants also looked more to the eyes and mouth of the confederate during the Question phase than during the Answer phase, for all conditions. This is consistent with previous studies showing that typical and autistic individuals present similar gaze patterns during conversation (Freeth & Bugembe, 2018; Vabalas & Freeth, 2016; Von dem Hagen & Bright, 2017 Experiment 2), and suggests that high-functioning autistic participants are able to modulate gaze behaviour according to their role in the conversation (i.e. speaker or listener). However, from these findings we cannot discern whether this pattern of behaviour is spontaneous, results from the use of compensation strategies (Del Bianco et al., 2018; Livingston & Happé, 2017), or is related to the degree of alexithymia (Bird et al., 2011).

When looking at differences between conditions along the trial time-course, we found that results for gaze-to-mouth patterns were the same across typical and autistic groups. For gaze-to-eyes both groups showed similar effects at the start and end of the interaction (i.e. participants looked less to the eyes in the VideoCall or Real conditions than in the Video condition), indicating that in live interactions autistic participants also avert gaze to reduce arousal associated with eye contact (Argyle & Dean, 1965; Pönkänen et al., 2011). The autistic group also showed differences between VideoCall and Video conditions along the whole trial time-course (i.e. at the end of the Question phase, Turn-taking, and start of the Answer phase), and there was less gaze-to-eyes in the Real than in the Video condition at Turn-taking. These effects were consistent with those found for gaze-to-mouth in both typical and autistic participants. Contrary to our hypotheses, this indicates that overall patterns of eye gaze in both groups are similarly modulated by the belief in being watched. As mentioned earlier, we cannot distinguish if among high-functioning autistic participants this reflects spontaneous gaze behaviour, the use of compensation strategies (Del Bianco et al., 2018; Livingston & Happé, 2017), or confounding effects of alexithymia (Bird et al., 2011).

Direct comparison between typical and autistic gaze patterns revealed that, only in the Real condition and at the start of the Question phase, autistic participants directed *more* gaze to the eyes of the confederate than the typical group. This evidence challenges previous studies showing that autistic participants (or individuals with high autistic traits) use eye gaze similarly to typical individuals during a live Q&A task (Freeth & Bugembe, 2018; Vabalas & Freeth, 2016; Von dem Hagen & Bright, 2017 Experiment 2), or that they spend less time looking at a live confederate and engage less in mutual eye contact (Hessels et al., 2018; Von dem Hagen & Bright, 2017 Experiment 2). A key difference is that these previous studies aggregated data across speaking and listening blocks, whereas the time-course analysis in the present study can distinguish effects at different stages along the interaction: this provides a much more detailed description of the use of eye gaze over time. Interestingly, two recent studies have found that participants with high social anxiety traits (i.e. fear of scrutiny and negative evaluations from others) look earlier and more to faces at the start of the interaction, compared to participants with low social anxiety traits (Gregory, Bolderston, & Antolin, 2019; Gutiérrez-García, Fernández-Martín, Del Líbano, & Calvo, 2019). The authors suggest that this attentional bias could reflect compensation strategies to anticipate negative evaluations. In our study, the initial attentional bias to the eyes of the Real confederate could also reflect a general compensation strategy, where autistic participants have learnt that they need to make more eye contact during face-to-face interactions (Del Bianco et al., 2018; Livingston & Happé, 2017).

Finally, we examined facial motion and speech patterns in autistic individuals. Both aggregated and time-course analyses yielded no differences between typical and autistic groups. The fact that autistic participants show more facial motion during the Real and VideoCall conditions (live) than during the Video condition (pre-recorded), and during the Answer phase (speaking) than during the Question phase (listening), suggests that they also used facial displays as a social signal (Chovil, 1991a; Crivelli & Fridlund, 2018). These findings do not support previous studies where autistic participants showed less spontaneous production of facial displays compared to typical participants (Trevisan et al., 2018). A limitation to our findings is that we do not have information about *which* facial displays participants made. In this sense, a recent study found that facial displays of autistic individuals are more ambiguous and variable than facial displays of typical individuals (Zane et al., 2019). Studying whether, beyond amount of facial motion, facial displays are meaningful or not to the spoken message will be an interesting question for future research.

Altogether, our findings indicate that autistic individuals do coordinate eye gaze and facial displays with their speaking and listening role. Consistent with our findings for the typical group, effects of being watched on eye gaze and facial displays are stronger when these social signals need to regulate the interaction (e.g. start of the interaction and turn-taking). However, we found that at the start of the Real interaction autistic participants gaze more to the eyes of the confederate than the typical group. Although this suggests that autistic participants may rely on compensation strategies to plan their eye movements (Livingston & Happé, 2017), future studies will be needed to clarify if it just reflects a spontaneous behaviour.

4.5.3. Limitations and future research

A main limitation in our study is that the task that we used was very structured: the confederate always asked a question upon hearing a tone, and the participant would then give an answer until another tone indicated the end of the trial. Using a task were confederate and participants engage in a more natural conversation with continuous exchange of information could provide further insight into how eye gaze and facial displays are used in real life. For instance, we find that participants averted gaze to reduce arousal at the start and end of the live interactions, but it could be that this only happened because there was an awkward silence between trials. Moreover, autistic participants may be able to appropriately use eye gaze in structured settings, but they may fail to do so during spontaneous interactions. Comparing these gaze patterns with those in natural conversations could clarify the external validity of our findings.

Another limitation is that we could not use the eye-tracking data from the confederates, since the recordings had poor signal quality. Thus, we could not check whether gaze patterns of the confederate in Experiment 2 were the same for the typical and autistic group: although we gave specific instructions to the confederate regarding gaze patterns during the task, it could be that he was more accommodating to autistic participants. Moreover, examining how patterns of social behaviour are related between partners can provide further insight about how they use social signals to communicate with each other. For instance, previous studies have used cross-recurrence quantification analysis (CRQA), which detects recurrent patterns of states between two time series to reveal their temporal dynamics (Zbilut, Giuliani, & Webber, 1998). Using CRQA it has been found that listeners' eye movements follow the speakers' eye movements at a delay of 2 seconds (Richardson & Dale, 2005), and that speakers gaze to listeners when ending their turn (Ho et al., 2015). Thus, future studies could investigate how recurrent patterns between speakers and listeners vary between live and pre-recorded interactions.

Another interesting question for future research is to what extent high-functioning autistic individuals use compensation strategies to guide gaze patterns during social interactions (Livingston & Happé, 2017). Designing more elaborate paradigms in ecologically valid environments and using more fine-grained analysis can help identify which cognitive components of gaze processing are disrupted in autism. For instance, although in the present study there were no overall differences in gaze patterns between typical and autistic participants, using time-course analysis we found that they gazed more to the eyes of the confederate at the start of a face-to-face interaction. Another way to bypass compensation strategies is to use neuroimaging paradigms: Greene and colleagues (Greene et al., 2011) found different patterns of brain activity between typical and autistic individuals during a gaze-cueing task, although behavioural performance was similar. Finally, developmental studies can also help to clarify how accumulation of experience in social interactions refines compensation strategies and helps recover gaze and face processing skills in adulthood (Del Bianco et al., 2018).

4.6. Conclusion

This chapter investigated how eye gaze and facial motion patterns of typical and autistic individuals are modulated by the belief in being watched and the potential for true direct gaze. Across two experiments, we show that typical participants modulated eye gaze according to their role in the interaction (e.g. speaker or listener), as well as to reduce arousal and regulate the interaction (when gaze had a signalling function). We also found that typical participants use facial displays as a social signal during live interactions. Contrary to our hypotheses, we found that patterns of gaze-to-eyes, gaze-to-mouth and facial displays in the autistic group are overall similar to those in the typical group. These findings indicate that planning of eye gaze and production of facial displays in autism are less disrupted than previously reported: whether this reflects spontaneous behaviour or results from compensation strategies will be an interesting question for future research.

4.7. Supplementary materials

4.7.1. List of questions in Experiment 1

Set 1 - Video

1. Summer is coming and you are planning your holidays. Would you rather: option A, take a European sight-seeing vacation, or option B, take a relaxing Caribbean vacation?
2. You have saved £200 during the last month. Would you rather: option A, donate it to a local fundraising event, or option B, spend it on a trip?
3. You have some spare time this term. Would you rather: option A, go to the gym, or option B, volunteer for a children's sport charity?
4. A witch casts a spell on you and lets you choose. Would you rather: option A, go on your perfect holiday for a month, or option B, volunteer in a developing country for a month?
5. Your vision skills will be modified for a day. Would you rather: option A, only see infrared rays, or option B, only see ultraviolet rays?
6. You have a free afternoon this weekend. Would you rather: option A, help prepare games for a charity event, or option B, spend the afternoon in a café with your friends?
7. Your boss gives you a day off. Would you rather: option A, spend the day hiking, or option B, spend the day cycling?

8. A magician gives you £400. Would you rather: option A, give it to a disabilities-related charity, or option B, spend it on your next holiday?
9. You have some spare mornings this year. Would you rather: option A, work as an assistant in your department, or option B, volunteer in a nursing home?
10. You have a lot of work today. Would you rather: option A, help a colleague who is stuck in his project, or option B, concentrate and finish your work quickly?
11. You want to be very skilled at something. Would you rather: option A, be able to play all musical instruments, or option B, be able to speak all foreign languages?
12. You have found a £20 note in the street. Would you rather: option A, give it to a homeless busker, or option B, save it for a concert of your favourite music band?

Set 2 - VideoCall

1. You don’t have much work this month. Would you rather: option A, do some personal tutoring with children, or option B, volunteer in a children-related charity?
2. You have some spare time this term. Would you rather: option A, volunteer teaching disabled people how to play an instrument, or option B, learn to play an instrument?
3. A witch casts a spell on you and lets you choose. Would you rather: option A, provide resources to developing countries for a year, or option B, travel around the world for a year?

4. You have found a £10 note in the staircase of your building. Would you rather: option A, save it to have a treat next weekend, or option B, give it to a homeless man in your neighbourhood?
5. You are free on a Saturday. Would you rather: option A, help organise a game for a fundraising event, or option B, spend the day out with your friends?
6. You have won a voucher. Would you rather: option A, have free coffee for a year, or option B, have free cake for a year?
7. After Christmas you have saved £200. Would you rather: option A, buy new furniture for your place, or option B, give it to a charity for old people?
8. A witch will make your wish come true. Would you rather: option A, find your true love, or option B, find £100,000?
9. A magician gives you £400. Would you rather: option A, spend it on a nice holiday next summer, or option B, donate it to help people in poor countries?
10. You have a free weekend to spend with your friends. Would you rather: option A, spend it by the sea, or option B, spend it in the mountains?
11. You are going to the cinema this evening. Would you rather: option A, watch a fantasy film, or option B, watch a comedy film?
12. You have quite a lot of homework to do. Would you rather: option A, help a classmate who struggles with homework, or option B, finish your homework as soon as possible?

Set 3 - Real

1. You have some spare time this year. Would you rather: option A, volunteer in a homeless shelter, or option B, find a part-time job in a café?

2. You have a free evening. Would you rather: option A, spend it in a concert, or option B, spend it at the cinema?
3. You have won £500 in the lottery. Would you rather: option A, donate it to help developing countries, or option B, buy something you really want?
4. You want to reduce your electricity expenses for a week. Would you rather: option A, live without the Internet, or option B, live without heating and hot water?
5. You have one free evening during the week. Would you rather: option A, have a nice dinner with your flatmates, or option B, volunteer in a charity that helps old people?
6. A wizard gives you £100. Would you rather: option A, give it to an NGO that helps protect natural environments, or option B, spend it on a nice weekend out of town?
7. You don’t have access to water for a day. Would you rather: option A, only drink coke, or option B, only drink tea?
8. A magician casts a spell on you and lets you choose. Would you rather: option A, have no work for a week, or option B, help disabled people for a week?
9. You have found a £20 note in the changing room of a shop. Would you rather: option A, buy a new jumper you need, or option B, give it to a homeless woman?
10. You are in the airport and need to pass the security check. Would you rather: option A, let a big group of old people go ahead, or option B, hurry up to have the place in the fastest line?

11. A wizard will give you a superpower for a day. Would you rather: option A, be invisible, or option B, be able to fly?
12. You are taking the mornings off work this week. Would you rather: option A, do some leisure activity, or option B, collaborate in a fundraising event?

4.7.2. Post-test questionnaire

Section 1

I think the interaction in the video was very natural.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction in the video was very reciprocal.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction in the video-conference was very natural.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction in the video-conference was very reciprocal.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction face-to-face was very natural.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

I think the interaction face-to-face was very reciprocal.

(disagree) 0 1 2 3 4 5 6 7 8 (agree)

Section 2

Which interaction (video / video-conference / face-to-face) did you like the most? Why?

Which interaction (video / video-conference / face-to-face) did you like the least? Why?

What do you think was the purpose of the experiment?

4.7.3. Tables with full results from time-course analyses

Table 4-9. Results for time-course analyses in Experiment 1

		Prop. gaze to Eye[a]	Prop. gaze to Mouth	Number facial AUs
Condition	main effect	$F(2,54) = 6.82$ $p < .01^{**}$ $n_p^2 = .202$	$F(2,54) = 4.17$ $p < .05^{*}$ $n_p^2 = .134$	$F(2,54) = 4.63$ $p < .05^{*}$ $n_p^2 = .146$
	V vs. C	$p > .05$ ($p < .05^{*}$)	$p < .01^{**}$	$p > .05$
	V vs. R	$p < .01^{**}$	$p > .05$	$p < .05^{*}$
	C vs. R	$p > .05$	$p > .05$	$p > .05$
Time-window	main effect	$F(4,108) = 21.9$ $p < .001^{***}$ $n_p^2 = .447$	$F(4,108) = 44.2$ $p < .001^{***}$ $n_p^2 = .621$	$F(4,108) = 110.2$ $p < .001^{***}$ $n_p^2 = .803$
	Q1 vs. Q2	$p > .05$	$p < .001^{***}$	$p < .001^{***}$
	Q1 vs. TT	$p < .001^{***}$	$p > .05$	$p > .05$
	Q1 vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	Q1 vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	Q2 vs. TT	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	Q2 vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	Q2 vs. A2	$p < .01^{**}$	$p < .001^{***}$	$p < .001^{***}$
	TT vs. A1	$p > .05$	$p < .001^{***}$	$p < .001^{***}$
	TT vs. A2	$p > .05$	$p > .05$	$p < .001^{***}$
	A1 vs. A2	$p < .01^{**}$	$p < .05^{*}$	$p < .001^{***}$
Condition X Time-window	interaction effect	$F(8,216) = 4.81$ $p < .01^{**}$ $n_p^2 = .151$	$F(8,216) = 3.52$ $p < .05^{*}$ $n_p^2 = .115$	$F(8,216) = 2.60$ $p > .05$ $n_p^2 = .088$
	Q1: V vs. C	$p < .01^{**}$	$p < .01^{**}$	-
	Q1: V vs. R	$p < .001^{***}$	$p < .01^{**}$	
	Q1: C vs. R	$p > .05$	$p > .05$	
	Q2: V vs. C	$p > .05$ ($p < .05^{*}$)	$p < .05^{*}$	-
	Q2: V vs. R	$p < .05^{*}$ ($p > .05$)	$p > .05$	
	Q2: C vs. R	$p > .05$	$p > .05$	
	TT: V vs. C	$p > .05$ ($p < .05^{*}$)	$p < .001^{***}$	-
	TT: V vs. R	$p < .05^{*}$ ($p > .05$)	$p > .05$	
	TT: C vs. R	$p > .05$	$p > .05$	
	A1: V vs. C	$p > .05$	$p > .05$	-

A1: V vs. R	*p* > .05	*p* > .05	
A1: C vs. R	*p* > .05	*p* > .05	
A2: V vs. C	*p* < .05*	*p* < .05*	
A2: V vs. R	*p* < .01**	*p* < .01**	-
A2: C vs. R	*p* < .05*	*p* > .05	
V: Q1 vs. Q2	*p* > .05	*p* < .05*	
V: Q1 vs. TT	*p* < .001***	*p* < .05*	
V: Q1 vs. A1	*p* < .001***	*p* < .001***	
V: Q1 vs. A2	*p* < .001***	*p* < .001***	
V: Q2 vs. TT	*p* < .001***	*p* < .001***	
V: Q2 vs. A1	*p* < .001***	*p* < .001***	-
V: Q2 vs. A2	*p* < .05*	*p* < .001***	
V: TT vs. A1	*p* > .05	*p* < .001***	
V: TT vs. A2	*p* > .05	*p* < .05*	
V: A1 vs. A2	*p* < .001***	*p* < .001***	
C: Q1 vs. Q2	*p* > .05	*p* < .01**	
C: Q1 vs. TT	*p* < .001***	*p* < .01**	
C: Q1 vs. A1	*p* < .01**	*p* < .001***	
C: Q1 vs. A2	*p* < .01**	*p* < .001***	
C: Q2 vs. TT	*p* < .01**	*p* < .001***	
C: Q2 vs. A1	*p* < .01**	*p* < .001***	-
C: Q2 vs. A2	*p* < .01**	*p* < .001***	
C: TT vs. A1	*p* > .05	*p* < .01**	
C: TT vs. A2	*p* < .05*	*p* > .05	
C: A1 vs. A2	*p* > .05	*p* < .01**	
R: Q1 vs. Q2	*p* < .05*	*p* < .001***	
R: Q1 vs. TT	*p* < .01**	*p* > .05	
R: Q1 vs. A1	*p* < .05*	*p* < .01**	
R: Q1 vs. A2	*p* < .05*	*p* < .001***	
R: Q2 vs. TT	*p* < .01**	*p* < .001***	
R: Q2 vs. A1	*p* < .01**	*p* < .001***	-
R: Q2 vs. A2	*p* < .01**	*p* < .001***	
R: TT vs. A1	*p* > .05	*p* < .001***	
R: TT vs. A2	*p* > .05	*p* < .01**	
R: A1 vs. A2	*p* > .05	*p* > .05	

[a]Values after removal of the outlier are in brackets. V = Video; C = VideoCall; R = Real; Q1 = start Question; Q2 = end Question; TT = Turn-taking; A1 = start Answer; A2 = end Answer. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

Table 4-10. Results for time-course analyses in Experiment 2: eye gaze and speech

		Prop. gaze to Eye	Prop. gaze to Mouth	Proportion speech
Condition	main effect	$F(2,100) = 10.4$ $p < .001^{***}$ $n_p^2 = .172$	$F(2,100) = 4.83$ $p < .05^{*}$ $n_p^2 = .088$	$F(2,100) = 1.02$ $p > .05$ $n_p^2 = .020$
	V vs. C	$p < .01^{**}$	$p < .05^{*}$	-
	V vs. R	$p < .01^{**}$	$p > .05$	-
	C vs. R	$p > .05$	$p > .05$	-
Time-window	main effect	$F(4,200) = 39.7$ $p < .001^{***}$ $n_p^2 = .443$	$F(4,200) = 38.7$ $p < .001^{***}$ $n_p^2 = .437$	$F(4,200) = 250$ $p < .001^{***}$ $n_p^2 = .833$
	Q1 vs. Q2	$p < .001^{***}$	$p < .001^{***}$	$p < .01^{**}$
	Q1 vs. TT	$p < .05^{*}$	$p < .001^{***}$	$p < .001^{***}$
	Q1 vs. A1	$p < .01^{**}$	$p < .05^{*}$	$p < .001^{***}$
	Q1 vs. A2	$p < .01^{**}$	$p < .01^{**}$	$p < .001^{***}$
	Q2 vs. TT	$p < .01^{**}$	$p > .05$	$p < .001^{***}$
	Q2 vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	Q2 vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	TT vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	TT vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	A1 vs. A2	$p > .05$	$p > .05$	$p > .05$
Group	main effect	$F(1,50) = .214$ $p > .05$ $n_p^2 = .004$	$F(1,50) = 2.08$ $p > .05$ $n_p^2 = .040$	$F(1,50) = .248$ $p > .05$ $n_p^2 = .005$
Condition X Time-window	interaction effect	$F(8,400) = 5.55$ $p < .001^{***}$ $n_p^2 = .100$	$F(8,400) = 4.86$ $p < .01^{**}$ $n_p^2 = .089$	$F(8,400) = 9.99$ $p < .001^{***}$ $n_p^2 = .166$
	Q1: V vs. C	$p < .001^{***}$	$p > .05$	$p > .05$
	Q1: V vs. R	$p < .001^{***}$	$p < .001^{***}$	$p > .05$
	Q1: C vs. R	$p < .05^{*}$	$p < .01^{**}$	$p > .05$
	Q2: V vs. C	$p < .01^{**}$	$p < .05^{*}$	$p > .05$
	Q2: V vs. R	$p > .05$	$p > .05$	$p > .05$
	Q2: C vs. R	$p > .05$	$p > .05$	$p > .05$
	TT: V vs. C	$p < .01^{**}$	$p < .01^{**}$	$p < .01^{**}$
	TT: V vs. R	$p < .01^{**}$	$p < .05^{*}$	$p > .05$
	TT: C vs. R	$p > .05$	$p > .05$	$p < .01^{**}$
	A1: V vs. C	$p < .01^{**}$	$p < .05^{*}$	$p < .001^{***}$
	A1: V vs. R	$p > .05$	$p < .05^{*}$	$p < .01^{**}$
	A1: C vs. R	$p > .05$	$p > .05$	$p < .01^{**}$

	A2: V vs. C	$p < .05^{*}$	$p > .05$	$p > .05$
	A2: V vs. R	$p < .05^{*}$	$p > .05$	$p < .05^{*}$
	A2: C vs. R	$p > .05$	$p > .05$	$p < .05^{*}$
	V: Q1 vs. Q2	$p < .001^{***}$	$p < .001^{***}$	$p > .05$
	V: Q1 vs. TT	$p < .05^{*}$	$p < .01^{**}$	$p < .001^{***}$
	V: Q1 vs. A1	$p < .001^{***}$	$p < .01^{**}$	$p < .001^{***}$
	V: Q1 vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	V: Q2 vs. TT	$p < .01^{**}$	$p > .05$	$p < .001^{***}$
	V: Q2 vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	V: Q2 vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	V: TT vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	V: TT vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	V: A1 vs. A2	$p < .05^{*}$	$p > .05$	$p < .01^{**}$
	C: Q1 vs. Q2	$p < .001^{***}$	$p < .001^{***}$	$p > .05$
	C: Q1 vs. TT	$p > .05$	$p > .05$	$p < .001^{***}$
	C: Q1 vs. A1	$p < .01^{**}$	$p < .01^{**}$	$p < .001^{***}$
	C: Q1 vs. A2	$p < .01^{**}$	$p < .01^{**}$	$p < .001^{***}$
	C: Q2 vs. TT	$p < .05^{*}$	$p < .01^{**}$	$p < .001^{***}$
	C: Q2 vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	C: Q2 vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	C: TT vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	C: TT vs. A2	$p < .01^{**}$	$p < .01^{**}$	$p < .001^{***}$
	C: A1 vs. A2	$p > .05$	$p > .05$	$p > .05$
	R: Q1 vs. Q2	$p < .05^{*}$	$p < .001^{***}$	$p < .01^{**}$
	R: Q1 vs. TT	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	R: Q1 vs. A1	$p > .05$	$p > .05$	$p < .001^{***}$
	R: Q1 vs. A2	$p > .05$	$p > .05$	$p < .001^{***}$
	R: Q2 vs. TT	$p < .01^{**}$	$p < .01^{**}$	$p < .001^{***}$
	R: Q2 vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	R: Q2 vs. A2	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	R: TT vs. A1	$p < .001^{***}$	$p < .001^{***}$	$p < .001^{***}$
	R: TT vs. A2	$p < .01^{**}$	$p < .001^{***}$	$p < .001^{***}$
	R: A1 vs. A2	$p > .05$	$p < .01^{**}$	$p > .05$
Condition X Group	interaction effect	$F(2,100) = 2.10$ $p > .05$ $n_p^2 = .040$	$F(2,100) = .168$ $p > .05$ $n_p^2 = .003$	$F(2,100) = 1.50$ $p > .05$ $n_p^2 = .029$
Time-window X Group	interaction effect	$F(4,200) = .783$ $p > .05$ $n_p^2 = .015$	$F(4,200) = .964$ $p > .05$ $n_p^2 = .019$	$F(4,200) = .966$ $p > .05$ $n_p^2 = .019$
	interaction effect	$F(8,400) = 2.81$	$F(8,400) = .553$	$F(8,400) = 1.03$

Condition X Time-window X Group		$p < .05^{*}$ $n_p^2 = .053$	$p > .05$ $n_p^2 = .011$	$p > .05$ $n_p^2 = .020$
	R,Q1: Typ vs. Aut	$p < .05^{*}$	-	-
	All other contrasts between Typ and Aut are not significant			
	Typ,Q1: V vs. C	$p < .05^{*}$	-	-
	Typ,Q1: V vs. R	$p < .001^{***}$		
	Typ,Q1: C vs. R	$p < .01^{**}$		
	Typ,Q2: V vs. C	$p > .05$	-	-
	Typ,Q2: V vs. R	$p > .05$		
	Typ,Q2: C vs. R	$p > .05$		
	Typ,TT: V vs. C	$p > .05$	-	-
	Typ,TT: V vs. R	$p > .05$		
	Typ,TT: C vs. R	$p > .05$		
	Typ,A1: V vs. C	$p > .05$	-	-
	Typ,A1: V vs. R	$p > .05$		
	Typ,A1: C vs. R	$p > .05$		
	Typ,A2: V vs. C	$p < .05^{*}$	-	-
	Typ,A2: V vs. R	$p > .05$		
	Typ,A2: C vs. R	$p > .05$		
	Aut,Q1: V vs. C	$p < .01^{**}$	-	-
	Aut,Q1: V vs. R	$p < .01^{**}$		
	Aut,Q1: C vs. R	$p > .05$		
	Aut,Q2: V vs. C	$p < .01^{**}$	-	-
	Aut,Q2: V vs. R	$p > .05$		
	Aut,Q2: C vs. R	$p < .01^{**}$		
	Aut,TT: V vs. C	$p < .001^{***}$	-	-
	Aut,TT: V vs. R	$p < .05^{*}$		
	Aut,TT: C vs. R	$p < .05^{*}$		
	Aut,A1: V vs. C	$p < .01^{**}$	-	-
	Aut,A1: V vs. R	$p > .05$		
	Aut,A1: C vs. R	$p > .05$		
	Aut,A2: V vs. C	$p < .01^{**}$	-	-
	Aut,A2: V vs. R	$p > .05$		
	Aut,A2: C vs. R	$p > .05$		
	Typ,V: Q1 vs. Q2	$p < .05^{*}$	-	-
	Typ,V: Q1 vs. TT	$p > .05$		
	Typ,V: Q1 vs. A1	$p < .001^{***}$		
	Typ,V: Q1 vs. A2	$p < .001^{***}$		

Typ,V: Q2 vs. TT	$p < .001^{***}$		
Typ,V: Q2 vs. A1	$p < .001^{***}$		
Typ,V: Q2 vs. A2	$p < .001^{***}$		
Typ,V: TT vs. A1	$p < .01^{**}$		
Typ,V: TT vs. A2	$p < .05^{*}$		
Typ,V: A1 vs. A2	$p < .05^{*}$		
Typ,C: Q1 vs. Q2	$p < .001^{***}$		
Typ,C: Q1 vs. TT	$p > .05$		
Typ,C: Q1 vs. A1	$p < .05^{*}$		
Typ,C: Q1 vs. A2	$p < .05^{*}$		
Typ,C: Q2 vs. TT	$p < .05^{*}$	-	-
Typ,C: Q2 vs. A1	$p < .001^{***}$		
Typ,C: Q2 vs. A2	$p < .001^{***}$		
Typ,C: TT vs. A1	$p < .001^{***}$		
Typ,C: TT vs. A2	$p < .01^{**}$		
Typ,C: A1 vs. A2	$p > .05$		
Typ,R: Q1 vs. Q2	$p < .001^{***}$		
Typ,R: Q1 vs. TT	$p < .05^{*}$		
Typ,R: Q1 vs. A1	$p > .05$		
Typ,R: Q1 vs. A2	$p > .05$		
Typ,R: Q2 vs. TT	$p < .05^{*}$	-	-
Typ,R: Q2 vs. A1	$p < .01^{**}$		
Typ,R: Q2 vs. A2	$p < .01^{**}$		
Typ,R: TT vs. A1	$p > .05$		
Typ,R: TT vs. A2	$p > .05$		
Typ,R: A1 vs. A2	$p > .05$		
Aut,V: Q1 vs. Q2	$p < .001^{***}$		
Aut,V: Q1 vs. TT	$p < .001^{***}$		
Aut,V: Q1 vs. A1	$p < .001^{***}$		
Aut,V: Q1 vs. A2	$p < .01^{**}$		
Aut,V: Q2 vs. TT	$p > .05$	-	-
Aut,V: Q2 vs. A1	$p < .001^{***}$		
Aut,V: Q2 vs. A2	$p < .001^{***}$		
Aut,V: TT vs. A1	$p < .001^{***}$		
Aut,V: TT vs. A2	$p < .001^{***}$		
Aut,V: A1 vs. A2	$p > .05$		
Aut,C: Q1 vs. Q2	$p > .05$		
Aut,C: Q1 vs. TT	$p > .05$	-	-
Aut,C: Q1 vs. A1	$p > .05$		

Aut,C: Q1 vs. A2	$p > .05$		
Aut,C: Q2 vs. TT	$p > .05$		
Aut,C: Q2 vs. A1	$p < .05^{*}$		
Aut,C: Q2 vs. A2	$p < .05^{*}$		
Aut,C: TT vs. A1	$p < .05^{*}$		
Aut,C: TT vs. A2	$p > .05$		
Aut,C: A1 vs. A2	$p > .05$		
Aut,R: Q1 vs. Q2	$p < .001^{***}$		
Aut,R: Q1 vs. TT	$p < .01^{**}$		
Aut,R: Q1 vs. A1	$p > .05$		
Aut,R: Q1 vs. A2	$p > .05$		
Aut,R: Q2 vs. TT	$p < .05^{*}$	-	-
Aut,R: Q2 vs. A1	$p < .001^{***}$		
Aut,R: Q2 vs. A2	$p < .001^{***}$		
Aut,R: TT vs. A1	$p < .001^{***}$		
Aut,R: TT vs. A2	$p < .01^{**}$		
Aut,R: A1 vs. A2	$p > .05$		

V = Video; C = VideoCall; R = Real; Q1 = start Question; Q2 = end Question; TT = Turn-taking; A1 = start Answer; A2 = end Answer; Typ = typical; Aut = autism. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

Table 4-11. Results for time-course analyses in Experiment 2: facial motion

		Number facial AUs
Condition	main effect	$F(2,7657.5) = 59.0$ $p < .001^{***}$
	V vs. C	$p > .05$
	V vs. R	$p < .05^{*}$
	C vs. R	$p > .05$
Time-window	main effect	$F(4,7669.2) = 76.0$ $p < .001^{***}$
	Q1 vs. Q2	$p < .001^{***}$
	Q1 vs. TT	$p > .05$
	Q1 vs. A1	$p < .001^{***}$
	Q1 vs. A2	$p < .001^{***}$
	Q2 vs. TT	$p < .001^{***}$
	Q2 vs. A1	$p < .001^{***}$
	Q2 vs. A2	$p < .001^{***}$
	TT vs. A1	$p < .001^{***}$
	TT vs. A2	$p < .001^{***}$

	A1 vs. A2	*p* > .05
Group	main effect	*F*(1,51.003) = 1.48 *p* > .05
Speech	main effect	*F*(1,6506.7) = .233 *p* > .05
Condition X Time-window	interaction effect	*F*(8,7653.5) = 1.99 *p* < .05*
	Q1: V vs. C	*p* < .001***
	Q1: V vs. R	*p* < .01**
	Q1: C vs. R	*p* > .05
	Q2: V vs. C	*p* < .001***
	Q2: V vs. R	*p* < .001***
	Q2: C vs. R	*p* < .05*
	TT: V vs. C	*p* < .001***
	TT: V vs. R	*p* < .001***
	TT: C vs. R	*p* > .05
	A1: V vs. C	*p* < .001***
	A1: V vs. R	*p* < .001***
	A1: C vs. R	*p* > .05
	A2: V vs. C	*p* < .05*
	A2: V vs. R	*p* < .05*
	A2: C vs. R	*p* > .05
	V: Q1 vs. Q2	*p* < .001***
	V: Q1 vs. TT	*p* > .05
	V: Q1 vs. A1	*p* < .001***
	V: Q1 vs. A2	*p* < .001***
	V: Q2 vs. TT	*p* > .05
	V: Q2 vs. A1	*p* < .001***
	V: Q2 vs. A2	*p* < .001***
	V: TT vs. A1	*p* < .001***
	V: TT vs. A2	*p* < .001***
	V: A1 vs. A2	*p* < .01**
	C: Q1 vs. Q2	*p* < .01**
	C: Q1 vs. TT	*p* > .05
	C: Q1 vs. A1	*p* < .001***
	C: Q1 vs. A2	*p* < .001***
	C: Q2 vs. TT	*p* < .001***
	C: Q2 vs. A1	*p* < .001***
	C: Q2 vs. A2	*p* < .001***

	C: TT vs. A1	*p* < .001***
	C: TT vs. A2	*p* < .001***
	C: A1 vs. A2	*p* > .05
	R: Q1 vs. Q2	*p* < .001***
	R: Q1 vs. TT	*p* < .05*
	R: Q1 vs. A1	*p* < .001***
	R: Q1 vs. A2	*p* < .001***
	R: Q2 vs. TT	*p* < .001***
	R: Q2 vs. A1	*p* < .001***
	R: Q2 vs. A2	*p* < .001***
	R: TT vs. A1	*p* < .001***
	R: TT vs. A2	*p* < .001***
	R: A1 vs. A2	*p* > .05
Condition X Group	interaction effect	*F*(2,7657.5) = .496 *p* > .05
Time-window X Group	interaction effect	*F*(4,7669.2) = 1.52 *p* > .05
Speech X Group	interaction effect	*F*(2,5617.9) = .092 *p* > .05
Time-window X Condition	interaction effect	*F*(8,7653.5) = 1.99 *p* > .05
Speech X Condition	interaction effect	*F*(2,7660.8) = 1.86 *p* > .05
Time-window X Speech	interaction effect	*F*(3,7676.3) = .883 *p* > .05
Group X Condition X Time-window	interaction effect	*F*(8,7653.5) = .875 *p* > .05
Group X Condition X Speech	interaction effect	*F*(2,7675.4) = .729 *p* > .05
Group X Time-window X Speech	interaction effect	*F*(3,7675.3) = .376 *p* > .05
Condition X Time-window X Speech	interaction effect	*F*(5,7669.9) = 1.88 *p* > .05
Group X Condition X Time-window X Speech	interaction effect	*F*(4,7673.9) = 1.19 *p* > .05

V = Video; C = VideoCall; R = Real; Q1 = start Question; Q2 = end Question; TT = Turn-taking; A1 = start Answer; A2 = end Answer. Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

4.7.4. List of questions in Experiment 2

Set 1 - Video

1. Summer is coming and you are planning your holidays. Would you rather: option A, take a European sight-seeing vacation, or Option B, take a relaxing Caribbean vacation?
2. You have saved £150. Would you rather: option A, give it to a homeless shelter, or Option B, spend it on a weekend trip?
3. Your vision skills will be modified for a day. Would you rather: option A, only see infrared rays, or Option B, only see ultraviolet rays?
4. You have some spare mornings this year. Would you rather: option A, work as an assistant in a company, or Option B, volunteer in a nursing home?
5. You want to be very skilled at something. Would you rather: option A, be able to play all musical instruments, or Option B, be able to speak all foreign languages?
6. Your boss gives you a day off. Would you rather: option A, spend the day hiking, or Option B, spend the day cycling?
7. You have a free afternoon this weekend. Would you rather: option A, collaborate in a charity event, or Option B, do an outdoors activity you like?
8. You have a free afternoon. Would you rather: option A, go to a museum, or Option B, go to the theatre?
9. You have saved £280. Would you rather: option A, buy something you really want, or Option B, donate it to a fundraising event?
10. You are very impatient and don’t like to wait. Would you rather: option A, never have to wait in line at airports, or Option B, never have to wait in line at stores?

Set 2 - VideoCall

1. You don’t have much work this year. Would you rather: option A, work part-time in a department store, or Option B, volunteer in a charity shop?
2. You have won a voucher. Would you rather: option A, have free coffee for a year, or Option B, have free cake for a year?
3. A witch will make your wish come true. Would you rather: option A, find your true love, or Option B, find £100,000?
4. You have saved £300. Would you rather: option A, donate it to an international NGO, or Option B, buy new furniture for your place?
5. You have a free weekend. Would you rather: option A, spend it by the sea, or Option B, spend it in the mountains?
6. You have a free day this week. Would you rather: option A, participate in a fundraising campaign, or Option B, enjoy a relaxing day to do things you like?
7. You are going to the cinema this evening. Would you rather: option A, watch a fantasy film, or Option B, watch a comedy film?
8. Your watch is broken. Would you rather: option A, always be 10 minutes late, or Option B, always be 20 minutes early?
9. You have a special power during this month. Would you rather: option A, discover a new planet, or Option B, discover a new animal specie?
10. You have saved £210. Would you rather: option A, spend it during your holidays, or Option B, give it to a local charity?

Set 3 - Real

1. You have some spare time this year. Would you rather: option A, volunteer in a homeless shelter, or Option B, find a part-time job in a café?

2. You have a free evening. Would you rather: option A, spend it in a concert, or Option B, spend it at the cinema?
3. You have saved £180. Would you rather: option A, donate it to a charity, or Option B, spend it on a trip?
4. You want to reduce your electricity expenses for a week. Would you rather: option A, live without the Internet, or Option B, live without heating and hot water?
5. It's Christmas and you are about to open your presents. Would you rather: option A, receive cash, or Option B, receive a gift?
6. You have saved £320. Would you rather: option A, do some refurbishments in your home, or Option B, give it to an online fundraising cause?
7. You don't have access to water for a day. Would you rather: option A, only drink coke, or Option B, only drink juice?
8. You have the special power to become an animal for a day. Would you rather: option A, become a fish, or Option B, become a bird?
9. You have a free evening during the week. Would you rather: option A, have a nice and relaxing dinner, or Option B, volunteer in a soup kitchen?
10. A wizard will give you a superpower for a day. Would you rather: option A, be invisible, or Option B, be able to fly?

Chapter 5. Social signals and neural mechanisms for reciprocal face-to-face interactions

Data for this chapter was collected during a research visit at the Brain Function Laboratory at Yale University. I would like to thank Prof. Joy Hirsch and her team for their help and supervision throughout this project, and the Yale-UCL Collaborative and Bogue Fellowship for their financial support.

5.1. Abstract

Second-person neuroscience suggests that reciprocal social interactions activate neurocognitive mechanisms not engaged in non-interactive situations. Here, we created a situation where pairs of participants engaged in reciprocal (or non-reciprocal) social interactions. By combining simultaneous eye-tracking, face-tracking and functional near-infrared spectroscopy (fNIRS) recordings, this chapter examined how reciprocal social interactions modulate social signalling and brain activity while pairs of participants disclose (or not) biographical information. When information was disclosed, participants directed more eye gaze to the face of the partner and produced more facial displays. Moreover, bilateral temporo-parietal junction (TPJ) and left dorsolateral prefrontal cortex (dlPFC) increased their activity when information was disclosed. We also found that spontaneous production and observation of facial displays was associated with activity in the left supramarginal gyrus (SMG) and right dlPFC, respectively. These multimodal findings are consistent with the second-person neuroscience approach, and advance our current understanding of neurocognitive mechanisms that underlie reciprocal social interactions.

5.2. Introduction

The second-person neuroscience approach suggests that neurocognitive mechanisms engaged during social interactions are different from those engaged in non-interactive situations, i.e. when participants only observe videos or pictures of another person (Redcay & Schilbach, 2019; Schilbach et al., 2013; see also Di Paolo & De Jaegher, 2012). For instance, brain activity in frontal regions is different when making eye contact with a live person compared to making eye contact with a picture (Cavallo et al., 2015; Hirsch et al., 2017) and, as shown in Chapter 2 and 4, eye gaze shows different patterns when directed to a live person or when directed to a pre-recorded person (Gobel et al., 2015; Laidlaw et al., 2011). Second-person neuroscience also proposes that studying effects related to mutual engagement between partners (i.e. beyond the mere presence of a real person) is key to understand the mechanisms underlying social information processing (Redcay & Schilbach, 2019).

Reciprocal social interactions are characterised by two (or more) partners mutually engaged with each other, that is, jointly sharing information with one another (Di Paolo & De Jaegher, 2012; Hasson & Frith, 2016; Redcay & Schilbach, 2019). During reciprocal social interactions partners regulate each other through eye gaze, facial displays, speech and gestures: in this context, these behaviours acquire a communicative function and become social signals (Cañigueral & Hamilton, 2019; Crivelli & Fridlund, 2018; Gobel et al., 2015; Holler, Kendrick, & Levinson, 2016). Moreover, reciprocal social interactions recruit specific brain systems for social information processing, for instance during dialogue compared to monologue (Hirsch et al., 2018). This chapter investigated how social signalling (eye gaze and facial displays) and brain activity are modulated by reciprocal social interactions. In the context of our study, reciprocal social interactions are characterised by disclosure of biographical information. In the following we describe which cognitive processes might be engaged when sharing information with another person.

5.2.1. Neurocognitive mechanisms for information sharing

When sharing biographical information with another person our preferences and actions are at risk of being judged by other people, and consequently our reputation is at risk. Thus, one mechanism that may be engaged during information sharing is reputation management. Reputation management is a social goal that emerges from the desire to promote a positive judgement when we are in the presence of others (Cage, 2015; Emler, 1990; Resnick et al., 2006; Silver & Shaw, 2018; Tennie et al., 2010). For instance, acting for the benefit of other people (i.e. prosocial behaviour; Cage, 2015; Cage, Pellicano, Shah, & Bird, 2013; Izuma et al., 2011, 2009) and conforming to social norms (e.g. agreeing with the group; Asch, 1955) are two examples of how we can signal a positive reputation and try to gain approval from others. Management of reputation is closely related to the audience effect, which refers to changes in behaviour specifically caused by the belief that someone is watching us (Hamilton & Lind, 2016): in social contexts where others can observe us and instantaneously evaluate our actions, beliefs and attitudes, our behaviours are adjusted to maintain a positive public image.

Three main cognitive processes have a key role in the maintenance or management of reputation (Cage, 2015; Cage et al., 2013; Izuma et al., 2011, 2009). First, we need to infer what others think of us, which means that we need to attribute mental states to others in relation to oneself (Cage, 2015). Second, we need to care about how others see us and have the desire to foster positive impressions on others, which means that reputation management also requires some degree of social motivation (Cage, 2015; Izuma et al., 2010). Third, it may involve strategic decision-making and self-control processes to guide strategic behavioural changes aimed at promoting a positive reputation in front of others (Izuma, 2012). In line with this, neuroimaging studies have shown that brain regions recruited during mentalising (e.g. medial prefrontal cortex, mPFC; Frith & Frith, 2006) and social reward processing (e.g. ventral striatum, VS) are engaged during reputation management (Izuma, 2012; Izuma et al., 2009, 2010). Moreover, the dorsolateral prefrontal cortex (dlPFC), a neural correlate for strategic decision making and deception (Soutschek et al., 2015; Speitel, Traut-Mattausch, & Jonas, 2019), might also be recruited in situations where reputation is at stake.

Two more cognitive mechanisms could be involved during sharing of biographical information. On the one hand, mutual sharing of information implies that we will learn new information about other people, which we may use or not to guide our future behaviours. On the other hand, during mutual sharing of information it is likely that we will be thinking about other people and the information they have shared with us. In both cases, mentalising brain areas such as the mPFC and right temporoparietal junction (right TPJ) (Frith & Frith, 2006; Saxe & Kanwisher, 2003; Saxe & Wexler, 2005) may be engaged when others share information with us. Learning and thinking about others may also recruit regions involved in working memory, such as the dlPFC (Barbey, Koenigs, & Grafman, 2013; Veltman, Rombouts, & Dolan, 2003): in the context of mutual information sharing, this system may allow us to maintain and manipulate information about others in short-term memory to influence our own beliefs and behaviours.

In previous studies looking at information sharing (mainly in the context of reputation management) participants are not engaged in reciprocal social interactions: they are missing the continuous exchange and integration of social signals that shape face-to-face encounters. Furthermore, these studies happen in restricted neuroimaging environments, such as functional magnetic resonance imaging (fMRI) where participants are alone inside the scanner (Izuma et al., 2009, 2010; Müller-Pinzler et al., 2016). In this chapter, we addressed these limitations by using a dyadic experimental paradigm where participants mutually engage (or not) with each other. Pairs of participants privately indicated their personal preferences or behaviours in different everyday situations. Critically, prior to each block participants were informed whether their choices would be disclosed or not to the partner. Disclosure of biographical information created a shared environment where participants could reciprocally engage with each other. Multimodal measurements of these face-to-face interactions with eye-tracking, face-tracking and functional near-infrared spectroscopy (fNIRS), allows us to study how social signals (eye gaze and facial displays) and brain activity are modulated during reciprocal interactions.

5.2.2. Social signalling in social interactions

In face-to-face interactions there is typically a continuous exchange and integration of social signals, such as eye gaze, facial displays, speech and gestures. The rapid processing and timed coordination of these social signals allows partners to successfully gather and communicate information between each other (Cañigueral & Hamilton, 2019; Di Paolo & De Jaegher, 2012; Hirsch et al., 2018, 2017; Redcay & Schilbach, 2019). Using a variety of experimental settings, it has been shown that we use social cues differently when we are in face-to-face interactions compared to when we are just observing a picture or video, since images are not able to perceive us or respond. For the scope of the present study, we focus on eye gaze and facial displays.

Recent studies have shown that eye gaze acquires a communicative function when we are in the presence of other people. For instance, it has been shown that people direct less amount of gaze to a real person than to a video of the same person (Laidlaw et al., 2011), and that the ratio of gaze directed to eyes relative to gaze directed to mouth is modulated by social rank of the confederate only when participants believe their gaze patterns will later be seen by the confederate (Gobel et al., 2015). This suggests that gaze patterns in real interactions are modulated to signal compliance to social norms (e.g. it is not polite to stare at someone; Foulsham et al., 2011; Gobel et al., 2015; Goffman, 1963). A recent proposal suggests that these changes may also respond to the dynamics of communicative encounters (Cañigueral & Hamilton, 2019). In line with this, Kendon (1967) originally described three functions of eye gaze during conversation: regulatory (gaze modulates turn-taking between speaker and listener), monitoring (gaze tracks attentional states and facial displays of the partner), and expressive (gaze regulates the level of arousal in the interaction). Of particular interest to the present study is the monitoring function of gaze: as shown in Chapter 2, in situations where participants share information with each other, eye gaze may be used to check for social approval from others by tracking their facial displays and attentional states (Efran, 1968; Efran & Broughton, 1966; Kleinke, 1986).

Similar to eye gaze, it has been suggested that we make facial displays not only to convey emotions, but also as a means of communication (Crivelli & Fridlund, 2018). For instance, Fridlund (1991) showed that the amount of smiling when watching a video was higher when participants were (or imagined they were) with a friend than when they were alone (see also Chovil, 1991), and similar patterns have been found in infants during play (Jones, Collins, & Hong, 1991). Similarly, participants show increased mimicry of smiles from faces that can reciprocate compared to faces that cannot (J. K. Hietanen, Kylliäinen, et al., 2018). In Chapter 4, we have also shown that participants make more facial displays when they are being watched by a live confederate. Thus, facial displays may serve to influence, or signal, a target audience (Crivelli & Fridlund, 2018). To our knowledge there are no previous studies that directly look at the relationship between facial displays and reciprocity in social interactions. Building on the studies presented above and our findings in Chapter 4, we hypothesised that reciprocal interactions might lead to more exchanges of facial displays between the interacting partners, since they need to signal what they think of each other. In the present study we tested this hypothesis by using facial motion tracking.

5.2.3. Using fNIRS for the study of social interactions

The study of neural correlates of social interactions is challenged within restricted neuroimaging environments (e.g. fMRI), since it is hard to measure brain activity in face-to-face interactions. This limitation can be addressed using functional near-infrared spectroscopy (fNIRS), a non-invasive neuroimaging technique that enables the recording of neural activity using near-infrared light. This technique uses light sources and detectors placed on the scalp, which measure changes in spectral absorbance of oxyhemoglobin (OxyHb) and deoxyhemoglobin (deOxyHb) in the cortex. These measures are then converted to concentration of OxyHb and deOxyHb, respectively. Similar to fMRI, this hemodynamic signal is taken as a proxy for brain activity (Boas et al., 2014; Cui et al., 2011; Ferrari & Quaresima, 2012; Scholkmann et al., 2014).

It is important to note that fNIRS has lower spatial resolution than fMRI, and that it measures brain activity only in outer layers of the cortex (Pinti, Aichelburg, et al., 2018). Nonetheless, due to its high portability and tolerance to motion, fNIRS allows researchers to record brain activity in ecologically valid settings (Pinti, Aichelburg, et al., 2018). For instance, it has been used in two-person studies where individuals are interacting face-to-face (Cui et al., 2012; Hirsch et al., 2018, 2017; Jiang et al., 2012; Piva, Zhang, Noah, Chang, & Hirsch, 2017), in studies with infants (Lloyd-Fox et al., 2010), and for bedside imaging (Obrig, 2014). Here, we used fNIRS to simultaneously measure brain activity of two participants while they interact face-to-face and share information with each other.

5.2.4. The present study

The aims in Chapter 5 were twofold. First, to investigate how social signals (eye gaze and facial displays) are modulated during reciprocal social interactions. Second, to examine which brain systems are recruited by this shared experience. To do this, pairs of participants sat across a table from each other and performed the Public Feedback Task during dual eye-tracking, face-tracking, and fNIRS recordings. In this task, participants first heard a statement describing some biographical information (Question phase; e.g. “I try not to cover up my mistakes”). Then, they privately indicated (keyboard press) if this statement was true or false about themselves (Answer phase). Prior to each block, participants were informed whether, after each trial, their choices would be disclosed or not to the dyad. Thus, after each choice the answers of both partners were either revealed or not to the dyad (Feedback phase). If choices were disclosed (Public condition; recording says “Same answers” or “Different answers”) participants would share information with partner and would be likely to engage in reputation management, as well as learning or thinking about others. This was not the case when choices were not disclosed (Private condition; recording says “Answers received”).

Our hypotheses were the following. First, we expected that participants would gaze more to the face of the partner and produce more facial displays in the Public condition compared to the Private condition, particularly during the Feedback phase. Second, we expected that in the Public condition there would be increased brain activity in regions related to reputation management, learning and thinking about others. The fNIRS headset used in our study covered the lateral sides of both hemispheres, so our hypotheses were restricted to these brain regions. We expected that the right temporo-parietal junction (right TPJ) would be up-regulated during the Feedback phase, when participants’ choices are shared. We also expected that the dlPFC, responsible for strategic decision-making, self-control and working memory, would be recruited during the Question and Answer phases, i.e. when participants were generating their choices. Finally, we performed an exploratory analysis to investigate how the amount of spontaneous facial motion is related to brain activity in face-to-face interactions. We were particularly interested in brain activity associated with the spontaneous production (participants moving their own face) and observation (participants seeing their partner move the face) of facial displays.

5.3. Materials and Methods

5.3.1. Participants

Thirty healthy adult participants (15 dyads) participated in the study: 22 females, 8 males; mean age: 28.2 ± 7.33, age range from 18 to 45 years; 28 right-handed, 2 left-handed (Oldfield, 1971). The study took place at the Brain Function Laboratory (Yale University). All thirty participants were included in the facial motion analysis and neural data analysis. However, nine participants were excluded from the eye gaze analysis due to poor signal quality in the eye-tracking data. Participants included in the study previously demonstrated reliable fNIRS signal responses over the primary motor cortex during a screening process involving a finger-thumb tapping task. Participants were assigned to pairs in order of recruitment: they were all strangers prior to the study, and no participant was included in more than one dyad. Eight pairs were mixed gender, and eleven pairs were female-female. All participants provided written informed consent and were compensated for their participation in the study, in accordance with established and approved guidelines at Yale University and University College London.

5.3.2. Experimental paradigm

To manipulate the opportunity for reciprocal engagement we designed the Public Feedback Task. This task is inspired by Izuma et al. (2010), where participants disclosed their tendencies relative to social norms. We created a set of 40 statements, each one describing a particular personal preference or behaviour. Half of these statements described daily situations (e.g. “I sometimes drink coffee in the morning”) and half were taken from pre-existing questionnaires measuring concerns about reputation (e.g. “I try not to cover up my mistakes”) (Crowne & Marlowe, 1960; Paulhus, 1984, 1991). Note that for the analyses we pooled all statements together, since there was not enough power to test the effect of a 3-way interaction between type of statement, condition and phase. See section *5.7.1. List of statements* for a full list of statements used in the study.

For each trial, participants first heard a recording of a statement that was between 3 and 5 seconds long (Question phase) (see Figure 5-1a). This was followed by a tone and a 3 second period where participants indicated if the statement was true or false about themselves by pressing a key on the desktop keyboard (Answer phase). Then, the choices of both participants could be either disclosed or not to the dyad (Feedback phase). In the Public condition, choices were disclosed and participants heard a recording saying “Same answers” or “Different answers”. In either case, participants could learn about their partners’ choices and evaluate their choices relative to their partners’, thus generating opportunity for reciprocal engagement between partners. In the Private condition, choices were not disclosed and participants heard a recording saying “Answers received”, so there was no opportunity for reciprocal interaction. If any of the choices were missing, then participants heard a recording saying “Answer missing”. After hearing the recording, there was a silence period of 5 seconds for processing information from the

Feedback. Note that participants were instructed not to talk to each other during the task. After the Feedback phase, participants heard the instruction "Rest" and they looked at a fixation cross on their left side of the table for 10 seconds. Then, the next trial started. The total duration of each trial was between 21 and 23 seconds long.

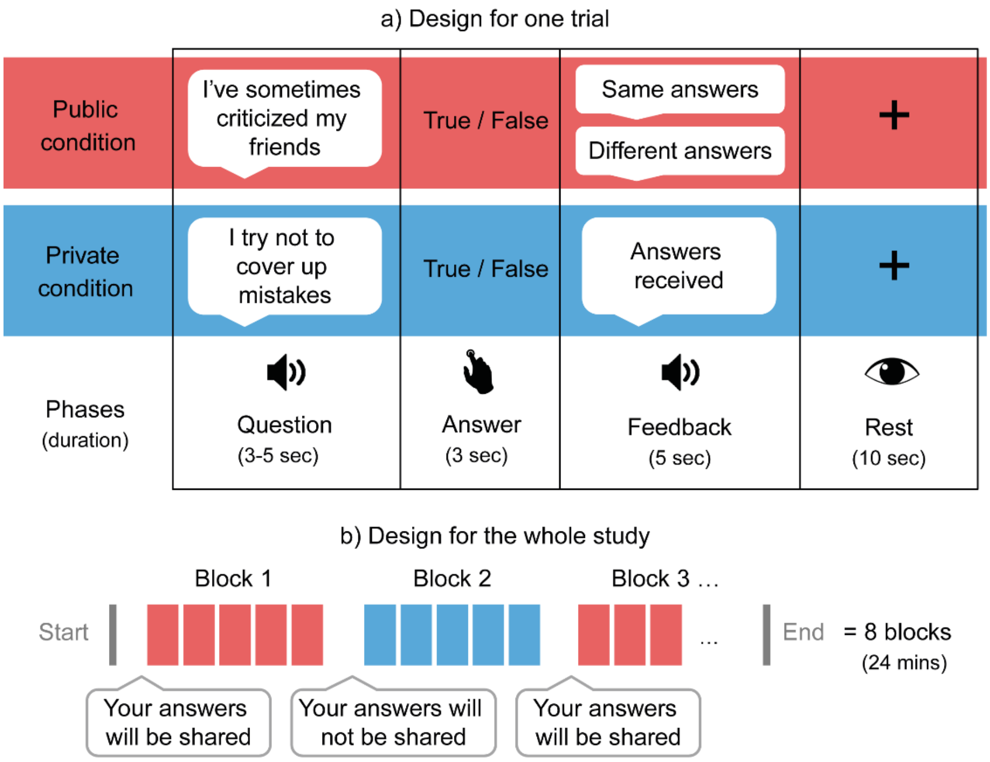

Figure 5-1. Study design.
a) Timeline for one trial. b) Design of the whole task.

Participants completed 8 blocks of 5 trials each. Half of the blocks were Public and half were Private. Before each block started, participants heard a recording saying "Your answers will be shared" or "Your answers will *not* be shared" to indicate if that block was Public or Private (see Figure 5-1b). The statements were randomly assigned to the blocks for each participant, and the order of the blocks was randomised across participants. Each fNIRS run was composed of 2 blocks, and participants had a short break between runs. The total duration of the task was around 25 minutes.

5.3.3. Experimental set-up

Participants sat across a table at approximately 140 cm from each other, in an experimental room with dim fluorescent light. Noise around the experimental room was minimised to prevent distraction of participants during the study. The room was equipped with an fNIRS, eye-tracking and video-camera system arranged to record data from the faces of two participants (see Figure 5-2a). Each participant had a keyboard on the table to indicate their answers. An occluder was positioned between participants to prevent them from seeing the keyboard of their partner. On the left side of each participant, a black fixation-cross was located as a resting position between trials and blocks. This set-up is similar to those used in previous publications (e.g. Hirsch et al., 2018, 2017), and combines simultaneous recordings of eye-tracking, face-tracking and fNIRS (see Figure 5-2a,b,c).

5.3.4. Eye-tracking and facial motion signal acquisition

The two-person eye-tracking system included a webcam placed above each participant's head to record the face of the partner, and a table-based eye-tracker (Tobii Pro Lab X3-120) attached to each side of the occluder to record eye movements of the participant. The system then merged the input from both cameras to map the gaze of each participant onto the scene recorded by the webcam. Participants sat approximately 70 cm from the eye-tracker and a 3-point calibration routine (right eye, left eye, and tip of chin of the partner) was employed before starting the task. The eye-tracker recorded eye positions within 0.4 degrees of visual angle and movements of both eyes at a rate of 120 Hz. This signal was synchronized with stimulus presentations and fNIRS acquisition of neural signal via a TTL trigger mechanism.

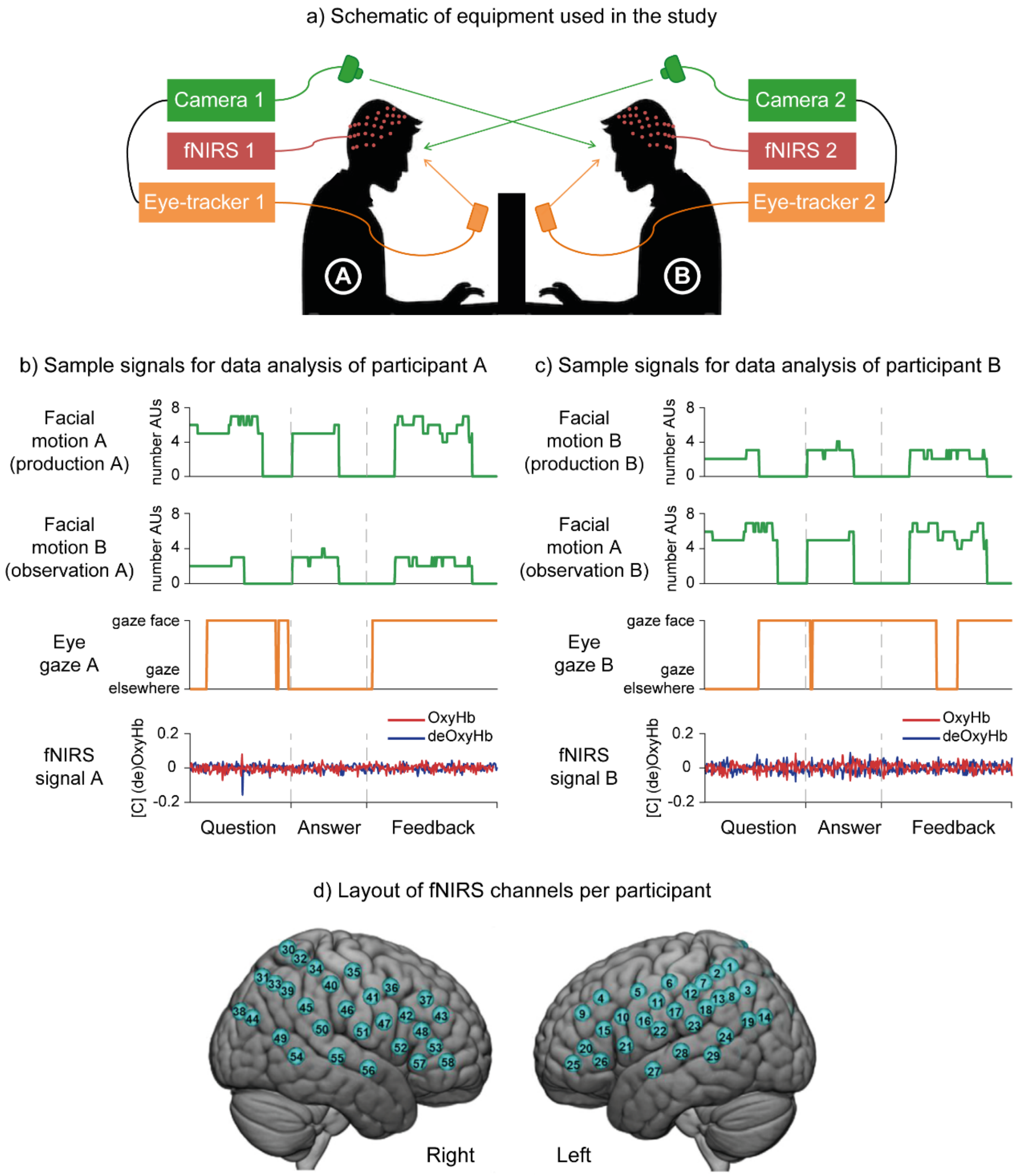

Figure 5-2. Experimental set-up.
a) Schematic of the testing room showing the equipment used to test a dyad: fNIRS (red), eye-tracking (orange), and video-cameras for face-tracking (green). b) Sample signals contributing to data analysis for participant A. Behavioural signals comprise production of facial motion from A (recorded with camera 2), observation of facial motion from B (recorded with camera 1), and gaze of A towards/away from B's face (eye-tracker 1). A sample fNIRS signal (recorded with fNIRS 1) is shown from one channel, 58 channels were recorded in the study. c) Sample signals contributing to data analysis for participant B: production of facial motion from B (recorded with camera 1), observation of facial motion from A (recorded with camera 2), gaze of B towards/away from A's face (eye-tracker 2), and fNIRS signal (recorded with fNIRS 2). d) Layout of fNIRS channels: average locations of channel centroids (blue dots) are represented on the right and left hemisphere of a single rendered brain.

To track facial motion (i.e. facial displays), the video-camera information was further processed with OpenFace (Baltrusaitis et al., 2016). The OpenFace algorithm uses the Facial Action Coding System (FACS; Ekman & Friesen, 1976) to taxonomise movements of human facial muscles and deconstruct facial displays in specific Action Units (AU). OpenFace can recognise a subset of 18 facial AUs (including facial muscles in areas near the eyes, nose, cheeks, mouth and chin), and gives information about the presence or absence of each of these facial AUs for each frame of the video.

5.3.5. Gaze and facial motion analysis

For the eye gaze analysis, three time windows and one area of interest was defined. The 3 time windows corresponded to the Question phase, Answer phase and Feedback phase. The area of interest corresponded to the face of the partner, and it was manually defined frame-by-frame using the Tobii Pro Lab eye-tracking software. To measure eye gaze, we computed the mean fixation duration at the face of the partner for each time phase. For the facial motion analysis, the same three time windows were defined (Question phase, Answer phase and Feedback phase). To measure facial motion, we combined all 18 facial AUs to compute the mean number of active facial AUs for each time phase. For each measure, a 2-way repeated measures ANOVA with Condition (Public and Private) and Phase (Question, Answer and Feedback) as within-subject factors was performed, using post-hoc pairwise comparisons and Bonferroni’s adjustment for multiple comparisons.

5.3.6. Neural signal acquisition

Hemodynamic signals were acquired using an 80-fiber (116-channel) continuous wave fNIRS system (Shimadzu LABNIRS, Kyoto, Japan) configured for hyperscanning of two participants. Each participant in a dyad had the same distribution of 58 channels over both hemispheres (see Figure 5-2d). Participants were fitted with a cap with optode holders, where channel separations were adjusted by individual differences in head size (2.5 cm for small heads, 2.75 cm for medium heads, and 3.0 cm for large heads). This ensured that across participants the same channels (source-detector pairs) overlaid the same cortical areas. A lighted fiber-optic probe (Daiso, Hiroshima, Japan) was used to remove hair from each optode holder area before placing the optode inside the holder, to maximise the transmission of light through the scalp. Before starting the signal recording, light intensity for each channel (source-detector pair) was measured and the signals were adjusted to assure each detector was able to detect sufficient light output from each paired source. Temporal resolution for signal acquisition was 27 Hz, and signals were down-sampled to 3 Hz to reduce temporal autocorrelation. Three wavelengths of light (780, 805 and 830 nm) were delivered by each source and their reflectance was measured by each detector.

5.3.7. Optode localisation

Once the signal acquisition was finished, the optodes were removed but the cap was left on the head of the participant to map the optode locations on the scalp. Anatomical locations of optodes were determined for each participant in relation to standard 10-20 system based on head landmarks (inion, nasion, top center (Cz), and left and right tragi) using a Patriot 3D Digitizer (Polhemus, Rochester, VT) and linear transform techniques (Eggebrecht et al., 2012; Ferradal, Eggebrecht, Hassanpour, Snyder, & Culver, 2014; Okamoto & Dan, 2005). Montreal Neurological Institute (MNI) coordinates for the channels were obtained using NIRS-SPM (Ye, Tak, Jang, Jung, & Jang, 2009) with MATLAB (Mathworks, Natick, MA), and corresponding anatomical locations of each channel were determined using the Talairach Atlas (see Figure 5-2d and section *5.7.2. Channel description* for median channel centroids).

5.3.8. Signal processing

Using the modified Beer–Lambert equation, levels of absorption for each of the three wavelengths were converted to concentration changes for oxyhemoglobin (OxyHb), deoxyhemoglobin (deOxyHb), and total combined deoxyhemoglobin and oxyhemoglobin. Note that we did not apply a differential pathlength correction factor, given the large distribution of optodes in our study and its unknown variance between subjects, age, gender and specific anatomy. Baseline drift was removed using wavelet detrending (NIRS-SPM), and hemodynamic modelling of the data served as a low-pass filter. For each participant, channels with strong noise were automatically identified and removed from the analyses if the root mean square of the raw data was more than 10 times the average signal. Approximately 14% of the channels were automatically excluded using this criterion. Global components originating from systemic activity (e.g. blood pressure, respiration and blood flow) were removed from the fNIRS signal using a principle components analysis (PCA) spatial filter (Zhang, Noah, Dravida, & Hirsch, 2017; Zhang, Noah, & Hirsch, 2016) prior to hemodynamic modelling of the data. This method detects and removes components in the signal that are present throughout the brain (related to systemic effects), to isolate localised signals originating from neural activity related to the task.

5.3.9. Signal selection

In the present study we have analysed both OxyHb and deOxyHb signals (Tachtsidis & Scholkmann, 2016). We base our findings on the deOxyHb signal (Dravida, Noah, Zhang, & Hirsch, 2017; Hirsch et al., 2018, 2017; Piva et al., 2017; Rojiani, Zhang, Noah, & Hirsch, 2018; Zhang et al., 2017, 2016). However, results using the filtered OxyHb signal are included in sections *5.7.5. Full OxyHb results for task effects* and *5.7.7. Full OxyHb results for task+face effects*, and are confirmatory.

5.3.10. Data analysis: voxel-wise contrast effects

The general linear model (GLM, SPM8) was used to fit the deOxyHb signal to the convolved hemodynamic response function. Beta values (i.e. deOxyHb signal amplitudes) were obtained for each channel and reshaped into a 3-D volume image with 2x2x2 mm voxels that tiled the brain regions covered by the channels.

The GLM was then used to generate contrast comparisons for two different analyses. First, to identify task-related effects (Public versus Private), the “task GLM” included 6 categorical regressors, corresponding to all combinations of Condition and Phase levels: Public-Question, Public-Answer, Public-Feedback, Private-Question, Private-Answer, Private-Feedback. This GLM generated contrast comparisons between Public and Private conditions for each Phase (Question, Answer and Feedback).

Second, to identify effects related to facial displays, the “task+face GLM” included all 6 previous categorical regressors and 2 additional parametric regressors that accounted for production (participants moving their own face) and observation (participants seeing their partner move the face) of facial displays, respectively. To generate the Production regressor, we matched the brain activity of participant A in each dyad with the amount of facial motion in the same participant. To generate the Observation regressor we matched the brain activity of participant A in each dyad with the amount of facial motion from participant B in the same dyad. The comparable matching was used to generate the Production and Observation regressors for participant B in each dyad. Contrast comparisons were generated between Public and Private conditions for each Phase, and for each of the parametric regressors (Production and Observation) for the whole trial duration.

For each contrast comparison, one-tailed *t*-tests were computed using SPM8. The FDR correction method ($q < .05$) was used to correct for multiple comparisons. All results are presented on a normalised brain using images rendered on a standardized MNI template, using a $p < .05$ threshold. Anatomical locations of peak voxel activity were identified using the NIRS-SPM atlas (Ye et al., 2009).

5.3.11. Effects related to behavioural choices

During the task we also recorded the choices of participants. Particularly in the Public condition, where choices are disclosed to the dyad, eye gaze and facial motion might be modulated by whether partners agree or disagree in their choices: it could be that effects of reciprocal interactions on eye gaze and facial motion are stronger if partners disagree than if they agree. To test this, we ran two additional analyses (for eye gaze and for facial motion) and found that there were no effects of agreement on these measures (see section *5.7.3. Effects of agreement on eye gaze and facial motion* for details of these analyses). Note that, since participants made choices freely, the mean number of trials for agree and disagree categories was not balanced: there were around 3 times more trials where participants agreed than disagreed, for both Public and Private conditions. Thus, we did not test effects of agreement on brain activity due to lack of sufficient statistical power.

5.4. Results

5.4.1. Eye gaze and facial motion

To test effects of reciprocal interactions on eye gaze, we measured the mean fixation duration at the face of the partner for each Condition and Phase (see Table 5-1a for descriptives: mean and SD). There was no main effect of Condition ($F(1,20) = 1.15$, $p > .05$, $n_p^2 = .054$) or Phase ($F(2,40) = 1.54$, $p > .05$, $n_p^2 = .072$), but there was an interaction effect between Condition and Phase, $F(2,40) = 6.77$, $p = .003$, $n_p^2 = .253$. Post-hoc pairwise comparisons showed that the mean fixation duration to the face of the partner was higher in the Public condition compared to the Private condition in the Feedback phase, $t(20) = 3.10$, $p = .006$, $d_z = .676$ (see Figure 5-3a,b). Specifically, participants looked more at the face of the partner in the Public condition during the Feedback phase.

To test effects of reciprocal interactions on facial motion, we measured the mean number of facial Action Units (AUs) for each Condition and Phase (see Table 5-1b for descriptives: mean and SD). There was a main effect of Condition, $F(1,29) = 23.6$, $p < .001$, $\eta_p^2 = .449$, showing that there were more facial AUs in the Public compared to the Private condition. There was also a main effect of Phase, $F(2,58) = 132.3$, $p < .001$, $\eta_p^2 = .820$, and post-hoc pairwise comparisons showed that the number of facial AUs was higher in the Feedback phase than in the Question phase ($t(29) = 4.82$, $p < .001$, $d_z = .881$)

and Answer phase ($t(29) = 13.2$, $p < .001$, $d_z = 2.41$). We also found an interaction effect between Condition and Phase, $F(2,58) = 7.71$, $p = .004$, $\eta_p^2 = .210$. Post-hoc pairwise comparisons replicated the pattern of results found for the main effects: there were more facial AUs in the Public than in the Private condition for all Phases (Question: $t(29) = 4.81$, $p < .001$, $d_z = .860$; Answer: $t(29) = 4.05$, $p < .001$, $d_z = .740$; Feedback: $t(29) = 4.70$, $p < .001$, $d_z = .860$), and there were more facial AUs in the Feedback phase compared to the Question and Answer phases for both Conditions (Public Feedback-Question: $t(29) = 4.26$, $p < .001$, $d_z = .780$; Public Feedback-Answer: $t(29) = 12.03$, $p < .001$, $d_z = 2.20$; Private Feedback-Question: $t(29) = 3.33$, $p = .002$, $d_z = .610$; Private Feedback-Answer: $t(29) = 12.06$, $p < .001$, $d_z = 2.20$) (see Figure 5-3c,d). Specifically, participants moved more facial muscles in the Public condition across all phases, and during the Feedback phase compared to all other phases.

Table 5-1. Descriptives for eye gaze and facial motion

a) Duration fixation of gaze to face of partner (in ms)

Condition	**Phase**		
	Question	Answer	Feedback
Public	*M* = 389.05 *SD* = 205.89	*M* = 349.57 *SD* = 195.20	*M* = 477.38 *SD* = 247.20
Private	*M* = 367.76 *SD* = 180.32	*M* = 395.81 *SD* = 189.97	*M* = 367.52 *SD* = 181.91

b) Number of facial AUs

Condition	**Phase**		
	Question	Answer	Feedback
Public	*M* = 2.65 *SD* = .898	*M* = 1.84 *SD* = .600	*M* = 2.99 *SD* = 1.05
Private	*M* = 2.27 *SD* = .796	*M* = 1.52 *SD* = .485	*M* = 2.42 *SD* = .862

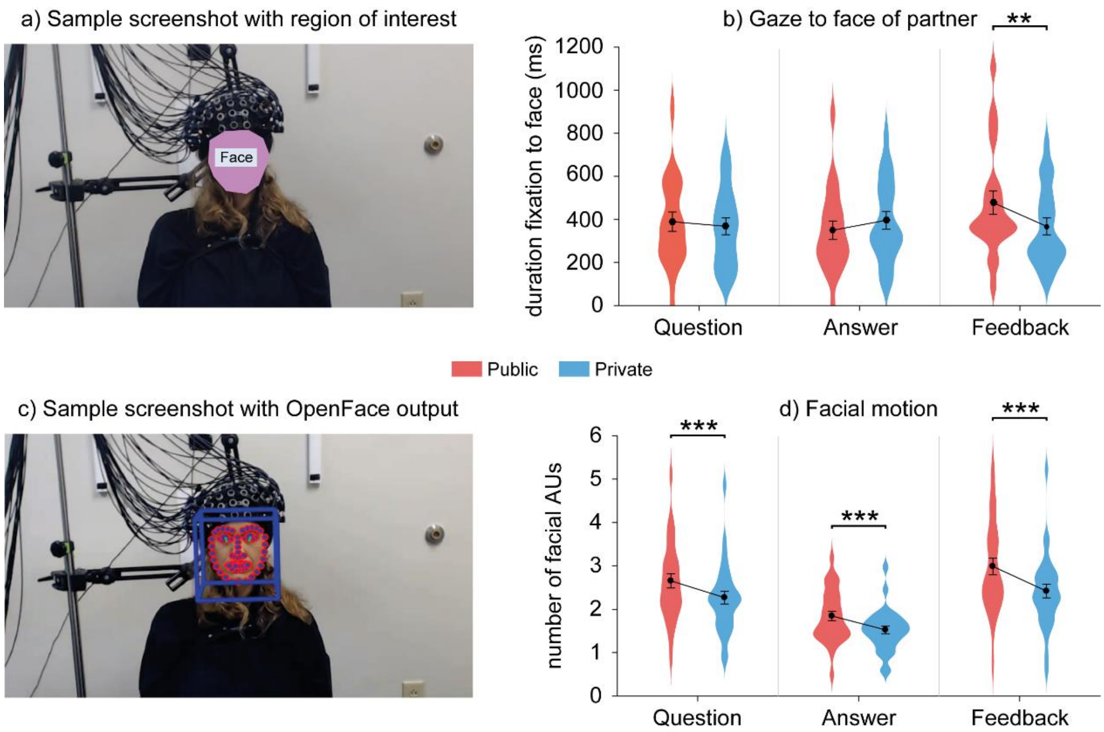

Figure 5-3. Results for eye gaze and facial motion analyses.
a) Region of interest for gaze analysis (face of partner). b) Duration fixation of gaze to the partner's face for each Condition and Phase. c) Sample frame of the OpenFace output video. d) Number of facial AUs for each Condition and Phase. Mean (filled circle), SE (error bars), and frequency of values (width of distribution). Asterisks signify difference at p < .05 (*), p < .01 (**) and p < .001 (***).

5.4.2. Brain activity related to reciprocal interactions

To test effects of reciprocal interactions on brain activity, we used the "task GLM" to generate contrast comparisons between Public and Private conditions for each Phase (Question, Answer and Feedback). Only significant FDR-corrected clusters for deOxyHb signal are reported in the main text and Table 5-2 (see also Figure 5-4); full statistics for all activated clusters are given in section *5.7.4. Full deOxyHb results for task effects*, and results for the same analysis using the OxyHb signal are given in section *5.7.5. Full OxyHb results for task effects*.

For the Question phase, results showed that there was greater brain activity in the Public compared to the Private condition in two clusters located in the left hemisphere. First, a cluster with peak voxel located at (-48, 24, 40)

(p = .005) included the dlPFC (BA9, 49% probability inclusion; BA46, 15% probability inclusion) and frontal eye fields, FEF (BA8, 35% probability inclusion). Second, a cluster with peak voxel located at (-60, -60, 28) (p = .005) included the angular gyrus, AG, which is part of the TPJ (BA39, 45% probability inclusion), supramarginal gyrus, SMG, also part of TPJ (BA40, 38% probability inclusion), and superior temporal gryus, STG (BA22, 14% probability inclusion). For the Answer phase, there was greater activity in the Public compared to the Private condition in a cluster with peak voxel located at (-48, -72, 26) (p = .002), which included the left AG (BA39, 78% probability inclusion) and left visual area 3, V3 (BA19, 22% probability inclusion). For the Feedback phase, there was greater activity in the Public compared to the Private condition in a cluster with peak voxel located at (52, -76, 22) (p = .002), which included the right AG (BA39, 57% probability inclusion) and right V3 (BA19, 43% probability inclusion). For the opposite contrast (Private > Public) no effects were found for any of the phases.

Table 5-2. Voxel-wise GLM contrast comparisons for task-related effects (deOxyHb signal)

Contrast (contrast threshold)	**Phase**	**Peak voxels** MNI coords.[1] (X	Y	Z)	*t*	*p*	df	**Anatomical region**	**BA**	**Prob. incl.**	**Voxels** (n in cluster)
Public > Private (p < .05)	Question	-48	24	40	2.78	.005	29	Dorsolateral Prefrontal Cortex	9	.494	592
								Frontal Eye Fields	8	.349	
								Dorsolateral Prefrontal Cortex	46	.152	
		-60	-60	28	2.74	.005	29	Angular Gyrus, part of TPJ	39	.447	146
								Supramarginal Gyrus, part TPJ	40	.380	
								Superior Temporal Gyrus	22	.145	
	Answer	-48	-72	26	3.22	.002	29	Angular Gyrus, part of TPJ	39	.776	845
								V3	19	.223	
	Feedback	52	-76	22	3.18	.002	29	Angular Gyrus, part of TPJ	39	.566	189
								V3	19	.433	

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere

df = degrees of freedom, BA = Brodmann Area

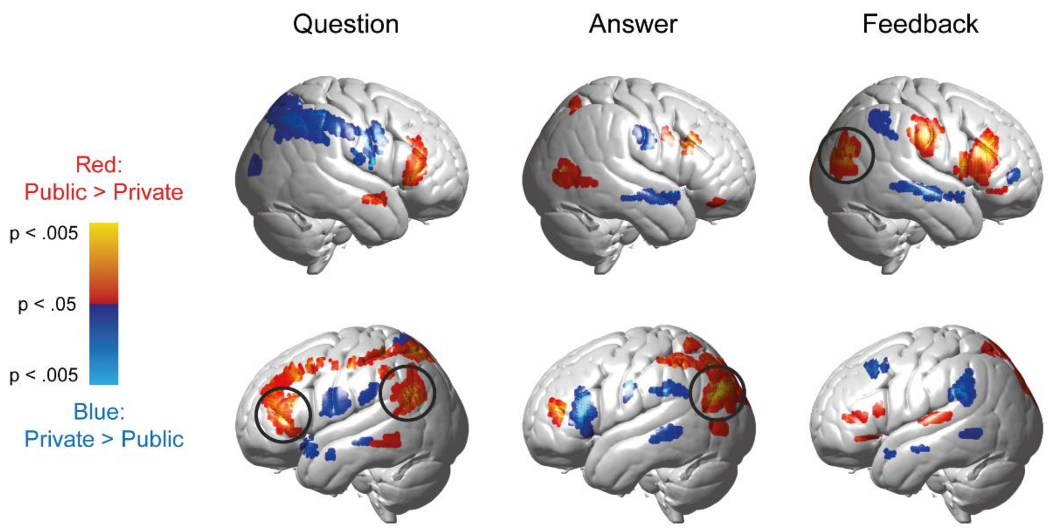

Figure 5-4. Contrast effects for "task GLM" (deOxyHb signal).
Brain activity correlated with Public > Private (red colour; p < .05) and Private > Public (blue colour; p < .05) for each trial Phase (red colour; p < .05). Areas of contrasts in black circles indicate FDR-corrected clusters at q = .05.

5.4.3. Brain activity related to production and observation of facial motion

To test effects of production and observation of facial motion on brain activity, we used the "task+face GLM" to generate contrast comparisons between Public and Private conditions for each Phase (Question, Answer and Feedback), as well as for each of the facial motion regressors (Production and Observation). Only significant FDR-corrected clusters are reported in the main text and Table 5-3 (see also Figure 5-5); full statistics for all activated clusters are given in section *5.7.6. Full deOxyHb results for task+face effects*, and results for the same analysis using the OxyHb signal are given in section *5.7.7. Full OxyHb results for task+face effects*.

We expected that brain regions involved in face processing would be differently activated during production and observation of facial motion. We found that Production of facial motion showed greater activity in a cluster with peak voxel located at (-64, -42, 42) (p = .007), which included the left SMG

(BA40, 95% probability inclusion). However, Observation of facial motion showed greater activity in a cluster with peak voxel located at (40, 30, 30) (*p* = .014), which included the right dlPFC (BA9, 58% probability inclusion; BA46, 42% probability inclusion). See Figure 5-5a.

Table 5-3. Voxel-wise GLM contrast comparisons for task- and face- related effects (deOxyHb signal)

Contrast (contrast threshold)	**Phase**	**Peak voxels** MNI coords.[1] (X Y Z)	*t*	*p*	df	**Anatomical region**	**BA**	**Prob. incl.**	**Voxels** (n in cluster)
Public > Private (p < .05)	Question	-54 34 2	2.47	.010	29	Inferior Frontal Gyrus	47	.506	250
						Pars Triangularis, part of IFG	45	.257	
						Dorsolateral Prefrontal Cortex	46	.206	
	Answer	-56 -46 52	3.13	.002	29	Supramarginal Gyrus, part TPJ	40	1	193
	Feedback	42 -78 40	2.68	.006	29	V3	19	.550	17
						Angular Gyrus, part of TPJ	39	.236	
						Somatosensory Assoc. Cortex	7	.208	
Private > Public (p < .05)	Answer	42 34 24	-3.16	.002	29	Dorsolateral Prefrontal Cortex	46	.813	659
						Dorsolateral Prefrontal Cortex	9	.135	
Face > Baseline	Production	-64 -42 42	2.63	.007	29	Supramarginal Gyrus, part TPJ	40	.949	12
(p < .05)	Observation	40 30 30	2.32	.014	29	Dorsolateral Prefrontal Cortex	9	.578	44
						Dorsolateral Prefrontal Cortex	46	.422	

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere

df = degrees of freedom, BA = Brodmann Area

Moreover, we expected that the comparison between Public and Private conditions would yield results similar to those in the previous analysis using the “task GLM”, and we found that this was the case (Figure 5-5b). For the Question phase, results showed that there was greater brain activity in the Public compared to the Private condition in a left-hemisphere cluster with peak voxel located at (-54, 34, 2) (*p* = .01), which included the inferior frontal gyrus, IFG (BA47, 51% probability inclusion), pars triangularis, which is part of IFG (BA45, 26% probability inclusion), and dlPFC (BA46, 21% inclusion probability). For the Answer phase, there was greater activity in the Public compared to the Private condition in a cluster with peak voxel located at (-56,

-46, 52) (p = .002), which included the left SMG (BA40, 100% probability inclusion). For the Feedback phase, there was greater activity in the Public compared to the Private condition in a cluster with peak voxel located at (42, -78, 40) (p = .006), which included the right V3 (BA19, 55% probability inclusion), right AG (BA39, 24% probability inclusion) and right somatosensory association cortex (BA7, 21% probability inclusion). For the opposite contrast (Private > Public) we found greater activity during the Answer phase in a cluster with peak voxel located at (42, 34, 24) (p = .002), which included the right dlPFC (BA46, 81% probability inclusion; BA9, 13% probability inclusion).

5.5. Discussion

This chapter aimed to investigate how reciprocal social interactions modulate social signalling and brain activity during mutual sharing of information. To investigate this, our experimental set-up combined dual eye-tracking, video-recordings for face-tracking and fNIRS. This allowed us to measure brain activity while participants were dynamically interacting face-to-face and, in turn, evaluate how they used social signals (eye gaze and facial displays) during reciprocal interactions. Our findings showed that participants gazed more at each other's face and produced more facial displays when they were reciprocally engaged with each other. We also found that, in this situation, there was more brain activity in the left dorsolateral prefrontal cortex (dlPFC), left temporo-parietal junction (TPJ) and right TPJ, and that these regions were differently activated depending on cognitive processes related to each stage of the trial. Moreover, we found a different pattern of brain activity during spontaneous production (left supramarginal gyrus; SMG) and observation (right dlPFC) of facial motion. We discuss the implications of these findings below.

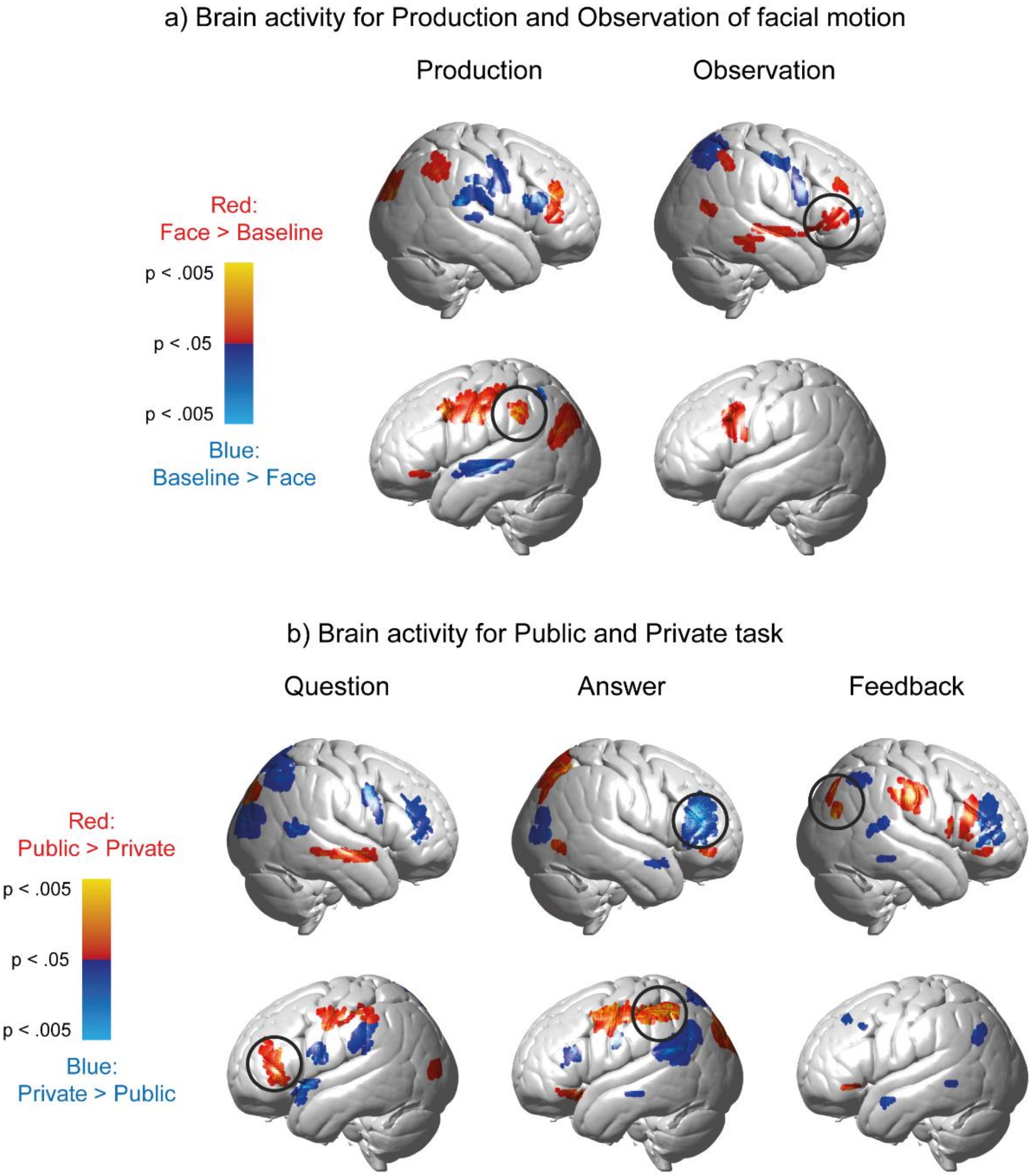

Figure 5-5. Contrast effects for "task+face GLM" (deOxyHb signal).
a) Brain activity correlated with Production of facial motion > Baseline (left) and Observation of facial motion > Baseline (right) (red colour; p < .05), as well as Baseline > Production and Baseline > Observation (blue colour; p < .05). Areas of contrasts in black circles indicate FDR-corrected clusters at q = .05. b) Brain activity correlated with Public > Private (red colour; p < .05) and Private > Public (blue colour; p < .05) for each trial Phase. Areas of contrasts in black circles indicate FDR-corrected clusters at q = .05.

5.5.1. Eye gaze and facial displays are used as social signals

Results showed that participants gazed more to the face of the partner in the Public compared to the Private condition, particularly during the Feedback phase. Interestingly, it was only in the Public condition and during the Feedback phase that partners shared biographical information, which in turn implies that they were learning about each other's choice in relation to their own choice. This subtle manipulation created a shared environment where participants could reciprocally engage with each other to evaluate and manage their reputation, as well as learn or think about each other. This was not the case for the Private condition, where the answers of the participants were not shared. Thus, our findings are in line with previous studies suggesting that in reciprocal interactions people use eye gaze as a communicative signal. In particular, and as we have shown in Chapter 2, eye gaze may be used to monitor the attentional states and facial displays of the partner when reputation is under public scrutiny (Efran, 1968; Efran & Broughton, 1966; Kendon, 1967; Kleinke, 1986). Another possibility is that gaze directed to the partners' face is used to show interest in learning more about them.

We also found that participants produce more facial displays (as measured by the amount of facial motion) in the Public condition, that is, when they can engage in a reciprocal interaction. Moreover, we found that participants made more facial displays in the Feedback phase compared to the Question and Answer phases. This is in line with our findings in Chapter 4 and previous studies showing that participants use facial displays as a means of communication, to signal or influence an audience (Chovil, 1991b; Crivelli & Fridlund, 2018; Fridlund, 1991; J. K. Hietanen, Kylliäinen, et al., 2018; Jones et al., 1991). Here, we suggest that participants produce more facial displays to communicate judgements regarding the shared information, that is, whether they like or dislike their partners' choices.

Altogether, our findings suggest that gaze patterns and facial displays are closely intertwined: when participants gaze more to each other's face, they also produce more facial displays. The coordinated exchange and integration of these social signals, characteristic of face-to-face interactions, allowed participants to efficiently perceive and send information with each other (Cañigueral & Hamilton, 2019; Schilbach et al., 2013). In the context of our task, social signals were used to receive and send information about how participants evaluated and learnt about each other's answers. Thus, we show for the first time that a live and dynamic situation where participant engage in mutual sharing of information translates into both more production and monitoring of facial displays. This suggests that eye gaze and facial displays share a communicative function during reciprocal social interactions.

5.5.2. Brain systems for reciprocal interactions

Using fNIRS, we measured brain activity associated with reciprocal social interactions during mutual sharing of information. Results showed that there was a different pattern of activation depending on cognitive processes related to each stage of the trial. Our strongest hypothesis was that in the Public Feedback condition (compared to the Private Feedback) there would be more activation in the right TPJ, and our findings confirm this assumption (particularly for the angular gyrus, AG). Previous studies have related activity in the right TPJ with mentalising (Saxe & Kanwisher, 2003; Saxe & Wexler, 2005), that is, the ability to infer other people's beliefs and intentions. The activation of the right TPJ specifically during the Public Feedback condition (when participants had already shared their answers) could be explained by three different mechanisms. First, it has been reported that reputation management recruits mentalising brain areas (e.g. mPFC; Frith & Frith, 2006), suggesting that it is a core cognitive process involved in reputation management (Izuma, 2012; Izuma et al., 2010). Note that the fNIRS headset used in our study covered the lateral sides of both hemispheres, so our hypotheses could not be tested on the mPFC. However, the activation in the right TPJ suggests that mutual sharing of biographical information may trigger reputation management mechanisms that allow participants to evaluate each other's choices. Second, recruitment of right TPJ during the Public Feedback condition could be related to increased mentalising while learning information about others. Finally, it could also be that activity in the right TPJ is linked to participants just thinking about their partners once information has been shared.

As expected, we also found that the dlPFC (particularly in the left hemisphere) was more activated in the Public compared to the Private condition, and that this activation was specific to the Question phase (i.e. when participants were deciding what answer to give). The dlPFC has been associated with strategic decision-making against self-interests. For instance, it has been shown that disruption of the dlPFC with transcranial magnetic stimulation during presentation of moral dilemmas decreases the amount of cooperative choices (Soutschek et al., 2015). Similarly, inhibition of right dlPFC when playing economic games increases selfish responses to unfair offers (Speitel et al., 2019). The dlPFC is also linked to working memory, which allows us to maintain and manipulate verbal and visual information about others in short-term memory (Barbey et al., 2013; Veltman et al., 2003). In the context of our task, it is likely that the left dlPFC contributes to the selection of an appropriate answer in the Public Question condition, either by making choices that help maintain one's reputation or by integrating new information learnt from the partner.

Although unpredicted by our initial hypotheses, during both the Question and Answer phase the left TPJ (particularly the AG and SMG) showed more activation in the Public than in the Private condition. Previous studies link the left TPJ with mentalising, visual perspective-taking, memory retrieval in relation to the self (i.e. autobiographical memory system), and prospection (see Seghier, 2013 for a review on TPJ functions). Any of these processes could be more in demand in the context of a reciprocal social interaction during the Public condition. The specific functional role of this activation in the left TPJ will need to be clarified in future studies.

Overall, our findings show that a context where it is possible to engage in a reciprocal interaction (even with the very minimal exchange of information available in the present study) recruits more brain systems than equivalent trials without any explicit interaction or communication. This suggests that, as communication contexts become richer, more complex patterns of brain activity may be seen. We suggest that these may draw on neural mechanisms for managing one's own reputation, learning or thinking about others. Future studies will be needed to understand how all of these systems work together to ultimately enable successful face-to-face communication.

5.5.3. Brain systems for spontaneous face processing

Since we simultaneously recorded brain activity and amount of facial displays (i.e. facial motion), we performed an exploratory analysis to test how spontaneous production and observation of facial motion relates to brain activity. Results showed that production of facial displays (i.e. participants moving their own face) recruited the left SMG. This region is associated with motor planning for hand action (Tunik, Lo, & Adamovich, 2008), and is also engaged when producing speech actions (Wildgruber, Ackermann, Klose, Kardatzki, & Grodd, 1996) and smiles (Wild, Erb, Eyb, Bartels, & Grodd, 2003). We also found that observation of facial displays (i.e. participants seeing their partner move the face) recruited the right dlPFC. Previous studies have shown that the right dlPFC is recruited when inferring emotions from faces (A. Nakamura, Maess, Knösche, & Friederici, 2014; K. Nakamura et al., 1999; Ran, Chen, Zhang, Ma, & Zhang, 2016). Interestingly, we also observed activations of motor processing areas (e.g. premotor and supplementary motor area) during production of facial displays, as well as activations of face processing areas (e.g. superior, middle and inferior temporal gyrus) during observation of facial displays. These activations match traditional brain areas related to motor and perceptual processing of actions, but their threshold values do not meet our stringent statistical criteria. Overall, our results reveal that spontaneous production and perception of facial displays in a dynamic task engage a wide network of brain regions (e.g. left SMG and right dlPFC), beyond those traditionally linked to face perception and motor control. Understanding how this wider network works together to enable real-world face-to-face social interaction is an important challenge for future research.

Finally, when our GLM included facial motion as a regressor (“task+face GLM”), the Answer phase of the Public condition showed a reliable deactivation in the right dlPFC. Although this seemed surprising, the same pattern of activity in the right dlPFC is present across task-related contrasts of both “task” and “task+face” GLMs: in both cases, the amount of activation in Answer phase is smaller than in Question and Feedback phases (Figure 5-6). Since in the “task+face” GLM activity in right dlPFC seems strongly linked to observation of facial motion, there might be a decrease in the model fit across all three task-related regressors, which might then appear as a significant deactivation in the Public Answer condition.

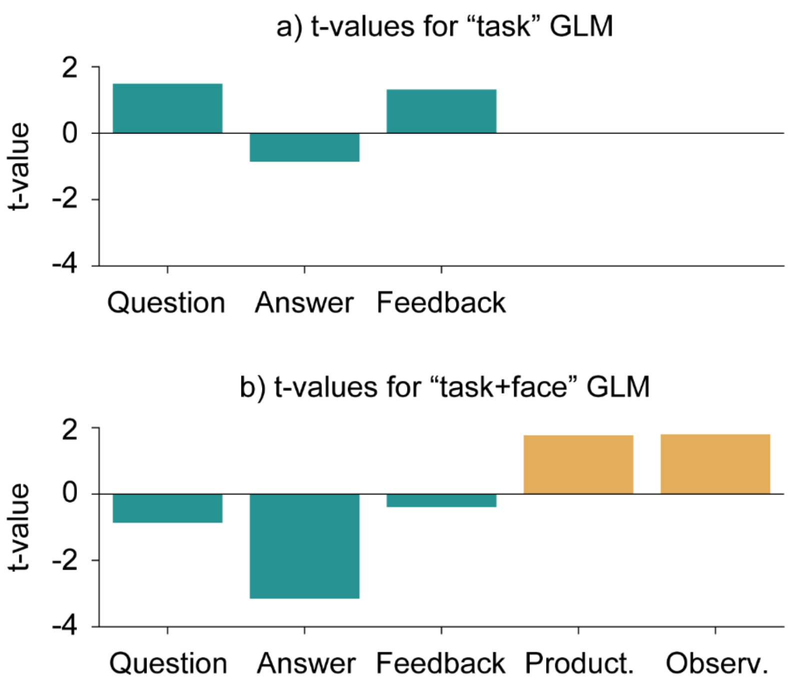

Figure 5-6. Representation of t-values at MNI coordinates (42, 34, 24), which correspond to the peak voxel for the contrast Private > Public during the Answer phase in the “task+face” GLM (where deactivation was observed).
a) Pattern of t-values for the contrast Public > Private in the “task” GLM: activations are greater during Question and Feedback phase than during Answer phase. b) Pattern of t-values for the contrast Public > Private (green) and Face > Baseline (yellow) in the “task+face” GLM: activations for task-related effects are generally lower than in “task” GLM, although they are still greater during Question and Feedback phase than during Answer phase; this might be explained by higher activation of this area during Production and Observation of facial motion.

5.5.4. Limitations and future directions

The present findings open up promising avenues for future research on how social information is processed during reciprocal social interactions. However, there are also limitations that could be addressed in future studies. First, it is important to bear in mind that fNIRS measures activity from the cortical surface, and that the headset used in this study did not include frontal and occipital cortices. Thus, our hypotheses and findings were constrained to the lateral sections of the cortical surface. Studies using fNIRS on different cortical regions, as well as fMRI studies that can measure brain activity beyond the cortex (e.g. ventral striatum for reward processing) are needed to complement the present findings. Moreover, although we recorded data from two participants simultaneously, our design was not powered for cross-brain coherence analyses (Cui et al., 2012; Hirsch et al., 2018, 2017): investigating how our brain uses social signals to synchronise with the brain of our partner will be key to understand how we are able to communicate with others.

Second, we find greater brain activity in the right TPJ during the Public condition, but three different mechanisms could explain this result: reputation management, learning about others, thinking about others. Similarly, activity in the dlPFC could be related to either greater strategic decision-making or greater working memory when participants know their answers will be shared. Using a paradigm where only the choices of one participant are disclosed (i.e. one participant's reputation is at risk, while the other one learns new information) or a paradigm where we test how well participants recall choices of their partner could help to clarify the cognitive mechanisms underlying these activations. Moreover, in our paradigm participants did not speak to each other: they pressed a key to choose their answer, and a pre-recorded voice informed participants whether they chose the same answer or not. Although this design offers good experimental control for speech-related artifacts, it is a rather unnatural situation that may lead to ambiguous interpretations of facial displays. Future designs that allow participants to speak to each other, such as a semi-structured conversation, will be helpful to test how our findings apply to more natural environments.

Finally, our findings provide novel evidence of two brain regions (left SMG and right dlPFC) that are recruited when producing and observing facial displays with a real partner. However, there are a few limitations to these findings. First, we did not control for gaze direction of participants when testing the effect of observation of facial displays, so the interpretation of our findings is limited by the fact that participants may or may not be actually gazing at their partner's face (note that, since nine participants had poor signal quality in the eye-tracking data, we would need to exclude almost a third of our sample if we controlled for gaze direction of participants). Second, we tested how the overall amount of facial displays modulates brain activity, but it is likely that different patterns of brain activity are engaged depending on the facial expression being displayed as well as the communicative context where it takes place (e.g. what is being said). Third, due to the lack of a control condition for observation of facial motion, we cannot rule out the possibility that our findings are related to observation of motion in general rather than face-specific motion. Thus, further research is needed to elucidate the details of the results reported in our exploratory analysis. Together with the findings reported in the present study, this will advance our current understanding of how two people regulate each other through social signals to achieve successful communication.

5.6. Conclusion

This chapter investigated how reciprocal social interactions modulate social signalling and brain activity during mutual sharing of information. We show that a shared situation where participants can engage with each other translated into both more monitoring and production of facial displays. This suggests that eye gaze and facial displays share a communicative function during reciprocal social interactions. We also found that reciprocal interactions recruited the right TPJ, left dlPFC and left TPJ, indicating a complex mechanism involving mentalising and strategic decision-making. Finally, we found that spontaneous production and observation of facial displays with a real partner recruited the left SMG and right dlPFC, respectively. These findings are consistent with the second-person neuroscience hypothesis and further suggest that, as social interactions become richer (e.g. by mutually exchanging information), they recruit more complex and dynamic neurocognitive mechanisms.

5.7. Supplementary Materials

5.7.1. List of statements

Daily statements

1. I usually travel abroad during my summer holidays.
2. If I had a day off I'd go to the mall to shop.
3. I sometimes drink coffee in the mornings.
4. I usually spend summer weekends by the sea.
5. I usually cycle to work.

6. I sometimes go hiking in the mountains.
7. When I go to the cinema I usually watch comedy films.
8. I'd like to play an instrument in an orchestra.
9. I'd like to speak many foreign languages.
10. If I could have a superpower, I'd like to be invisible.
11. I try to follow a healthy lifestyle.
12. I usually go out on Friday or Saturday nights.
13. When I was a teenager I sometimes went to concerts.
14. I usually choose chocolate brownie as a dessert.
15. I usually watch football games with my friends.
16. I rarely go to the theatre.
17. I don't mind walking in the rain.
18. I try not to watch too much TV in the evenings.
19. If I were an animal, I would be a bird.
20. I sometimes drink soda with my meals.

Statements from impression management questionnaires

1. I try not to cover up my mistakes.
2. I've sometimes criticized my friends.
3. I sometimes tell lies to get what I want.
4. I sometimes persuade people to do things to my advantage.
5. I usually tell a salesperson if there is too much change.
6. I try not to say things that hurt other's feelings.
7. When I was young I sometimes stole things.
8. I try not to drop litter on the street.
9. I like to drive faster than the speed limit.
10. I usually let other people sit in the bus before I do.

11. I like to gossip about other people's business.

12. If I damaged a library book, I would report it.

13. I don't mind going out of my way to help others.

14. I enjoy meeting other people.

15. If I weren't seen, I'd get into a movie without paying.

16. I sometimes play sick to get out of something.

17. I'm usually courteous, even to rude people.

18. People who ask me favors sometimes irritate me.

19. I sometimes laugh at dirty jokes people make.

20. I usually keep my promises to other people.

5.7.2. Channel description

Table 5-4. Channels, group-averaged coordinates and anatomical regions

Channel number	MNI Coordinates[1] X	Y	Z	Anatomical Region	BA	Prob. incl.
1	-40	-63	61	Somatosensory Association Cortex	7	0.73
				Supramarginal gyrus part of temporo-parietal junction	40	0.27
2	-49	-55	57	Supramarginal gyrus part of temporo-parietal junction	40	0.95
				Somatosensory Association Cortex	7	0.05
3	-45	-75	46	Angular gyrus part of temporo-parietal junction	39	0.33
				Somatosensory Association Cortex	7	0.31
				V3	19	0.29
				Supramarginal gyrus part of temporo-parietal junction	40	0.07
4	-49	27	39	Dorsolateral prefrontal cortex	9	0.67
				Includes Frontal eye fields	8	0.17
				Dorsolateral prefrontal cortex	46	0.16
5	-58	1	44	PreMotor and Supplementary Motor Cortex	6	0.9
				Dorsolateral prefrontal cortex	9	0.06
				Includes Frontal eye fields	8	0.04
6	-59	-23	52	Primary Somatosensory Cortex	2	0.35
				Primary Somatosensory Cortex	1	0.28
				Primary Somatosensory Cortex	3	0.12
				Pre-Motor and Supplementary Motor Cortex	6	0.12
				Primary Motor Cortex	4	0.06
				Supramarginal gyrus part of temporo-parietal junction	40	0.06
7	-59	-47	52	Supramarginal gyrus part of temporo-parietal junction	40	1
8	-53	-67	46	Angular gyrus part of temporo-parietal junction	39	0.53

				Supramarginal gyrus part of temporo-parietal junction	40	0.45
				Somatosensory Association Cortex	7	0.02
9	-48	39	27	Dorsolateral prefrontal cortex	46	0.92
				Dorsolateral prefrontal cortex	9	0.05
				Frontopolar area	10	0.03
10	-59	12	29	Dorsolateral prefrontal cortex	9	0.65
				pars triangularis part of inferior frontal gyrus	45	0.19
				Pre-Motor and Supplementary Motor Cortex	6	0.1
				pars opercularis part of inferior frontal gyrus	44	0.06
11	-64	-11	38	PreMotor and Supplementary Motor Cortex	6	0.71
				Primary Somatosensory Cortex	3	0.16
				Primary Motor Cortex	4	0.08
				Primary Somatosensory Cortex	1	0.04
				Primary Somatosensory Cortex	2	0
12	-65	-35	44	Supramarginal gyrus part of temporo-parietal junction	40	0.81
				Primary Somatosensory Cortex	2	0.12
				Primary Somatosensory Cortex	1	0.06
13	-60	-58	43	Supramarginal gyrus part of temporo-parietal junction	40	0.87
				Angular gyrus part of temporo-parietal junction	39	0.13
14	-44	-84	32	V3	19	0.59
				Angular gyrus part of temporo-parietal junction	39	0.41
15	-58	26	18	pars triangularis part of inferior frontal gyrus	45	0.64
				Dorsolateral prefrontal cortex	46	0.26
				pars opercularis part of inferior frontal gyrus	44	0.09
				Dorsolateral prefrontal cortex	9	0.01
16	-65	-1	25	PreMotor and Supplementary Motor Cortex	6	0.69
				Subcentral area	43	0.12
				Primary Motor Cortex	4	0.09
				Dorsolateral prefrontal cortex	9	0.07
				pars opercularis part of inferior frontal gyrus	44	0.03
				pars triangularis part of inferior frontal gyrus	45	0.01
				Primary Somatosensory Cortex	3	0
17	-68	-24	32	Supramarginal gyrus part of temporo-parietal junction	40	0.4
				Primary Somatosensory Cortex	2	0.29
				Primary Somatosensory Cortex	1	0.18
				Primary Somatosensory Cortex	3	0.11
				Pre-Motor and Supplementary Motor Cortex	6	0.02
18	-66	-47	34	Supramarginal gyrus part of temporo-parietal junction	40	1
19	-51	-77	30	Angular gyrus part of temporo-parietal junction	39	0.95
				V3	19	0.05
20	-55	37	6	Dorsolateral prefrontal cortex	46	0.34
				pars triangularis part of inferior frontal gyrus	45	0.33
				Inferior prefrontal gyrus	47	0.28
				Frontopolar area	10	0.04
21	-62	10	10	pars opercularis part of inferior frontal gyrus	44	0.5

				Pre-Motor and Supplementary Motor Cortex	6	0.23
				Superior Temporal Gyrus	22	0.2
				pars triangularis part of inferior frontal gyrus	45	0.07
22	-68	-14	17	Subcentral area	43	0.5
				Primary and Auditory Association Cortex	42	0.28
				Superior Temporal Gyrus	22	0.07
				Supramarginal gyrus part of temporo-parietal junction	40	0.05
				Primary Somatosensory Cortex	1	0.05
				Primary Somatosensory Cortex	3	0.02
				Primary Somatosensory Cortex	2	0.01
				Primary Motor Cortex	4	0.01
				Pre-Motor and Supplementary Motor Cortex	6	0.01
23	-69	-37	22	Supramarginal gyrus part of temporo-parietal junction	40	0.47
				Superior Temporal Gyrus	22	0.44
				Primary and Auditory Association Cortex	42	0.09
24	-64	-59	21	Superior Temporal Gyrus	22	0.46
				Angular gyrus part of temporo-parietal junction	39	0.34
				Supramarginal gyrus part of temporo-parietal junction	40	0.17
				V3	19	0.02
				Middle Temporal gyrus	21	0.01
25	-51	46	-4	Inferior prefrontal gyrus	47	0.68
				Frontopolar area	10	0.22
				Dorsolateral prefrontal cortex	46	0.09
				Orbitofrontal area	11	0.01
				pars triangularis part of inferior frontal gyrus	45	0
26	-56	23	-4	Inferior prefrontal gyrus	47	0.65
				pars triangularis part of inferior frontal gyrus	45	0.15
				Temporopolar area	38	0.12
				Superior Temporal Gyrus	22	0.08
27	-67	-6	-4	Middle Temporal gyrus	21	0.71
				Superior Temporal Gyrus	22	0.29
28	-71	-28	4	Middle Temporal gyrus	21	0.37
				Superior Temporal Gyrus	22	0.37
				Primary and Auditory Association Cortex	42	0.27
29	-68	-50	9	Superior Temporal Gyrus	22	0.62
				Middle Temporal gyrus	21	0.38
30	43	-66	55	Somatosensory Association Cortex	7	0.81
				Supramarginal gyrus part of temporo-parietal junction	40	0.19
31	46	-78	42	V3	19	0.53
				Angular gyrus part of temporo-parietal junction	39	0.31
				Somatosensory Association Cortex	7	0.15
32	53	-59	55	Supramarginal gyrus part of temporo-parietal junction	40	0.87
				Somatosensory Association Cortex	7	0.13
33	54	-70	41	Angular gyrus part of temporo-parietal junction	39	0.78
				Supramarginal gyrus part of temporo-parietal junction	40	0.14

				V3	19	0.06
				Somatosensory Association Cortex	7	0.02
34	62	-49	50	Supramarginal gyrus part of temporo-parietal junction	40	1
35	64	-23	49	Primary Somatosensory Cortex	2	0.34
				Primary Somatosensory Cortex	1	0.26
				Pre-Motor and Supplementary Motor Cortex	6	0.13
				Primary Somatosensory Cortex	3	0.1
				Supramarginal gyrus part of temporo-parietal junction	40	0.09
				Primary Motor Cortex	4	0.07
36	61	2	42	PreMotor and Supplementary Motor Cortex	6	0.84
				Dorsolateral prefrontal cortex	9	0.13
				Includes Frontal eye fields	8	0.03
37	52	29	38	Dorsolateral prefrontal cortex	9	0.67
				Dorsolateral prefrontal cortex	46	0.25
				Includes Frontal eye fields	8	0.08
38	44	-86	25	V3	19	0.92
				Angular gyrus part of temporo-parietal junction	39	0.08
39	61	-61	37	Supramarginal gyrus part of temporo-parietal junction	40	0.64
				Angular gyrus part of temporo-parietal junction	39	0.36
40	68	-36	41	Supramarginal gyrus part of temporo-parietal junction	40	0.88
				Primary Somatosensory Cortex	2	0.1
				Primary Somatosensory Cortex	1	0.02
41	67	-10	37	PreMotor and Supplementary Motor Cortex	6	0.73
				Primary Somatosensory Cortex	3	0.15
				Primary Motor Cortex	4	0.07
				Primary Somatosensory Cortex	1	0.06
42	63	13	25	Dorsolateral prefrontal cortex	9	0.49
				pars triangularis part of inferior frontal gyrus	45	0.23
				pars opercularis part of inferior frontal gyrus	44	0.22
				Pre-Motor and Supplementary Motor Cortex	6	0.05
43	51	40	27	Dorsolateral prefrontal cortex	46	0.89
				Frontopolar area	10	0.06
				Dorsolateral prefrontal cortex	9	0.04
44	51	-79	24	Angular gyrus part of temporo-parietal junction	39	0.53
				V3	19	0.47
45	67	-49	27	Supramarginal gyrus part of temporo-parietal junction	40	0.79
				Superior Temporal Gyrus	22	0.19
				Angular gyrus part of temporo-parietal junction	39	0.03
46	70	-25	29	Supramarginal gyrus part of temporo-parietal junction	40	0.54
				Primary Somatosensory Cortex	2	0.21
				Primary Somatosensory Cortex	1	0.16
				Primary and Auditory Association Cortex	42	0.03
				Primary Somatosensory Cortex	3	0.02
				Subcentral area	43	0.02
47	68	0	20	PreMotor and Supplementary Motor Cortex	6	0.6

				Subcentral area	43	0.12
				Primary Motor Cortex	4	0.08
				Superior Temporal Gyrus	22	0.08
				Dorsolateral prefrontal cortex	9	0.06
				pars opercularis part of inferior frontal gyrus	44	0.05
				pars triangularis part of inferior frontal gyrus	45	0.01
48	60	26	16	pars triangularis part of inferior frontal gyrus	45	0.67
				Dorsolateral prefrontal cortex	46	0.26
				pars opercularis part of inferior frontal gyrus	44	0.06
49	64	-62	13	Superior Temporal Gyrus	22	0.35
				Angular gyrus part of temporo-parietal junction	39	0.31
				Middle Temporal gyrus	21	0.19
				V3	19	0.09
				Fusiform gyrus lateral (Fusiform Face Area)	37	0.06
50	71	-38	16	Superior Temporal Gyrus	22	0.72
				Primary and Auditory Association Cortex	42	0.14
				Supramarginal gyrus part of temporo-parietal junction	40	0.13
51	71	-13	12	Primary and Auditory Association Cortex	42	0.39
				Superior Temporal Gyrus	22	0.28
				Subcentral area	43	0.28
				Supramarginal gyrus part of temporo-parietal junction	40	0.04
52	63	9	3	Superior Temporal Gyrus	22	0.58
				pars opercularis part of inferior frontal gyrus	44	0.24
				Pre-Motor and Supplementary Motor Cortex	6	0.1
				pars triangularis part of inferior frontal gyrus	45	0.05
				Temporopolar area	38	0.01
				Inferior prefrontal gyrus	47	0.01
53	57	38	6	Dorsolateral prefrontal cortex	46	0.38
				pars triangularis part of inferior frontal gyrus	45	0.32
				Inferior prefrontal gyrus	47	0.26
				Frontopolar area	10	0.04
54	69	-52	2	Middle Temporal gyrus	21	0.65
				Superior Temporal Gyrus	22	0.2
				Fusiform gyrus lateral (Fusiform Face Area)	37	0.15
55	73	-28	0	Middle Temporal gyrus	21	0.46
				Superior Temporal Gyrus	22	0.42
				Primary and Auditory Association Cortex	42	0.12
56	69	-5	-9	Middle Temporal gyrus	21	0.99
				Superior Temporal Gyrus	22	0.01
57	57	22	-7	Inferior prefrontal gyrus	47	0.64
				Temporopolar area	38	0.31
				Superior Temporal Gyrus	22	0.05
58	53	47	-4	Inferior prefrontal gyrus	47	0.64
				Frontopolar area	10	0.25
				Dorsolateral prefrontal cortex	46	0.1

	Orbitofrontal area	11	0
	pars triangularis part of inferior frontal gyrus	45	0

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere.
BA = Brodmann Area

5.7.3. Effects of agreement on eye gaze and facial motion

During the task we also recorded the choices of participants. Particularly in the Public condition, where choices are disclosed to the dyad, eye gaze and facial motion might be modulated by whether partners agree or disagree in their choices: it could be that effects of reciprocal interactions on eye gaze and facial motion are stronger if partners disagree than if they agree.

To test this, we run two additional analyses: for eye gaze (measure: duration fixation to the face of the partner) and for facial motion (measure: number of facial Action Units). For each analysis, a 3-way repeated measures ANOVA with Condition (Public and Private), Phase (Question, Answer and Feedback) and Agreement (Agree and Disagree) as within-subject factors was performed. Post-hoc pairwise comparisons using Bonferroni's adjustment were also computed. Note that, since participants made choices freely, the mean number of trials included in Agree and Disagree categories was not balanced: there were around 3 times more trials where participants agreed than disagreed for both Public and Private conditions (see Table 5-5). See Table 5-6 for descriptives (mean and SD) on eye gaze (a) and facial motion (b) measures.

For eye gaze (N = 21; see Figure 5-7a), results showed that there was no main effect of Condition ($F(1,20) = .054$, $p > .05$, $n_p^2 = .003$) or Phase ($F(2,40) = 2.29$, $p > .05$, $n_p^2 = .103$), but there was a main effect of Agreement ($F(1,20) = 7.88$, $p < .05$, $n_p^2 = .283$): participants gazed more at the face of the partner if they agreed (i.e. their answers were the same) than if they disagreed (i.e. their answers were different). There was no interaction effect between Condition and Phase ($F(2,40) = .032$, $p > .05$, $n_p^2 = .002$), Condition and Agreement ($F(1,20) = .799$, $p > .05$, $n_p^2 = .038$), and Phase and Agreement ($F(2,40) = .218$, $p > .05$, $n_p^2 = .011$). There was a tendency for an interaction effect between Condition, Phase and Agreement ($F(2,40) = 3.27$, $p = .064$, $n_p^2 = .141$), although it did not reach significance level. These findings suggest that Agreement did not have a meaningful effect on eye gaze patterns, since there was no interaction effect between Condition and Agreement, or between Condition, Phase and Agreement.

Table 5-5. Number of trials

Condition	**Agreement**	**Descriptives**
Public	Agree	*M* = 14.0 *SD* = 1.31
	Disagree	*M* = 5.87 *SD* = 1.41
Private	Agree	*M* = 14.00 *SD* = 1.25
	Disagree	*M* = 5.93 *SD* = 1.39

Table 5-6. Descriptives for eye gaze and facial motion

a) Duration fixation of gaze to face of partner (in ms)

Condition	**Agreement**	**Phase**		
		Question	Answer	Feedback
Public	Agree	*M* = 311.44 *SD* = 245.55	*M* = 297.61 *SD* = 250.57	*M* = 396.70 *SD* = 234.12
	Disagree	*M* = 261.59 *SD* = 268.10	*M* = 256.73 *SD* = 231.55	*M* = 260.19 *SD* = 240.88
Private	Agree	*M* = 323.42 *SD* = 200.15	*M* = 290.33 *SD* = 248.75	*M* = 331.31 *SD* = 225.35
	Disagree	*M* = 242.87 *SD* = 218.98	*M* = 237.87 *SD* = 260.83	*M* = 323.66 *SD* = 211.10

b) Number of facial AUs

Condition	Agreement	Phase		
		Question	Answer	Feedback
Public	Agree	M = 2.61 SD = .875	M = 1.79 SD = .583	M = 2.94 SD = 1.02
	Disagree	M = 2.65 SD = 1.02	M = 1.86 SD = .698	M = 3.03 SD = 1.11
Private	Agree	M = 2.24 SD = .797	M = 1.50 SD = .481	M = 2.36 SD = .866
	Disagree	M = 2.30 SD = .862	M = 1.56 SD = .529	M = 2.51 SD = .928

For facial motion (N = 30; see Figure 5-7b), there was a main effect of Condition, $F(1,29) = 22.61$, $p < .001$, $\eta_p^2 = .821$, showing that there were more facial AUs in the Public compared to the Private condition. There was also a main effect of Phase, $F(2,58) = 132.8$, $p < .001$, $\eta_p^2 = .821$, and post-hoc pairwise comparisons showed that the number of facial AUs was higher in the Feedback phase than in the Question phase ($t(29) = 5.22$, $p < .001$, $d_z = .953$) and Answer phase ($t(29) = 13.4$, $p < .001$, $d_z = 2.43$). There was a tendency for a main effect of Agreement ($F(1,29) = 3.15$, $p = .086$, $n_p^2 = .098$), although it did not reach significance level. We also found an interaction effect between Condition and Phase, $F(2,58) = 7.87$, $p < .01$, $\eta_p^2 = .213$. Post-hoc pairwise comparisons replicated the pattern of results found for the main effects: there were more facial AUs in the Public than in the Private condition for all Phases (Question: $t(29) = 4.33$, $p < .001$, $d_z = .790$; Answer: $t(29) = 3.86$, $p < .01$, $d_z = .704$; Feedback: $t(29) = 4.79$, $p < .001$, $d_z = .874$), and there were more facial AUs in the Feedback phase compared to the Question and Answer phases for both Conditions (Public Feedback-Question: $t(29) = 4.74$, $p < .001$, $d_z = .867$; Public Feedback-Answer: $t(29) = 12.82$, $p < .001$, $d_z = 2.34$; Private Feedback-Question: $t(29) = 3.17$, $p < .01$, $d_z = .579$; Private Feedback-Answer: $t(29) = 11.75$, $p < .001$, $d_z = 2.15$). There were no interaction effects between

Condition and Agreement, $F(1,29) = .044$, $p > .05$, $\eta_p^2 = .002$, Phase and Agreement, $F(2,58) = 1.26$, $p > .05$, $\eta_p^2 = .042$, and Condition, Phase and Agreement, $F(2,58) = .312$, $p > .05$, $\eta_p^2 = .011$. These results show that there was no effect of Agreement on facial motion.

Since we did not find any effects of Agreement on eye gaze and facial motion, and the number of agree and disagree trials were not balanced, we did not test effects of Agreement on brain activity due to lack of sufficient statistical power.

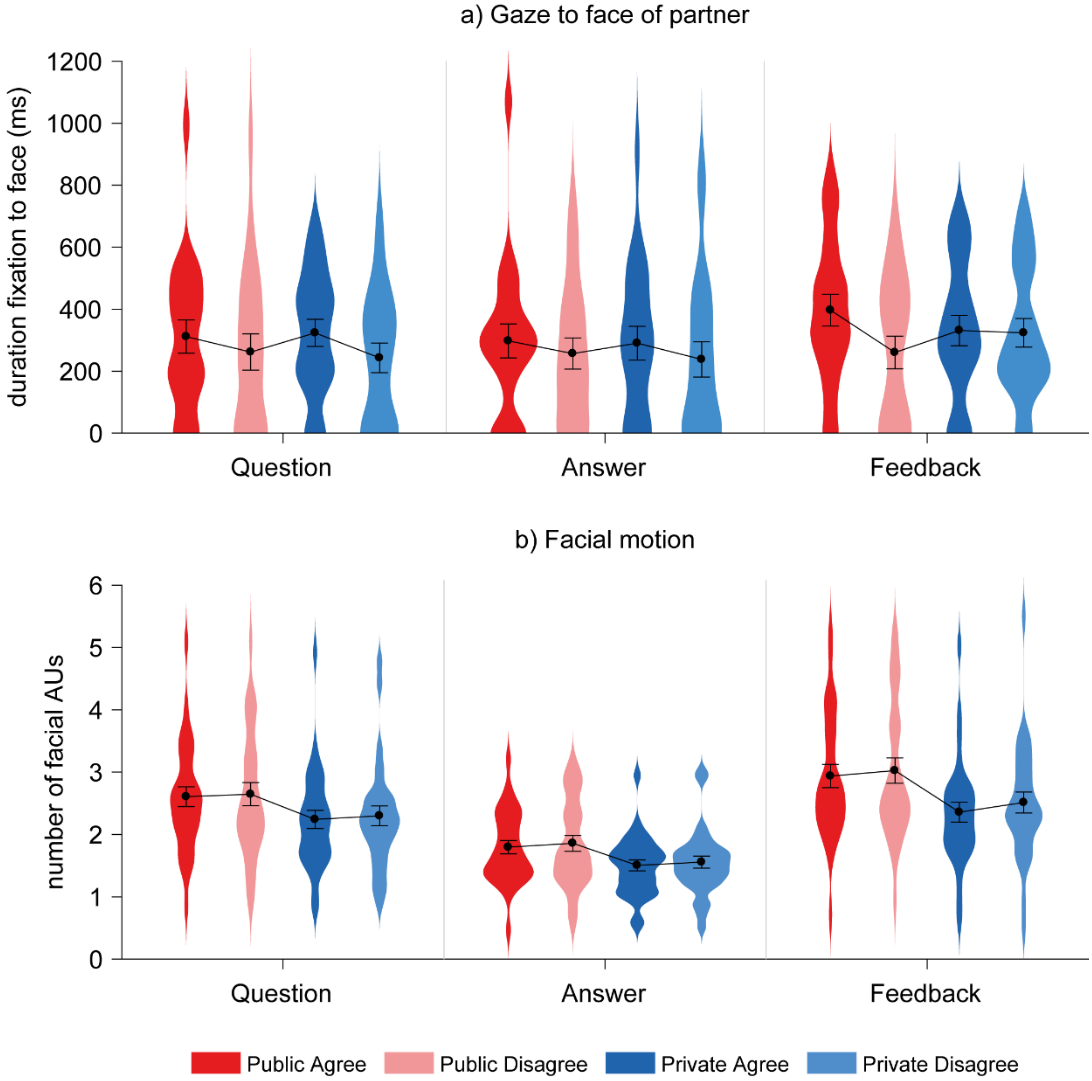

Figure 5-7. Results for eye gaze and facial motion analyses in relation to Agreement. a) Duration fixation of gaze to the face of partner for each Condition, Phase and Agreement. b) Number of facial AUs for each Condition, Phase and Agreement. Mean (filled circle), SE (error bars), and frequency of values (width of distribution).

5.7.4. Full deOxyHb results for task effects

Table 5-7. Voxel-wise GLM contrast comparisons for task-related effects (deOxyHb signal)

Contrast (contrast threshold)	Phase	Peak voxels MNI coords.[1] (X Y Z)	*t*	*p*	df	Anatomical region	BA	Prob. incl.	Voxels (n in cluster)
Public > Private (p < .05)	Question	56 0 -12	2.18	.019	29	Middle Temporal Gyrus	21	.714	74
						Temporopolar Area	38	.158	
						Superior Temporal Gyrus	22	.129	
		60 -32 -10	1.79	.042	29	Middle Temporal Gyrus	21	.964	50
		-48 24 40	2.78	.005	29	Dorsolateral Prefrontal Cortex	9	.494	592
						Frontal Eye Fields	8	.349	
						Dorsolateral Prefrontal Cortex	46	.152	
		56 28 2	2.47	.010	29	Inferior Prefrontal Gyrus	47	.473	226
						Pars Triangularis, part IFG	45	.353	
		-60 -60 28	2.74	.005	29	Angular Gyrus, part TPJ	39	.447	146
						Supramarginal Gyrus, part TPJ	40	.380	
						Superior Temporal Gyrus	22	.145	
		-62 -42 42	2.21	.018	29	Supramarginal Gyrus, part TPJ	40	.951	13
		-40 14 44	2.33	.013	29	Frontal Eye Fields	8	.631	35
						Pre- and Suppl. Motor Cortex	6	.217	
						Dorsolateral Prefrontal Cortex	9	.151	
		-56 -16 48	2.47	.010	29	Pre- and Suppl. Motor Cortex	6	.381	14
						Primary Somatosensory Cortex	3	.211	
						Primary Somatosensory Cortex	1	.154	
						Primary Somatosensory Cortex	2	.145	
						Primary Motor Cortex	4	.105	
		-50 -38 54	2.30	.014	29	Supramarginal Gyrus, part TPJ	40	.738	94
						Primary Somatosensory Cortex	2	.204	
		-34 -60 58	2.46	.010	29	Somatosensory Assoc. Cortex	7	.747	104
						Supramarginal Gyrus, part TPJ	40	.222	
	Answer	26 28 -14	1.79	.042	29	Inferior Prefrontal Gyrus	47	.497	17
						Orbitofrontal Area	11	.490	
		50 -68 10	2.49	.009	29	V3	19	.430	62
						Angular Gyrus, part TPJ	39	.335	
						Fusiform Gyrus lateral (FFA)	37	.197	
		66 -54 0	1.93	.032	29	Middle Temporal Gyrus	21	.405	11
						Fusiform Gyrus lateral (FFA)	37	.352	
						Superior Temporal Gyrus	22	.212	
		-52 -72 4	1.82	.040	29	V3	19	.630	28
						Fusiform Gyrus lateral (FFA)	37	.221	
						Angular Gyrus, part TPJ	39	.104	
		-50 42 10	2.88	.004	29	Dorsolateral Prefrontal Cortex	46	.537	60
						Frontopolar Area	10	.185	
						Pars Triangularis, part IFG	45	.140	
						Inferior Prefrontal Gyrus	47	.137	
		-48 -72 26	3.22	.002	29	Angular Gyrus, part TPJ	39	.776	845
						V3	19	.223	
		-44 -84 18	1.79	.042	29	V3	19	.738	11

								Angular Gyrus, part TPJ	39	.184	
		58	4	32	1.99	.028	29	Pre- and Suppl. Motor Cortex	6	.544	38
								Dorsolateral Prefrontal Cortex	9	.373	
		-52	-44	54	2.61	.007	29	Supramarginal Gyrus	40	.952	66
		42	-64	56	2.10	.022	29	Somatosensory Assoc. Cortex	7	.651	10
								Supramarginal Gyrus, part TPJ	40	.320	
		52	-34	54	2.05	.025	29	Supramarginal Gyrus, part TPJ	40	.600	10
								Primary Somatosensory Cortex	2	.227	
								Primary Somatosensory Cortex	1	.141	
		-34	-52	62	2.18	.019	29	Somatosensory Assoc. Cortex	7	.432	17
								Somatosensory Assoc. Cortex	5	.278	
								Supramarginal Gyrus, part TPJ	40	.243	
	Feedback	56	32	-8	1.93	.032	29	Inferior Prefrontal Gyrus	47	.788	10
								Temporopolar Area	38	.111	
		-46	28	-6	1.99	.028	29	Inferior Prefrontal Gyrus	47	.781	15
								Temporopolar Area	38	.180	
		52	28	24	2.79	.004	29	Dorsolateral Prefrontal Cortex	46	.527	449
								Pars Triangularis, part IFG	45	.231	
								Dorsolateral Prefrontal Cortex	9	.227	
		-60	-22	6	1.98	.028	29	Auditory Prim. & Assoc. Cortex	42	.465	78
								Superior Temporal Gyrus	22	.307	
								Middle Temporal Gyrus	21	.156	
		52	-76	22	3.18	.002	29	Angular Gyrus, part TPJ	39	.566	189
								V3	19	.433	
		-42	36	6	1.95	.030	29	Dorsolateral Prefrontal Cortex	46	.551	45
								Pars Triangularis, part IFG	45	.232	
								Inferior Prefrontal Gyrus	47	.143	
		-58	18	14	1.87	.035	29	Pars Triangularis, part IFG	45	.466	21
								Pars Opercularis, part IFG	44	.280	
		66	-14	30	2.82	.004	29	Pre- and Suppl. Motor Cortex	6	.360	331
								Subcentral Area	43	.166	
								Supramarginal Gyrus, part TPJ	40	.116	
								Primary Somatosensory Cortex	1	.109	
								Primary Somatosensory Cortex	3	.102	
		-8	-82	36	2.16	.020	29	V3	19	.783	27
								Somatosensory Assoc. Cortex	7	.216	
		-4	-76	46	2.26	.016	29	Somatosensory Assoc. Cortex	7	.774	45
								V3	19	.226	
		-30	-60	58	1.73	.047	29	Somatosensory Assoc. Cortex	7	.892	11
								Supramarginal Gyrus, part TPJ	40	.101	
Private > Public	Question	-62	-2	-16	-1.82	.040	29	Middle Temporal Gyrus	21	.835	19
		-56	14	-12	-2.27	.015	29	Temporopolar area	38	.423	78
								Middle Temporal Gyrus	21	.235	
								Inferior Prefrontal Gyrus	47	.182	
								Superior Temporal Gyrus	22	.156	
		-68	-22	-10	-2.07	.023	29	Middle Temporal Gyrus	21	.798	11
								Superior Temporal Gyrus	22	.106	
		-46	12	-6	-1.77	.044	29	Temporopolar area	38	.495	10
								Inferior Prefrontal Gyrus	47	.259	

							Superior Temporal Gyrus	22	.232	
	34	-84	10	-1.77	.044	29	V3	19	.755	10
							Visual Assoc. Cortex (V2)	18	.244	
	68	0	14	-3.02	.003	29	Pre- and Suppl. Motor Cortex	6	.308	15
							Superior Temporal Gyrus	22	.268	
							Pars Opercularis, part IFG	44	.139	
							Subcentral area	43	.135	
	-64	-2	18	-2.26	.016	29	Pre- and Suppl. Motor Cortex	6	.378	244
							Subcentral area	43	.174	
							Superior Temporal Gyrus	22	.172	
	70	-12	14	-2.46	.010	29	Superior Temporal Gyrus	22	.253	11
							Auditory Prim. & Assoc. Cortex	42	.234	
							Subcentral area	43	.204	
							Pre- and Suppl. Motor Cortex	6	.108	
	-62	-28	26	-1.88	.035	29	Supramarginal Gyrus, part TPJ	40	.498	33
							Primary Somatosensory Cortex	2	.139	
							Auditory Prim. & Assoc. Cortex	42	.112	
	66	6	22	-2.85	.004	29	Pre- and Suppl. Motor Cortex	6	.431	1026
							Pars Opercularis, part IFG	44	.201	
							Dorsolateral Prefrontal Cortex	9	.175	
	-20	-56	62	-2.07	.024	29	Somatosensory Assoc. Cortex	7	.965	24
	-42	-54	62	-2.02	.026	29	Supramarginal Gyrus, part TPJ	40	.482	10
							Somatosensory Assoc. Cortex	7	.333	
							Somatosensory Assoc. Cortex	5	.161	
Answer	62	12	-10	-2.25	.016	29	Temporopolar area	38	.324	141
							Middle Temporal Gyrus	21	.314	
							Superior Temporal Gyrus	22	.219	
							Inferior Temporal Gyrus	47	.124	
	66	-16	-12	-2.00	.027	29	Middle Temporal Gyrus	21	.799	13
							Inferior Temporal Gyrus	20	.162	
	-64	-26	-6	-2.17	.019	29	Middle Temporal Gyrus	21	.789	87
							Superior Temporal Gyrus	22	.155	
	-48	22	18	-3.05	.002	29	Pars Triangularis, part IFG	45	.491	294
							Dorsolateral Prefrontal Cortex	46	.321	
							Pars Opercularis, part IFG	44	.111	
	-66	-12	34	-2.22	.017	29	Pre- and Suppl. Motor Cortex	6	.469	11
							Primary Somatosensory Cortex	2	.118	
							Primary Somatosensory Cortex	1	.114	
							Subcentral area	43	.104	
	62	-10	32	-2.23	.017	29	Pre- and Suppl. Motor Cortex	6	.599	115
							Primary Somatosensory Cortex	3	.106	
	-68	-38	30	-2.57	.008	29	Supramarginal Gyrus, part TPJ	40	.798	36
							Superior Temporal Gyrus	22	.141	
Feedback	-56	10	-18	-2.09	.023	29	Middle Temporal Gyrus	21	.482	20
							Temporopolar area	38	.471	
	58	8	-14	-2.23	.017	29	Middle Temporal Gyrus	21	.473	18
							Temporopolar area	38	.375	
							Superior Temporal Gyrus	22	.133	
	-56	-10	-12	-2.05	.025	29	Middle Temporal Gyrus	21	1	16
	60	-12	-8	-2.86	.004	29	Middle Temporal Gyrus	21	.964	143

-58	-48	-2	-2.12	.021	29	Middle Temporal Gyrus	21	.641	29
						Fusiform Gyrus lateral (FFA)	37	.223	
						Superior Temporal Gyrus	22	.136	
40	46	4	-2.29	.015	29	Frontopolar area	10	.588	18
						Dorsolateral Prefrontal Cortex	46	.330	
-68	-38	28	-2.74	.005	29	Supramarginal Gyrus, part TPJ	40	.739	70
						Superior Temporal Gyrus	22	.198	
54	-44	48	-1.97	.029	29	Supramarginal Gyrus, part TPJ	40	1	45
-46	20	42	-2.37	.012	29	Dorsolateral Prefrontal Cortex	9	.454	42
						Frontal Eye Fields	8	.447	
-44	14	44	-2.16	.019	29	Frontal Eye Fields	8	.461	16
						Dorsolateral Prefrontal Cortex	9	.287	
						Pre- and Suppl. Motor Cortex	6	.252	

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere

df = degrees of freedom, BA = Brodmann Area

5.7.5. Full OxyHb results for task effects

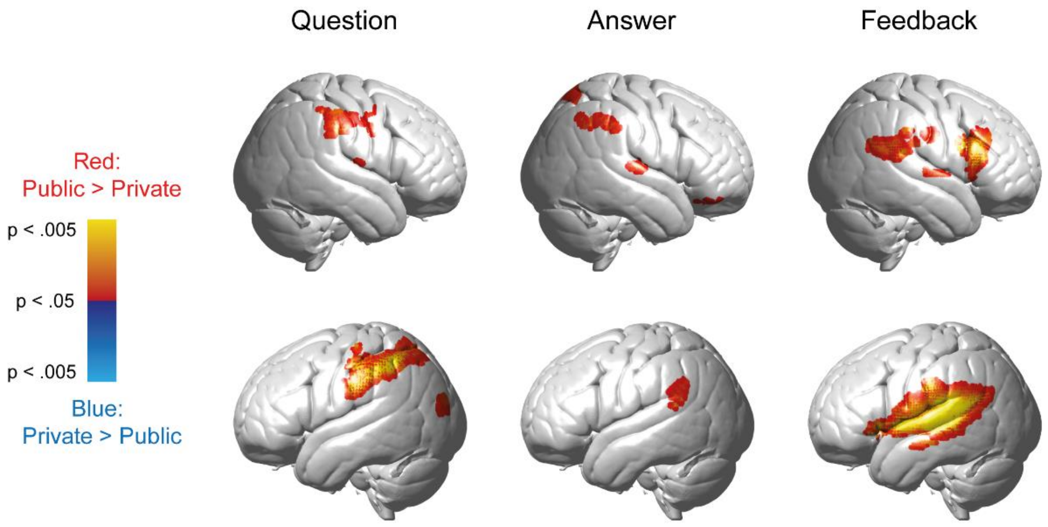

Figure 5-8. Contrast effects for "task GLM" (OxyHb signal).
Brain activity correlated with Public > Private for each trial Phase (red colour; p < .05).

Table 5-8. Voxel-wise GLM contrast comparisons for task-related effects (OxyHb signal)

Contrast (contrast threshold)	**Phase**	**Peak voxels** MNI coords.[1] (X	Y	Z)	*t*	*p*	df	**Anatomical region**	**BA**	**Prob. incl.**	**Voxels** (n in cluster)
Public > Private (p < .05)	Question	66	-10	12	1.84	.038	29	Superior Temporal Gyrus	22	.292	11
								Subcentral Area	43	.215	
								Auditory Prim. & Assoc. Cortex	42	.196	
								Pre- and Suppl. Motor Cortex	6	.143	
		-36	-80	16	2.06	.024	29	V3	19	.855	23
		-56	-34	42	3.88	<.001	29	Supramarginal Gyrus, part TPJ	40	.734	733
								Primary Somatosensory Cortex	2	.163	
		54	-20	44	2.21	.018	29	Primary Somatosensory Cortex	3	.252	178

							Pre- and Suppl. Motor Cortex	6	.244	
							Primary Somatosensory Cortex	1	.210	
							Primary Somatosensory Cortex	2	.164	
							Primary Motor Cortex	4	.114	
	54	0	34	1.92	.032	29	Pre- and Suppl. Motor Cortex	6	.711	28
							Dorsolateral Prefrontal Cortex	9	.254	
	56	0	48	1.88	.035	29	Pre- and Suppl. Motor Cortex	6	.779	10
	-42	-18	52	2.41	.011	29	Primary Somatosensory Cortex	3	.468	11
							Pre- and Suppl. Motor Cortex	6	.234	
							Primary Motor Cortex	4	.180	
							Primary Somatosensory Cortex	1	.113	
	-40	-56	60	2.10	.022	29	Supramarginal Gyrus, part TPJ	40	.440	22
							Somatosensory Assoc. Cortex	7	.432	
							Somatosensory Assoc. Cortex	5	.125	
Answer	26	24	-14	1.78	.043	29	Inferior Prefrontal Gyrus	47	.528	14
							Orbitofrontal Area	11	.430	
	66	-16	8	1.98	.028	29	Superior Temporal Gyrus	22	.337	45
							Auditory Prim. & Assoc. Cortex	42	.313	
							Subcentral Area	43	.157	
							Middle Temporal Gyrus	21	.145	
	-66	-50	20	2.18	.019	29	Superior Temporal Gyrus	22	.488	49
							Supramarginal Gyrus, part TPJ	40	.352	
	60	-38	40	2.16	.020	29	Supramarginal Gyrus, part TPJ	40	.908	46
	62	-52	40	2.30	.014	29	Supramarginal Gyrus, part TPJ	40	.917	28
	38	-62	60	1.99	.028	29	Somatosensory Assoc. Cortex	7	.775	11
							Supramarginal Gyrus, part TPJ	40	.198	
Feedback	66	-20	-12	2.31	.014	29	Middle Temporal Gyrus	21	.802	23
							Inferior Temporal Gyrus	20	.139	
	-64	-28	10	3.98	<.001	29	Superior Temporal Gyrus	22	.415	2427
							Auditory Prim. & Assoc. Cortex	42	.344	
							Middle Temporal Gyrus	21	.112	
	62	16	22	4.96	<.001	29	Pars Triangularis, part IFG	45	.322	436
							Dorsolateral Prefrontal Cortex	9	.287	
							Pars Opercularis, part IFG	44	.225	
							Pre- and Suppl. Motor Cortex	6	.107	
	60	-8	2	1.99	.028	29	Superior Temporal Gyrus	22	.489	40
							Middle Temporal Gyrus	21	.367	
							Auditory Prim. & Assoc. Cortex	42	.104	
	70	-34	20	2.43	.011	29	Supramarginal Gyrus, part TPJ	40	.442	277
							Superior Temporal Gyrus	22	.338	
							Auditory Prim. & Assoc. Cortex	42	.185	
	66	-8	32	2.06	.024	29	Pre- and Suppl. Motor Cortex	6	.606	56
							Subcentral Area	43	.114	

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere

df = degrees of freedom, BA = Brodmann Area

5.7.6. Full deOxyHb results for task+face effects

Table 5-9. Voxel-wise GLM contrast comparisons for task- and face- related effects (deOxyHb signal)

Contrast (contrast threshold)	**Phase**	**Peak voxels** MNI coords.[1] (X Y Z)	*t*	*p*	df	**Anatomical region**	**BA**	**Prob. incl.**	**Voxels** (n in cluster)
Public > Private (p < .05)	Question	56 0 -8	2.30	.014	29	Middle Temporal Gyrus	21	.714	74
						Superior Temporal Gyrus	38	.158	
						Temporopolar Area	22	.129	
		-54 34 2	2.47	.010	29	Inferior Frontal Gyrus	47	.506	250
						Pars Triangularis, part IFG	45	.257	
						Dorsolateral Prefrontal Cortex	46	.206	
		-40 -84 8	1.88	.035	29	V3	19	.764	12
						Visual Assoc. Cortex (V2)	18	.234	
		24 -78 38	2.36	.013	29	V3	19	.757	15
						Somatosensory Assoc. Cortex	7	.243	
		-60 -6 38	2.30	.014	29	Pre- and Suppl. Motor Cortex	6	.781	103
		-58 -16 48	2.18	.019	29	Pre- and Suppl. Motor Cortex	6	.380	11
						Primary Somatosensory Cortex	3	.209	
						Primary Somatosensory Cortex	2	.161	
						Primary Somatosensory Cortex	1	.153	
		-56 -38 54	2.07	.023	29	Supramarginal Gyrus, part TPJ	40	.769	22
						Primary Somatosensory Cortex	2	.197	
	Answer	-48 22 -12	2.29	.015	29	Inferior Prefrontal Gyrus	45	.489	50
						Temporopolar Area	28	.482	
		52 42 -6	2.02	.026	29	Inferior Prefrontal Gyrus	47	.672	19
						Frontopolar Area	10	.131	
		53 -66 -2	2.18	.019	29	V3	19	.450	11
						Fusiform Gyrus lateral (FFA)	37	.395	
		-22 -82 38	2.23	.017	29	V3	19	.789	35
						Somatosensory Assoc. Cortex	7	.211	
		-54 2 44	2.86	.004	29	Pre- and Suppl. Motor Cortex	6	.731	419
						Dorsolateral Prefrontal Cortex	9	.143	
		38 -78 38	2.22	.017	29	V3	19	.687	11
						Somatosensory Assoc. Cortex	7	.177	
						Angular Gyrus, part TPJ	39	.136	
		42 -64 56	2.78	.005	29	Somatosensory Assoc. Cortex	7	.651	118
						Supramarginal Gyrus, part TPJ	40	.320	
		-56 -46 52	3.13	.002	29	Supramarginal Gyrus, part TPJ	40	1	193
	Feedback	56 32 -8	2.11	.022	29	Inferior Prefrontal Gyrus	47	.788	27
						Temporopolar Area	38	.111	
		-44 28 -6	2.18	.019	29	Inferior Prefrontal Gyrus	47	.822	16
						Temporopolar Area	38	.178	
		50 26 18	2.22	.017	29	Dorsolateral Prefrontal Cortex	46	.517	135
						Pars Triangularis, part IFG	45	.421	
		62 12 10	2.19	.018	29	Pars Triangularis, part IFG	45	.280	14
						Pars Opercularis, part IFG	44	.270	
						Superior Temporal Gyrus	22	.235	

								Pre- and Suppl. Motor Cortex	6	.159	
		64	-16	38	2.50	.009	29	Pre- and Suppl. Motor Cortex	6	.410	256
								Primary Somatosensory Cortex	1	.174	
								Primary Somatosensory Cortex	3	.145	
								Primary Somatosensory Cortex	2	.135	
		42	-78	40	2.68	.006	29	V3	19	.550	17
								Angular Gyrus, part TPJ	39	.236	
								Somatosensory Assoc. Cortex	7	.208	
		-52	20	40	2.02	.026	29	Dorsolateral Prefrontal Cortex	9	.556	12
								Frontal Eye Fields	8	.296	
								Dorsolateral Prefrontal Cortex	46	.100	
Private > Public ($p < .05$)	Question	-46	12	-6	-2.79	.005	29	Temporopolar area	38	.495	166
								Inferior Prefrontal Gyrus	47	.256	
								Superior Temporal Gyrus	22	.232	
		54	42	4	-2.52	.009	29	Inferior Prefrontal Gyrus	47	.371	131
								Dorsolateral Prefrontal Cortex	46	.341	
								Frontopolar area	10	.149	
								Pars Triangularis, part IFG	45	.138	
		62	-52	10	-2.55	.008	29	Superior Temporal Gyrus	22	.502	54
								Middle Temporal Gyrus	21	.300	
		28	-84	18	-2.54	.008	29	V3	19	.952	175
		-64	4	16	-2.45	.010	29	Pre- and Suppl. Motor Cortex	6	.326	77
								Pars Opercularis, part IFG	44	.248	
								Superior Temporal Gyrus	22	.211	
		62	2	32	-2.50	.009	29	Pre- and Suppl. Motor Cortex	6	.654	157
								Dorsolateral Prefrontal Cortex	9	.261	
		-62	-30	32	-2.35	.013	29	Supramarginal Gyrus, part TPJ	40	.626	102
								Primary Somatosensory Cortex	2	.173	
		44	-60	46	-2.43	.011	29	Supramarginal Gyrus, part TPJ	40	.459	368
								Somatosensory Assoc. Cortex	7	.340	
								Angular Gyrus, part TPJ	39	.176	
		0	-66	56	-2.29	.015	29	Somatosensory Assoc. Cortex	7	1	12
		18	-56	62	-1.74	.046	29	Somatosensory Assoc. Cortex	7	1	10
	Answer	60	8	-16	-2.25	.016	29	Middle Temporal Gyrus	21	.549	43
								Temporopolar area	38	.361	
		-68	-24	-12	-1.99	.028	29	Middle Temporal Gyrus	21	.796	11
								Inferior Temporal Gyrus	20	.151	
		42	34	24	-3.16	.002	29	Dorsolateral Prefrontal Cortex	46	.813	659
								Dorsolateral Prefrontal Cortex	9	.135	
		52	-76	6	-2.27	.015	29	V3	19	.652	19
								Fusiform Gyrus lateral (FFA)	37	.151	
								Angular Gyrus, part TPJ	39	.138	
		-48	26	10	-1.82	.039	29	Pars Triangularis, part IFG	45	.581	12
								Dorsolateral Prefrontal Cortex	46	.240	
								Inferior Prefrontal Gyrus	47	.163	
		-56	-62	32	-2.68	.006	29	Angular Gyrus, part TPJ	39	.611	301
								Supramarginal Gyrus, part TPJ	40	.365	
		-56	26	22	-2.60	.007	29	Dorsolateral Prefrontal Cortex	46	.399	21
								Pars Triangularis, part IFG	45	.342	
								Dorsolateral Prefrontal Cortex	9	.171	

		48	-78	18	-1.93	.032	29	V3	19	.623	17
								Angular Gyrus, part TPJ	39	.360	
		-66	-10	30	-2.28	.015	29	Pre- and Suppl. Motor Cortex	6	.460	10
								Subcentral area	43	.199	
		-22	-62	58	-1.97	.029	29	Somatosensory Assoc. Cortex	7	1	16
	Feedback	-60	2	-16	-2.14	.020	29	Middle Temporal Gyrus	21	.735	28
								Temporopolar area	38	.156	
		66	-34	-12	-1.78	.043	29	Middle Temporal Gyrus	21	.720	13
								Inferior Temporal Gyrus	20	.219	
		-60	-42	-4	-2.01	.027	29	Middle Temporal Gyrus	21	.738	11
								Superior Temporal Gyrus	22	.167	
		54	40	4	-2.40	.011	29	Inferior Prefrontal Gyrus	47	.389	63
								Dorsolateral Prefrontal Gyrus	46	.344	
								Pars Triangularis, part IFG	45	.167	
		68	-48	10	-2.10	.022	29	Superior Temporal Gyrus	22	.631	21
								Middle Temporal Gyrus	21	.286	
		52	40	20	-2.26	.016	29	Dorsolateral Prefrontal Cortex	46	.810	109
								Frontopolar area	10	.110	
		-56	-66	34	-2.17	.019	29	Angular Gyrus, part TPJ	39	.726	13
								Supramarginal Gyrus, part TPJ	40	.274	
		-26	30	38	-1.90	.034	29	Frontal Eye Fields	8	.928	13
		50	-54	44	-1.89	.034	29	Supramarginal Gyrus, part TPJ	40	.853	27
								Angular Gyrus, part TPJ	39	.125	
Face > Baseline	Production	-54	34	-8	1.90	.034	29	Inferior Prefrontal Gyrus	47	.841	17
($p < .05$)		44	36	22	2.30	.014	29	Dorsolateral Prefrontal Cortex	46	.842	136
		-42	-72	26	2.45	.010	29	Angular Gyrus, part TPJ	39	.793	176
								V3	19	.207	
		34	-84	26	2.46	.010	29	V3	19	.988	74
		-64	-12	36	2.42	.011	29	Pre- and Suppl. Motor Cortex	6	.528	458
								Primary Somatosensory Cortex	1	.118	
								Primary Somatosensory Cortex	2	.112	
		60	-52	44	2.36	.012	29	Supramarginal Gyrus, part TPJ	40	.935	85
		-64	-42	42	2.63	.007	29	Supramarginal Gyrus, part TPJ	40	.949	12
	Observation	68	-34	-10	2.10	.022	29	Middle Temporal Gyrus	21	.740	47
								Inferior Temporal Gyrus	20	.129	
								Superior Temporal Gyrus	22	.102	
		66	-6	-4	2.02	.026	29	Middle Temporal Gyrus	21	.613	96
								Superior Temporal Gyrus	22	.341	
		56	8	-6	1.82	.039	29	Superior Temporal Gyrus	22	.309	15
								Temporopolar Area	38	.273	
								Middle Temporal Gyrus	21	.253	
								Inferior Temporal Gyrus	47	.107	
		60	20	-4	1.97	.029	29	Inferior Prefrontal Gyrus	47	.369	16
								Temporopolar Area	38	.239	
								Pars Triangularis, part IFG	45	.165	
								Superior Temporal Gyrus	22	.155	
		60	-62	14	1.96	.030	29	Angular Gyrus, part TPJ	39	.389	20
								Superior Temporal Gyrus	22	.227	

								Middle Temporal Gyrus	21	.147	
								V3	19	.110	
		-56	12	32	2.09	.023	29	Dorsolateral Prefrontal Cortex	9	.513	210
								Pre- and Suppl. Motor Cortex	6	.221	
								Pars Triangularis, part IFG	45	.112	
		40	30	30	2.32	.014	29	Dorsolateral Prefrontal Cortex	9	.578	44
								Dorsolateral Prefrontal Cortex	46	.422	
		-48	10	38	1.82	.039	29	Dorsolateral Prefrontal Cortex	9	.485	25
								Pre- and Suppl. Motor Cortex	6	.281	
								Frontal Eye Fields	8	.233	
		56	-46	44	2.14	.020	29	Supramarginal Gyrus, part TPJ	40	1	40
Baseline > Face ($p < .05$)	Production	-62	-14	-2	-2.28	.015	29	Middle Temporal Gyrus	21	.562	343
								Superior Temporal Gyrus	22	.316	
								Auditory Prim. & Assoc. Cortex	42	.122	
		64	-22	6	-1.83	.039	29	Auditory Prim. & Assoc. Cortex	42	.398	14
								Superior Temporal Gyrus	22	.341	
								Middle Temporal Gyrus	21	.166	
		62	16	20	-2.56	.008	29	Pars Triangularis, part IFG	45	.353	58
								Pars Opercularis, part IFG	44	.251	
								Dorsolateral Prefrontal Cortex	9	.238	
								Pre- and Suppl. Motor Cortex	6	.108	
		70	-36	20	-2.63	.007	29	Supramarginal Gyrus, part TPJ	40	.452	58
								Superior Temporal Gyrus	22	.383	
								Auditory Prim. & Assoc. Cortex	42	.158	
		68	-10	28	-2.33	.013	29	Pre- and Suppl. Motor Cortex	6	.444	181
								Subcentral area	43	.204	
		-48	-60	52	-2.55	.008	29	Supramarginal Gyrus, part TPJ	40	.674	10
								Somatosensory Assoc. Cortex	7	.216	
								Angular Gyrus, part TPJ	39	.111	
	Observation	54	42	8	-2.08	.023	29	Dorsolateral Prefrontal Cortex	46	.467	57
								Inferior Prefrontal Gyrus	47	.218	
								Frontopolar area	10	.165	
								Pars Triangularis, part IFG	45	.150	
		38	46	10	-2.17	.019	29	Frontopolar area	10	.605	13
								Dorsolateral Prefrontal Cortex	46	.395	
		62	4	28	-2.03	.026	29	Pre- and Suppl. Motor Cortex	6	.546	142
								Dorsolateral Prefrontal Cortex	9	.275	
		48	-54	54	-2.42	.011	29	Supramarginal Gyrus, part TPJ	40	.766	331
								Somatosensory Assoc. Cortex	7	.183	
		50	-12	46	-2.43	.011	29	Pre- and Suppl. Motor Cortex	6	.570	79
								Primary Somatosensory Cortex	3	.243	
								Primary Motor Cortex	4	.104	

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere

df = degrees of freedom, BA = Brodmann Area

5.7.7. Full OxyHb results for task+face effects

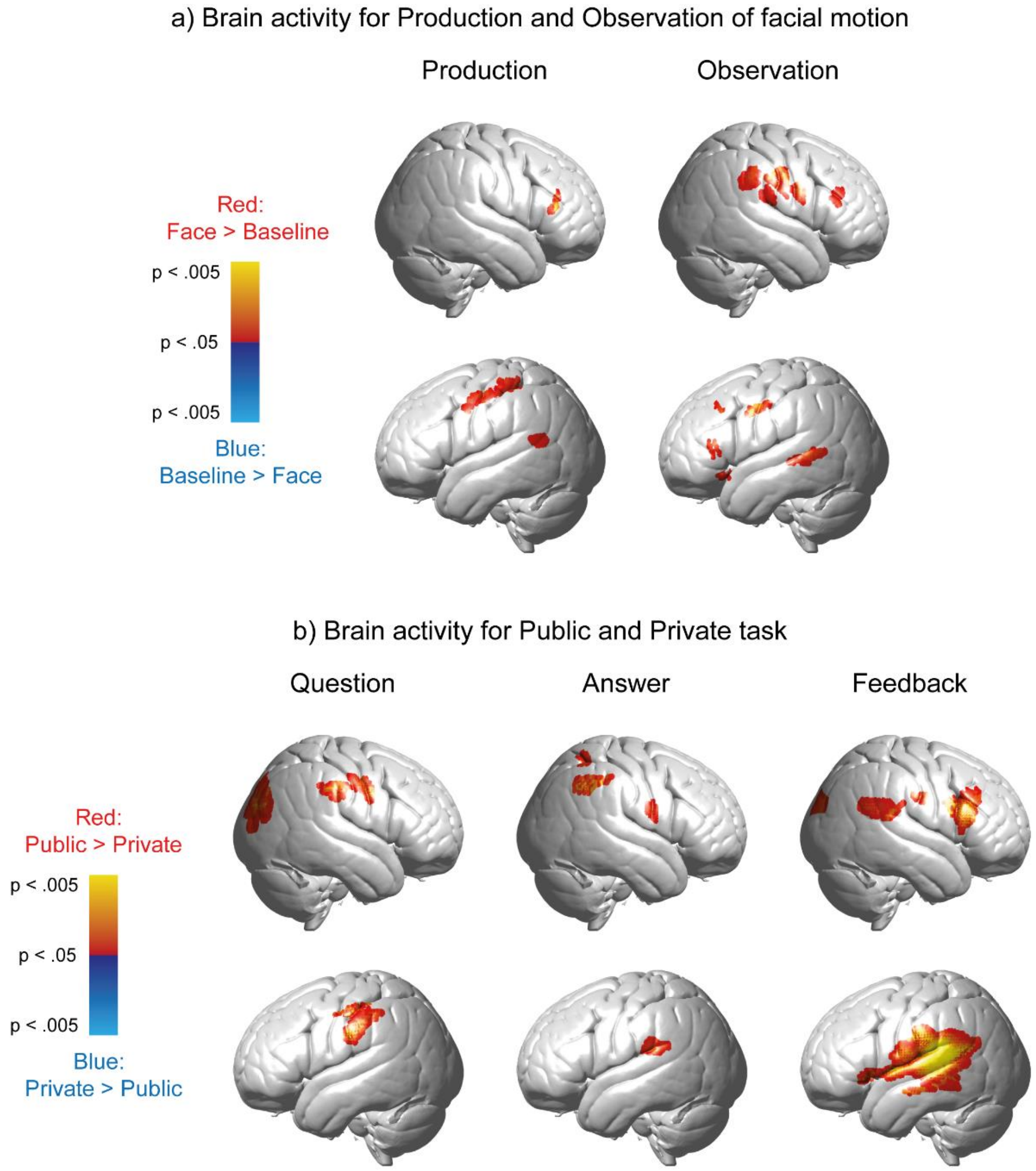

Figure 5-9. Contrast effects for "task+face GLM" (OxyHb signal).
a) Brain activity correlated with Production of facial motion > Baseline (left) and Observation of facial motion > Baseline (right) across both conditions (red colour; p < .05). b) Brain activity correlated with Public > Private for each trial Phase (red colour; p < .05).

Table 5-10. Voxel-wise GLM contrast comparisons for task- and face- related effects (OxyHb signal)

Contrast (contrast threshold)	**Phase**	**Peak voxels** MNI coords.[1] (X	Y	Z)	*t*	*p*	df	**Anatomical region**	**BA**	**Prob. incl.**	**Voxels** (n in cluster)
Public > Private (p < .05)	Question	34	-84	10	1.90	.034	29	V3	19	.756	11
								Visual Assoc. Cortex (V2)	18	.244	

		32	-82	24	2.50	.009	29	V3	19	1	167
		-66	-18	32	2.94	.003	29	Pre- and Suppl. Motor Cortex	6	.229	141
								Supramarginal Gyrus, part TPJ	40	.217	
								Primary Somatosensory Cortex	2	.145	
								Subcentral Area	43	.127	
								Primary Somatosensory Cortex	1	.119	
		58	0	32	2.29	.015	29	Pre- and Suppl. Motor Cortex	6	.713	156
								Dorsolateral Prefrontal Cortex	9	.264	
		66	-32	38	2.38	.012	29	Supramarginal Gyrus, part TPJ	40	.686	67
								Primary Somatosensory Cortex	2	.140	
								Primary Somatosensory Cortex	1	.100	
		-60	-20	48	2.51	.009	29	Pre- and Suppl. Motor Cortex	6	.242	40
								Primary Somatosensory Cortex	2	.228	
								Primary Somatosensory Cortex	3	.188	
								Primary Somatosensory Cortex	1	.165	
								Supramarginal Gyrus, part TPJ	40	.109	
	Answer	60	0	20	2.00	.028	29	Pre- and Suppl. Motor Cortex	6	.477	43
								Pars Opercularis, part IFG	44	.125	
								Subcentral Area	43	.110	
								Superior Temporal Gyrus	22	.106	
		-68	-34	18	2.10	.022	29	Superior Temporal Gyrus	22	.404	40
								Supramarginal Gyrus, part TPJ	40	.356	
								Auditory Prim. & Assoc. Cortex	42	.198	
		64	-40	44	2.69	.006	29	Supramarginal Gyrus, part TPJ	40	.899	68
		44	-52	58	2.09	.023	29	Supramarginal Gyrus, part TPJ	40	.552	21
								Somatosensory Assoc. Cortex	7	.288	
								Somatosensory Assoc. Cortex	5	.131	
	Feedback	-68	-34	14	5.02	<.001	29	Superior Temporal Gyrus	22	.476	2120
								Auditory Prim. & Assoc. Cortex	42	.233	
								Supramarginal Gyrus, part tPJ	40	.222	
		62	16	22	4.19	<.001	29	Pars Triangularis, part IFG	45	.322	408
								Dorsolateral Prefrontal Cortex	9	.287	
								Pars Opercularis, part IFG	44	.225	
								Pre- and Suppl. Motor Cortex	6	.107	
		70	-36	18	2.24	.016	29	Superior Temporal Gyrus	22	.444	157
								Supramarginal Gyrus, part TPJ	40	.373	
								Auditory Prim. & Assoc. Cortex	42	.180	
		36	-86	26	2.06	.024	29	V3	19	.967	10
		66	-10	34	2.12	.021	29	Pre and Suppl. Motor Cortex	6	.587	15
								Primary Somatosensory Cortex	3	.104	
Face > Baseline (p < .05)	Production	54	34	16	2.53	.008	29	Dorsolateral Prefrontal Cortex	46	.608	21
								Pars Triangularis, part IFG	45	.373	
		-62	-54	14	1.84	.038	29	Superior Temporal Gyrus	22	.452	33
								Middle Temporal Gyrus	21	.230	
								Angular Gyrus, part TPJ	39	.145	
								Supramarginal Gyrus, part TPJ	40	.120	
		-48	-10	44	2.05	.025	29	Pre- and Suppl. Motor Cortex	6	.719	97
								Primary Somatosensory Cortex	3	.173	
		-50	-34	56	2.04	.025	29	Supramarginal Gyrus, part TPJ	40	.525	61
								Primary Somatosensory Cortex	2	.253	

							Primary Somatosensory Cortex	1	.155	
Observation	-42	22	-10	1.89	.034	29	Inferior Prefrontal Gyrus	47	.559	16
							Temporopolar Area	38	.436	
	-64	-44	4	2.05	.025	29	Middle Temporal Gyrus	21	.497	70
							Superior Temporal gyrus	22	.482	
	48	30	16	1.88	.035	29	Dorsolateral Prefrontal Cortex	46	.686	43
							Pars Triangularis, part IFG	45	.314	
	62	2	26	2.19	.018	29	Pre- and Suppl. Motor Cortex	6	.550	61
							Dorsolateral Prefrontal Cortex	9	.199	
	70	-22	4	1.86	.036	29	Supramarginal Gyrus, part TPJ	40	.299	25
							Auditory Prim. & Assoc. Cortex	42	.210	
							Subcentral Area	43	.157	
	68	-20	36	2.05	.025	29	Supramarginal Gyrus, part TPJ	40	.255	15
							Pre- and Suppl. Motor Cortex	6	.248	
							Primary Somatosensory Cortex	1	.158	
							Primary Somatosensory Cortex	2	.142	
							Primary Somatosensory Cortex	3	.114	
	60	-30	36	2.02	.026	29	Supramarginal Gyrus, part TPJ	40	.630	56
							Primary Somatosensory Cortex	2	.154	
							Primary Somatosensory Cortex	1	.130	
	62	-8	36	2.37	.012	29	Pre- and Suppl. Motor Cortex	6	.749	77
							Primary Somatosensory Cortex	3	.119	
	-50	-4	36	2.36	.013	29	Pre- and Suppl. Motor Cortex	6	.942	42
	-50	24	38	2.03	.026	29	Dorsolateral Prefrontal Cortex	9	.535	10
							Frontal Eye Fields	8	.256	
							Dorsolateral Prefrontal Cortex	46	.196	

[1]Coordinates are based on the MNI system and (-) indicates left hemisphere

df = degrees of freedom, BA = Brodmann Area

Chapter 6. Discussion

Part of Chapter 6 was published in a review paper in Frontiers in Psychology:

Cañigueral, R., & Hamilton, A. F. de C. (2019). The Role of Eye Gaze During Natural Social Interactions in Typical and Autistic People. *Frontiers in Psychology*, *10*(560), 1–18. https://doi.org/10.3389/fpsyg.2019.00560

6.1. Summary of experimental chapters

This thesis aimed to investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched (and in reciprocal interactions), especially focusing on the use of eye gaze, facial displays and prosocial behaviour as social signals. To do so, it implemented well-controlled paradigms with high ecological validity, tasks that create a communicative environment, and novel techniques to record behaviour and brain activity in live interactions. In this chapter, I first present a summary of the findings, followed by discussion on their theoretical implications. Then, I focus on the dual function of eye gaze to propose a cognitive model of gaze processing in face-to-face interactions. Finally, I outline two directions for future research that could advance our understanding of social interactions.

Chapter 2 combined a novel paradigm with a communicative task to test which mechanisms underlie audience effects on eye gaze and prosocial behaviour. In particular, I found that the belief in being watched increases prosocial behaviour to signal good reputation, and decreases gaze directed to the confederate to reduce the intensity during an interaction with a stranger. Moreover, I found that prosocial choices influence subsequent gaze behaviour: participants gaze more to the confederate when they make less prosocial choices. This highlights the dynamic nature of eye gaze in relation to other social signals.

Chapter 3 used the same experimental paradigm as Chapter 2 to test the hypothesis that audience effects are related to an increase in self-referential processing when being watched. Although the belief manipulation and the self-referential effect task were effective, the belief in being watched did not modulate self-referential processing, self-awareness or prosocial behaviour. These findings do not provide enough evidence to support the self-referential processing hypothesis, but motivate further research on the role of the self and social context in audience effects.

Chapter 4 aimed to explore how being watched modulates gaze patterns in typical and autistic individuals during a structured conversation. Across two studies, I found that typical participants decrease gaze directed to the confederate when the confederate can see them, and when they are speaking. Time-course analysis of gaze further indicated that they direct gaze to the eyes and mouth of the confederate to perceive and signal distinct information. Contrary to our hypotheses, results for the autistic group suggest that their gaze patterns are overall similar to those found in the typical group. Moreover, being watched increased spontaneous production of facial displays for both groups, especially when participants are speaking. These findings demonstrate that typical and high-functioning autistic individuals use eye gaze and facial displays as social signals during communication.

Finally, Chapter 5 simultaneously recorded eye gaze, facial displays and brain activity in dyads to test how they are modulated when participants reciprocally disclose biographical information. Results showed that reciprocity translates into more production and monitoring of facial displays, suggesting that eye gaze and facial displays share a communicative function. Reciprocal disclosure of biographical information also engaged brain regions involved in mentalising and strategic decision-making. Finally, I identified two brain areas recruited during spontaneous production and observation of facial displays. These findings suggest that, as social interactions become richer (e.g. with reciprocal communicative exchanges), they recruit more complex and dynamic patterns of brain activity.

6.2. Theoretical implications and emerging questions

Real-life social interactions are characterised by two (or more) agents exchanging a variety of social signals. Key to these exchanges is the fact that the interacting partners can see each other, so both can receive and send information. Traditional paradigms in social neuroscience have largely ignored this interactive nature of social encounters, and it has only been recently acknowledged that research studies should break the “fourth wall” between stimuli and participants (Risko et al., 2016). This means that, to fully understand which cognitive mechanisms guide social behaviour, we should adopt a second-person neuroscience approach (Redcay & Schilbach, 2019; Schilbach et al., 2013), where participants are (or believe they are) in the presence of an audience who can perceive them: in this context, participants will modify their behaviour in order to send signals to, and communicate with, the audience watching them (Hamilton & Lind, 2016). The aim of this thesis was to investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched, focusing on the use of eye gaze, facial displays and prosocial behaviour as social signals. In Chapter 1, I reviewed four different cognitive theories that explain how the presence of an audience modulates these social behaviours (dual function of eye gaze, behavioural ecology view of facial displays, reputation management theory, and Watching Eyes model), as well as how reciprocity in social interactions might further modulate them. In the following, I discuss how the findings from this thesis support (or not) each of these theories.

6.2.1. The dual function of eye gaze

The theory of the dual function of eye gaze proposes that we use our eyes to perceive information from the environment, but also to signal information to others (Gobel et al., 2015; Risko et al., 2016; Simmel, 1908, 1921). This means that, when planning eye movements, our visual system needs to optimise both the information we gather and the information we signal to another person. In line with the second-person neuroscience approach, the signalling function of gaze will only make sense when we are in front of other people who can see us. Thus, comparing gaze patterns when participants are watching a picture or video versus watching a real person can provide insight into whether, and how, we implement the signalling function of gaze in real-life interactions. For instance, previous studies have found that we direct less gaze to the face of a live stranger than to the face of the same stranger in a video-clip (Foulsham et al., 2011; Laidlaw et al., 2011), suggesting that in real life we avert gaze to signal no interest in interacting with a stranger (Goffman, 1963) and low affiliation or intimacy (Argyle & Cook, 1976; Argyle & Dean, 1965).

However, these studies are limited by the fact that participants interact with a stranger with whom they are not supposed to communicate: it is not surprising that in this situation participants consistently avert their gaze in face-to-face interactions, but it is unknown whether these findings generalise to other communicative contexts such as a conversation. A primary aim in this thesis was to investigate how the dual function of eye gaze is implemented in communicative situations. This question was addressed in Chapter 2 and 4 by using variations of a Q&A task where participants and confederate were engaged in a structured communicative exchange. We also developed well-controlled ecologically valid paradigms to compare how gaze patterns are modulated by the belief in being watched throughout the course of the interaction.

Findings across Chapter 2 and Chapter 4 are overall consistent. I found that participants directed less gaze to the confederate when they believed the confederate could watch them. This supports the dual function of gaze, since the opportunity to send signals overrides our preferential bias to attend to faces (Birmingham et al., 2009; Foulsham et al., 2011; Gobel et al., 2015; Laidlaw et al., 2011). In Chapter 4 I also found that this change in gaze behaviour was especially true for gaze directed to the eyes of the confederate, but not for gaze directed to the mouth. This suggests that directing gaze to the eyes or mouth of the confederate allows us to perceive and signal distinct types of information, and the visual system will plan eye movements so as to optimise both functions of gaze. A crucial question to understand gaze behaviour in real life is whether, and how, this computation is actually implemented in our visual system.

Chapter 4 further suggested that, in the context of a structured Q&A task, these findings are driven by the need to reduce arousal at moments where the interaction could become awkward (i.e. start or end of the interaction). This reveals a potential limitation in the design: in both Chapter 2 and Chapter 4, the Q&A task was very structured, since the confederate always asked the questions and participants then gave an answer. Using a task where participants and confederate alternate between asking and answering questions, or where the structure is less rigid, could further clarify how we use eye gaze in real life. For instance, in a recent study where a confederate shared personal information, participants directed more gaze to the confederate in a live video-call than in a pre-recorded video-call, probably to signal interest (Mansour & Kuhn, 2019). Thus, the message we wish to send in different social contexts and communicative situations seems to be a key factor that modulates gaze planning.

We also found that, across both studies reported in Chapter 2 and 4, participants directed more gaze to the confederate when listening (i.e. question phase) than when speaking (i.e. answer or pre-answer phase), indicating that gaze and speech are closely coordinated. This is in line with previous studies showing that there is asymmetrical gaze behaviour between speakers and listeners, and with the proposal that eye gaze regulates turn-taking during conversation (Cummins, 2012; Duncan & Fiske, 1977; Ho et al., 2015; Kendon, 1967; Sandgren et al., 2012). These studies suggest that listeners gaze at speakers to signal interest, and that speakers avert gaze to indicate that they want to retain their role. However, the present findings show that this pattern is also true when participants complete the Q&A task with a pre-recorded video of the confederate. This suggests that averting gaze while speaking might result from, not only the regulatory function of gaze, but also cognitive demands associated with face processing (Beattie, 1981; Kendon, 1967; Markson & Paterson, 2009). Whether cognitive demands are the same across pictures and live faces, and how they modulate gaze planning, will be an interesting question for future research.

As shown above, studying how gaze patterns are modulated in live interactions, and how they change over the course of communicative exchanges, can help us to elucidate which cognitive mechanisms are involved in planning eye movements. Moreover, this is also useful to identify which cognitive components of gaze planning are disrupted in disorders of social interactions, such as autism. Although poor eye contact is considered to be the hallmark of autism (Zwaigenbaum et al., 2005), evidence among high-functioning autistic adults is mixed (Falck-Ytter & Von Hofsten, 2011). It has been suggested that a reason for these inconsistencies could be the use of poor ecologically valid paradigms, where eye gaze only has a perceiving function (Chevallier et al., 2015; Drysdale et al., 2018; Von dem Hagen & Bright, 2017). Thus, Chapter 4 also tested how autistic individuals modulate gaze behaviour in live versus pre-recorded interactions.

Contrary to what was expected, findings in Chapter 4 revealed no differences between general gaze patterns in typical and autistic individuals: everyone looked less to the confederate when being watched than when not being watched, and they looked more when listening than when speaking. This indicates that autistic participants do modulate eye gaze according to its perceiving and signalling functions, and also in relation to speech (Freeth & Bugembe, 2018; Vabalas & Freeth, 2016; Von dem Hagen & Bright, 2017 Experiment 2). However, I also found that at the start of the face-to-face interaction, they gazed more to the eyes of the confederate than typical participants. Similar evidence from studies on social anxiety suggests that high-functioning autistic participants might be using compensation strategies to guide their eye movements at the start of the interaction (Gregory et al., 2019; Gutiérrez-García et al., 2019). Whether their overall gaze patterns result from compensation strategies or just reflect a spontaneous behaviour remains to be seen. Future research using neuroimaging methods and fine-grained analysis of the dynamics of social signals will be critical to further understand autistic social cognition.

6.2.2. The behavioural ecology view of facial displays

Facial displays have been traditionally associated with expressing emotions (Ekman, 1992), but the behavioural ecology view has recently suggested that they should be considered as a tool for communication (Crivelli & Fridlund, 2018). In line with this, previous studies have found that we mimic and make more facial displays when we are (or believe we are) being watched by an audience (Chovil, 1991b; Fridlund, 1991; J. K. Hietanen, Helminen, et al., 2018). Moreover, facial displays are used alongside speech to complement verbal information (Chovil, 1991a). Although this communicative function of faces implies that facial displays are spontaneously produced during social interactions, past research has mainly focused on perception and production of isolated facial displays and their neural correlates. Therefore, Chapter 4 and Chapter 5 used a face-detection algorithm to measure spontaneous production of facial displays during a communicative task. Of particular interest was how facial displays are modulated by the belief in being watched (Chapter 4), as well as which brain systems are recruited during spontaneous production and observation of facial displays (Chapter 5).

Consistent with previous findings, in Chapter 4 I found that spontaneous production of facial displays increased when participants believed they were being watched. This is consistent with the behavioural ecology view of facial displays (Crivelli & Fridlund, 2018), that is, participants use facial displays as social signals. Moreover, the present findings also showed that participants produced more facial displays when they were speaking than when they were listening, even when controlling for speech production. This is in line with studies showing that we use facial displays to emphasise what we are saying, or to help convey ideas that are hard to express with words alone (Chovil, 1991a). Thus, these findings indicate that, similar to eye gaze, during communicative exchanges we coordinate facial displays and speech to send meaningful and accurate information to others.

Chapter 5 further tested which brain systems are recruited during spontaneous production and observation of facial displays. Note that in this study the two experimental conditions involved being watched by another participant, but in one condition participants shared biographical information whereas in the other they did not. Thus, for this exploratory analysis data was pooled across both experimental conditions. I found that the left supramarginal gyrus (SMG), a region associated with speech actions and smiles (Wild et al., 2003; Wildgruber et al., 1996), was recruited during spontaneous production of facial displays. Instead, spontaneous observation of facial displays was correlated with activity in the right dorsolateral prefrontal cortex (right dlPFC), which has been previously linked to inferring emotions from faces (A. Nakamura et al., 2014; K. Nakamura et al., 1999; Ran et al., 2016). These findings point out to specific brain systems that are recruited when producing and perceiving facial displays in dynamic contexts. A key question for future research will be to understand how these (and other) brain systems interact with each other over time to achieve successful communication.

6.2.3. Reputation management theory

Maintaining good reputation in front of others is crucial to build up trust among individuals and develop communities where members cooperate with each other (Nowak & Sigmund, 2005). It has been suggested that a way to signal good reputation is by behaving in more prosocial ways when we are in front of others (Bradley et al., 2018). To test this, previous studies have used economic games to compare how participants change their prosocial behaviour in the absence and presence of an audience who (they believe) can see them. These studies have found that participants do increase their prosocial behaviour when they believe they are being watched (Cage et al., 2013; Filiz-Ozbay & Ozbay, 2014; Izuma et al., 2011, 2009). However, these studies compare a condition where participants are alone in the room versus a condition where they are (or believe they are) in the presence of an audience: this means that changes in prosocial behaviour could result from the presence of a person rather than the presence of someone who can perceive them. Moreover, it has recently been reported that economic games have poor external validity (Galizzi & Navarro-Martinez, 2019). Thus, Chapter 2 and Chapter 3 combined a Q&A task (Story task) with a novel, well-controlled and ecologically valid paradigm (deceptive video-conference paradigm) to test whether prosocial behaviour is used as a signal of good reputation.

Unfortunately, findings across Chapter 2 and Chapter 3 were contradictory. In Chapter 2 participants made more prosocial choices when they believed they were being watched, supporting the proposal that changes in prosocial behaviour respond to the need to signal good reputation in front of an audience (Bradley et al., 2018). This finding also indicates that the deceptive video-conference paradigm and the Story task are both well-suited to test audience effects. Instead, in Chapter 3 there were no differences in prosocial choices between the belief in being or not being watched. A key difference between both studies is the identity of the confederate: in Chapter 2 participants were told that the confederate was a student volunteering in a charity, whereas in Chapter 3 participants were just told that she was a student in the university department. Since the student volunteering in a charity is a positive example of prosocial behaviour, she might be perceived as more entitled to judge participants' choices compared to a random student. Consequently, she might pose a greater challenge to participants' reputation, and they have greater incentive to make more prosocial choices.

In line with this, some studies suggest that the identity associated with an individual, especially their social status, might be relevant for reputation management. For instance, low-status participants are generally more prosocial than high-status participants (Guinote et al., 2015): they invest more money in economic games and donate more money to charities compared to high-status participants (Piff et al., 2010). It has been suggested that low-status people behave in more prosocial ways to increase their social status (Kafashan et al., 2014), which will in turn improve their reputation in the group. Future studies that systematically modulate the identity (e.g. social status) of the observer will be needed to clarify the relationship between reputation management and social context associated with the observer.

6.2.4. The Watching Eyes model

The Watching Eyes model was recently proposed as a mechanism to explain eye contact effects (Conty et al., 2016). This model consists of two stages: first, direct gaze captures the beholder's attention by a subcortical route that, in turn, recruits mentalising brain areas to process the perceptual state of the observer (i.e. can she watch me or not?); then, if the observer can see me, direct gaze will evoke self-referential processing and lead to changes in behaviour (Watching Eyes effects). In line with this, it has been shown that self-referential processing increases when participants see live direct gaze (compared to live averted gaze), but not when they see pre-recorded direct gaze (compared to pre-recorded averted gaze) (J. O. Hietanen & Hietanen, 2017). It has also been found that the mere belief in being watched (elicited by a confederate with hidden eyes, who wears opaque or clear sunglasses) increases bodily self-awareness (Hazem et al., 2017). However, it is unknown whether the belief in being watched alone is enough to trigger self-referential processing: if this were true, it could indicate that audience effects are mediated by self-referential processing. This question was addressed in Chapter 3, by combining the deceptive video-conference paradigm with tasks measuring self-referential processing (Self-Referential Effect memory task) and self-awareness (Confidence Bias and optimism Bias tasks).

Findings from Chapter 3 do not support the hypothesis that self-referential processing is related to audience effects: being watched did not increase self-referential processing (or self-awareness), although the Self-Referential Effect memory task worked well (participants remembered items related to the self better than those related to others, as would be expected;

Lombardo et al., 2007). There are two main concerns in relation to these findings. First, I found that participants remembered adjectives in the baseline session (without the confederate) better than in the test session (with the confederate, either ON or OFF). This reveals that seeing a face or a pair of eyes might bias our attention (from the task to the confederate) (Rösler et al., 2017) or, as noted earlier, increase our cognitive load (Beattie, 1981; Kendon, 1967; Markson & Paterson, 2009). Second, compared to J. O. Hietanen & Hietanen (2017), in the present study participants did not experience true direct gaze: they interacted with the confederate over a screen that resembled a video-conference software. This difference suggests that the belief in being watched needs to be embedded in true direct gaze to elicit self-referential processing.

Furthermore, it is important to consider that there are various forms of self-referential processing and self-awareness. This means that different tasks are likely to engage distinct self-related cognitive processes, which might respond differently to the belief in being watched. For instance, the pronoun-selection task used by Hietanen and Hietanen (2017) is rather intuitive and has been shown to be sensitive to manipulations of self-awareness (Davis & Brock, 1975). However, it could be that other tasks which elicit more complex self-referential cognitive processes (e.g. Self-Referential Effect memory task; Craik & Tulving, 1975; Lombardo et al., 2007) are not as sensitive to this top-down modulation. It is equally important to distinguish between different forms of self-awareness, such as bodily self-awareness (accuracy in reporting physiological signals; Cameron, 2001) and metacognitive self-awareness (accuracy in judging performance in a task; Fleming & Dolan, 2012).

Overall, these findings do not allow us to draw accurate conclusions about whether audience effects are mediated by self-referential processing. Studies that investigate the effects of seeing (or not seeing) a face, true direct gaze or perceived direct gaze, as well as the effects of being watched on different forms of self-referential processing and self-awareness, will be key to clarify this question.

6.2.5. Reciprocity in social interactions

A key component in real-life social interactions is that they are reciprocal, that is, partners mutually share information with each other by taking "complementary and alternating roles" over time (Redcay & Schilbach, 2019). Reciprocal interactions also imply that participants need to integrate social signals and new incoming information from their partners (Di Paolo & De Jaegher, 2012; Hasson & Frith, 2016). Past research has found that, in economic games assessing trust and reputation, brain regions linked to mentalising and reward learning (e.g. temporo-parietal junction, caudate) incorporate new information from the partner to build up predictions about the partner's future behaviour (Carter et al., 2012; King-Casas et al., 2005). However, a main limitation in these studies is that participants are isolated inside the fMRI scanner: this means that they are missing a crucial element of face-to-face interactions, that is, the exchange of social signals with a partner. Thus, Chapter 5 tested whether, beyond being watched, engaging in a reciprocal face-to-face interaction modulates social signals and brain activity during mutual information sharing. For this, eye gaze, facial motion and brain activity (fNIRS) were simultaneously recorded while pairs of participants shared (or not) biographical information.

Results from Chapter 5 showed that participants directed more gaze to the face of the partner during reciprocal interactions but, importantly, this was only true after they had shared biographical information. This suggests that participants might be using gaze to signal what they think about the partner's choice, but also to monitor what the partner thinks about their own choices. This is in line with findings in Chapter 2, where participants directed more gaze to the confederate after making less prosocial choices, indicating that participants used eye gaze to seek approval from the confederate and manage their reputation (Efran, 1968; Efran & Broughton, 1966; Kendon, 1967; Kleinke, 1986). Moreover, Chapter 5 also showed that participants produced more facial displays during reciprocal interactions and after sharing biographical information. This supports the proposal that facial displays have a communicative function, and that they may be used to influence others (Chovil, 1991b; Crivelli & Fridlund, 2018; Fridlund, 1991). Altogether, these findings indicate that eye gaze and facial displays share a signalling function during reciprocal communication. Future studies will be needed to fully understand the specific mechanisms by which these (and other) social signals are appropriately coordinated during face-to-face interactions.

In the study reported in Chapter 5 I also found that reciprocal interactions engaged a complex brain system that involved different brain regions depending on the stage of the trial. For instance, the dorsolateral prefrontal cortex, linked to strategic decision-making and working memory (Barbey et al., 2013; Soutschek et al., 2015; Speitel et al., 2019; Veltman et al., 2003), was more engaged in the reciprocal interaction before participants made and shared their choices. Instead, the right temporo-parietal junction, a classical mentalising region (Saxe & Kanwisher, 2003; Saxe & Wexler, 2005), was more engaged in the reciprocal interaction after participants shared their choices. It is important to note that this design and analysis do not allow us to distinguish whether these activations are related to making inferences about own reputation in the eyes of the partner, learning new information about the partner, or just thinking about the partner. Thus, it is necessary to further investigate how our brain integrates information from others over the course of face-to-face interactions.

6.2.6. Summary

The primary aim of this thesis was to investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched. For this, I focused on the use of eye gaze, facial displays and prosocial behaviour as social signals, and tested different cognitive theories that aim to explain audience effects on these social behaviours. Moreover, I also examined how reciprocity in social interactions (i.e. interactions where participants mutually share information with one another) further modulates social signals and brain activity.

These findings support the claim that eye gaze has perceiving and signalling functions in social interactions, and that it is coordinated with speech during communicative exchanges (Chapter 2 and Chapter 4). I also found that, contrary to our hypotheses, high-functioning autistic participants do use eye gaze as a social signal (Chapter 4). Future research should implement more naturalistic tasks as well as fine-grained analyses of gaze dynamics. In particular, it will be crucial to understand how our visual system plans eye movements to optimise both information we perceive from, and information we signal to, the environment.

I also found evidence in favour of the behavioural ecology view of facial displays, which proposes that facial displays are used as social signals: participants spontaneously produced more facial displays when they believed they were being watched and when they were speaking (Chapter 4). Moreover, I found that specific brain regions engaged during spontaneous production and perception of facial displays (Chapter 5). Studies that investigate how the time-course of brain activity tracks facial displays over the course of the interaction will be key to fully understand these mechanisms.

Regarding reputation management theory, I found contradictory results: whereas in Chapter 2 participants increased prosocial behaviour when they believed they were being watched, in Chapter 3 there was no such effect. Since these two studies differed on the identity of the observer (volunteer in a charity or random student), future studies will need to investigate how factors other than the belief in being watched have a role in reputation management.

I further tested whether audience effects are related to an increase in self-referential processing when being watched, but results did not provide enough evidence to support this hypothesis (Chapter 3). Future studies that control for effects related to seeing (or not seeing) a face or true direct gaze, and different forms of self-referential processing and self-awareness will be needed to clarify this question.

Finally, I found that being reciprocally engaged with another person (by mutually sharing information with each other) modulated social signals and brain activity (Chapter 5). In particular, participants monitored and produced more facial displays during reciprocal interactions, especially after sharing information with the partner. Reciprocal disclosure of biographical information also recruited brain areas linked to strategic decision-making (dlPFC) and mentalising (TPJ). Future studies will need to investigate how our brain integrates incoming information and social signals from other people to make sense of social interactions.

6.3. A cognitive model for social eye gaze

Throughout this thesis, I have highlighted the role of eye gaze as a social signal, both as a cue that "someone is watching" as well as to receive and send information during communicative interactions. Chapter 2 and Chapter 4 showed that, during communicative exchanges, eye gaze is used to both perceive and signal information, and that it is coordinated with speech. However, it is not yet known how our visual system plans eye movements to optimise the information we perceive and signal during face-to-face interactions. Here we draw on two distinct frameworks, from motor control (active sensing; Yang et al., 2016) and from animal communication (signalling theory; Grafen, 1990; Zahavi, 1975), to introduce the Interpersonal Gaze Processing model. This model considers how these two frameworks can be combined in the domain of social eye gaze to take into account both its perceiving and signalling functions.

6.3.1. Active sensing and eye gaze

As reviewed in Chapter 1 (see section *1.2.1. The perceiving function of eye gaze*), early cognitive research already described how the visual system gains information from the environment in non-social contexts: our visual cortex computes saliency and priority maps that represent low-level features of the visual scene and affective features associated with task goals (Itti & Koch, 2001; Jeong et al., 2008; Koch & Ullman, 1985; Veale et al., 2017). However, when viewing pictures or videos of another person there is a preferential bias to attend to faces (Birmingham et al., 2009; End & Gamer, 2017; Nasiopoulos et al., 2015; Rubo & Gamer, 2018). In such (non-interactive) social contexts implicit social task goals (e.g. identify feelings of an actress in a movie) will generate different sensing maps, just as non-social task goals (e.g. search for the cell phone) generate different priority maps.

The active sensing framework proposes that our sensors (e.g. our eyes) are directed to different locations in the environment to extract relevant information (Yang et al., 2016). Thus, by combining low-level and affective features in priority and sensing maps, our motor system (saccade planner) moves our eyes to specific locations of interest that are further processed by the visual system (Yang et al., 2016). Although this allows us to maximise the information we gain from the environment, it is not enough to account for gaze behaviour in face-to-face interactions, where we also need to optimise the information we signal to others (i.e. dual function of eyes; Argyle & Cook, 1976; Gobel et al., 2015; Risko et al., 2016).

6.3.2. Social signalling and eye gaze

Research on animal communication has explored in detail the question of what behaviour counts as a social signal and what message (if any) is sent (Stegmann, 2013). A cue is a behaviour or feature that can be used by another creature to guide its behaviour; for example, mosquitos use the increased carbon dioxide in exhaled air as a cue to find people to bite, but there is no benefit here to those sending the cue. In contrast, the mating call of a bird that attracts a mate acts as a signal because it benefits both sender and receiver (Stegmann, 2013). A key way to distinguish between these is that signals are sent with the purpose of having an effect on another individual, which means they are more likely to be sent when they can be received. In the context of human interaction, signals are sent when another person is present (an audience effect) but should not be sent when a person acts alone. A stronger definition of explicit and deliberate signalling might require sending a signal repeatedly or elaborating on the signal until it is received. However, based on animal communication models (Stegmann, 2013), we will use a minimal definition of communication where signals are sent implicitly.

As described above, our eyes can act both as a cue to our current thoughts (e.g. if I am looking at my watch, I want to know the time) and as a signal to another person (e.g. I ostentatiously stare at my watch to signal to my friend that we must leave the party) (Argyle & Cook, 1976; Gobel et al., 2015; Risko et al., 2016). However, as mentioned in Chapter 1 (see section *1.2.2. The signalling function of eye gaze*), “one cannot not communicate” (Watzlawick et al., 1967): in real life, even when we are not engaged in explicit communicative exchanges (e.g. conversation), we will send signals indicating whether we are interested in starting an interaction (direct gaze) or not (averted gaze) (Foulsham et al., 2011). We propose that the signalling function of gaze creates a signalling map in the brain equivalent to the sensing map generated by the perceiving/sensing function. In the same way that sensing maps show where to look to gain information, we hypothesize that signalling maps are computed in the brain to show where to look to send an appropriate signal to another person. In the following, we argue that the signalling map is computed by taking into account three key factors: communicative purpose, other's gaze direction, and coordination with other social signals.

First, the value of each gaze target in the signalling map will vary depending on the communicative purpose, that is, the type of message we wish to send. Just as saliency maps incorporate the task goal to create priority or sensing maps of visual attention, signalling maps need to take into account the communicative purpose. Imagine a waiting room with two people, where one person (A) wants to engage in an interaction, but the other person (B) does not. For person A, the optimal signalling behaviour is to direct gaze to person B in order to send the message "I want to engage in an interaction with you". However, person B should avert gaze to efficiently signal "I do not want to interact with you". Thus, the signalling map will be different for person A and B, depending on the message they want to send.

Second, the signalling map will change according to the direction of the other person's gaze. The relationship between other's gaze direction and the signalling map lies in the fact that signals will be received depending on whether the other person is gazing at us or not. Let's go back to the case of the waiting room with person A and B. For person A, who wishes to interact with person B, the optimal signalling behaviour is to direct her gaze when person B is also looking at her, in order to disclose interest in the interaction. Directing her gaze when B is not looking has little benefit, because the signal will not be received. Equally, for person B the optimal signalling behaviour is to avert gaze specifically when A is looking at her. This illustrates how the values associated with each location in the signalling map changes on a moment-by-moment basis, contingent on the gaze direction of the other person and in relation to communicative purpose.

Finally, the signalling map depends on the need to coordinate with other social signals that are sent in multimodal communication, such as speech, facial displays or gestures (Hirai & Kanakogi, 2018; Ho et al., 2015; Holler, Kendrick, & Levinson, 2018; Jack & Schyns, 2015; Trujillo, Simanova, Bekkering, & Özyürek, 2018; Vigliocco, Perniss, & Vinson, 2014). This is particularly relevant for explicit communicative encounters. Imagine that person A and B in the waiting room are now engaged in a lively conversation: to signal interest in keeping the conversation going, the choice of direct or averted gaze will vary depending on the role of each partner in the conversation, as well as the time-course of speech itself. For instance, when person A starts speaking, she may avert gaze every now and then to signal she still has more things to say (Ho et al., 2015; Kendon, 1967). While person B is listening, her gaze may be directed towards person A in order to signal interest in what A is saying (Ho et al., 2015; Kendon, 1967). However, when person A is finishing the utterance, she may look towards person B to signal that she can take the floor (Ho et al., 2015; Kendon, 1967). Thus, the coordination with other social signals also modulates the optimal location in the signalling map on a moment-by-moment basis.

Signalling theory provides a framework to understand how the communicative function of gaze shapes the planning of eye movements during face-to-face interactions. In the following, we propose a model where both active sensing and social signalling are combined to make sense of gaze patterns in face-to-face communication.

6.3.3. The Interpersonal Gaze Processing model

The Interpersonal Gaze Processing model considers how gaze transitions from one state to the other (i.e. how eye movements are planned) when presented with social stimuli (Figure 6-1 and 6-2). This model distinguishes between two situations that differ in the belief in being watched: one where the social stimulus is a picture or video (i.e. cannot see us), and one where the social stimulus is a real person in front of us (i.e. can see us).

In the first case, where the stimulus is a picture or video of another person, there is no need to send a signal because it will not be perceived. Thus, the planning of eye movements only responds to active sensing, which aims to gain maximal information from the stimulus (Yang et al., 2016). The Interpersonal Gaze Processing model considers that gaze patterns derived from active sensing correspond to baseline gaze behaviour. When the goal is to get social information from the picture or video (e.g. what is the man in the picture feeling?) gaze patterns will be mostly influenced by sensing maps (see Figure 6-1 and 6-2a). This baseline sensing map reveals how people use gaze to gain different types of social information during interactions. For example, in a noisy environment where it is hard to hear, they will look more to the centre of the face to help with speech comprehension; conversely, to recognise emotions they will look more to the eyes (Buchan, Paré, & Munhall, 2007, 2008; Lewkowicz & Hansen-Tift, 2012). This also demonstrates how task goals (e.g. speech comprehension or emotion recognition) translate in different eye movements depending on the information that needs to be maximised.

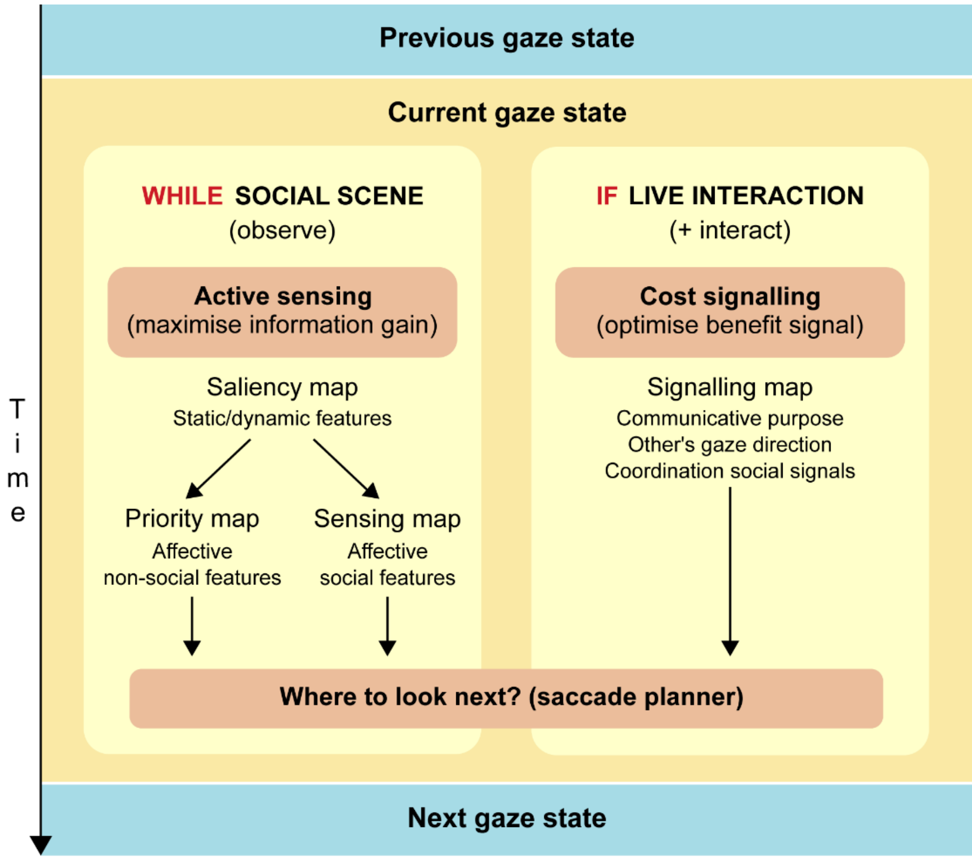

Figure 6-1. Diagram summarising the Interpersonal Gaze Processing model.

In the second case, where the stimulus is a real person in front of us, our eyes will be sending a signal to the other person. Here, the Interpersonal Gaze Processing model proposes that gaze patterns result from a trade-off between sensing maps and signalling maps (Figure 6-1 and 6-2b). This means that the planning of eye movements combines the maximal gain of information from a particular location in the sensing map (e.g. eyes of the other person), together with the optimal benefit of gazing to that location in the signalling map. Figure 6-3 illustrates how different possible gaze targets on the face can provide various types of information (sensing function), but also can send different signals (signalling function). Comparing baseline gaze behaviour in a video to gaze behaviour in a matched real-life interaction, can provide a measure of the signalling components of eye gaze. For example, it has been shown that people direct gaze to the eyes of a stranger in a video, but not to the eyes of a live stranger: this indicates that averting gaze from the real person has a meaningful signalling value, since it expresses no desire to affiliate with the stranger and reduces the intensity of the interaction (Argyle & Dean, 1965; Foulsham et al., 2011; Laidlaw et al., 2011).

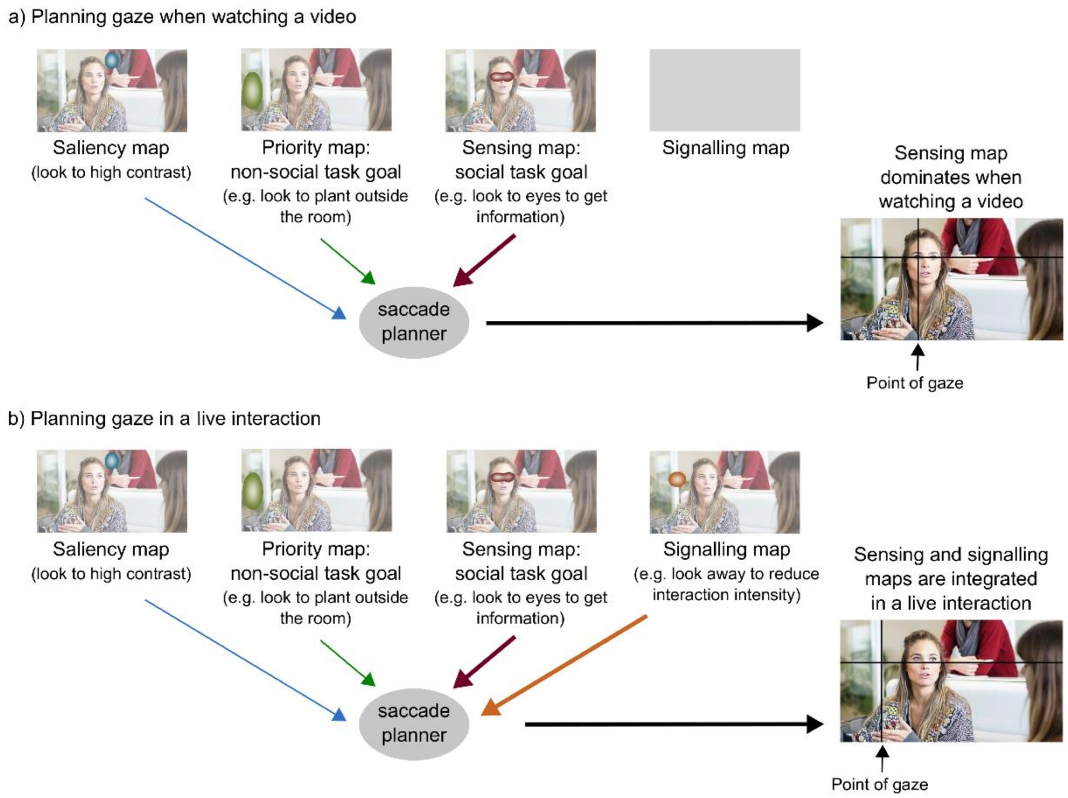

Figure 6-2. The Interpersonal Gaze Processing model in a real social scene. a) Planning gaze when watching a video. b) Planning gaze in a live interaction. Blurbs indicate areas of high saliency depending on the type of map. Original image published by Max Pixel under the Creative Commons CC0 License. Original maps were obtained with SaliencyToolbox for Matlab (Walther & Koch, 2006).

Thus, the Interpersonal Gaze Processing model proposes that, moment-by-moment, the gaze control systems in the brain must evaluate both the information gained and the signalling potential of a saccade, to determine where to look next. Note that, although the sensing and signalling maps are presented as separate maps (see Figure 6-1), this is just to emphasise the relevance of the signalling function introduced in our model of gaze planning. Instead, we propose that gaze planning relies on a single map that combines bottom-up modulation of salient physical features, as well as top-down modulation of affective features, task goals and the signalling value of eye gaze. Our model places special emphasis on communicative purpose and coordination with other social signals (e.g. other's gaze direction, speech, facial expressions): while communicative purpose (together with the belief in being watched) is key to define the signalling map, the coordination with other social signals modulates this map on a moment-by-moment basis. Future studies on gaze processing should try to elucidate how each of these factors modulates gaze sensing and signalling during communication, as well as if (and how) these maps are computed and integrated in the brain.

Gaze target	Eyes	Mouth	Background
Sensing function	Emotions Interest in me	Speech Emotions	No social information
Signalling function	Interaction intensity Affiliation Turn-taking	Interest in you	No interest in you Polite gaze aversion Hesitation

Figure 6-3. Different sensing and signalling maps may be used in different contexts. Original image published by Max Pixel under the Creative Commons CC0 License. Original maps were obtained with SaliencyToolbox for Matlab (Walther & Koch, 2006).

6.4. Future directions

Throughout this thesis I have presented evidence that the belief in being watched engages specific neurocognitive mechanisms that modulate eye gaze, facial displays and prosocial behaviour. I have also identified challenges that could be addressed in future research to further understand each of these mechanisms. In this section I propose two directions that could advance our overall understanding of the mechanisms engaged during face-to-face social interactions. The first direction is concerned about which features of social interactions drive the transition from an “observation” to an “interaction” standpoint. The second direction considers the question of how our brain keeps pace with the interpersonal dynamics and social signal exchanges that emerge as the interaction develops.

6.4.1. From observation to interaction

To gain more insight into the neurocognitive mechanisms engaged during face-to-face interactions it will be necessary to examine which features of social interactions drive the transition from an “observation” (passive) standpoint to an “interaction” (active) standpoint when we are in the presence of a potential audience. For this, it is key to consider which types of social stimuli are processed as an audience, and how specific features of social stimuli may engage the mechanisms involved in this transition.

As shown in Figure 6-4, social stimuli used in social neuroscience research can be represented along a spectrum of “observation” to “interaction” standpoints. One end of the spectrum corresponds to seeing drawings of eyes or photos of other people, where we will adopt an “observation” standpoint (i.e. the stimuli is not interactive). The opposite end corresponds to face-to-face reciprocal or non-reciprocal people, where we will adopt an “interaction” standpoint (i.e. the stimuli is potentially interactive). Instead, this thesis was particularly focused on using video-feeds as stimuli, where boundaries between taking an “observation” or “interaction” standpoint can be easily blurred. Within this group of stimuli there are pre-recorded video-clips (used in Chapters 2, 3 and 4), fake video-calls (used in Chapter 2 and 3) and real video-calls (used in Chapter 4). Importantly, the similar visual appearance among these conditions (e.g. all of them show a close-up shot of a confederate though a monitor) allows for subtle manipulations of different features of social interactions to test if they induce one or other standpoint. For example, this thesis tested how the belief that a video-clip is live or pre-recorded modulates gaze patterns and prosocial behaviour (Chapter 2). Using this type of stimuli, future studies could test how other features of social interactions contribute towards taking an "observation" or "interaction" standpoint.

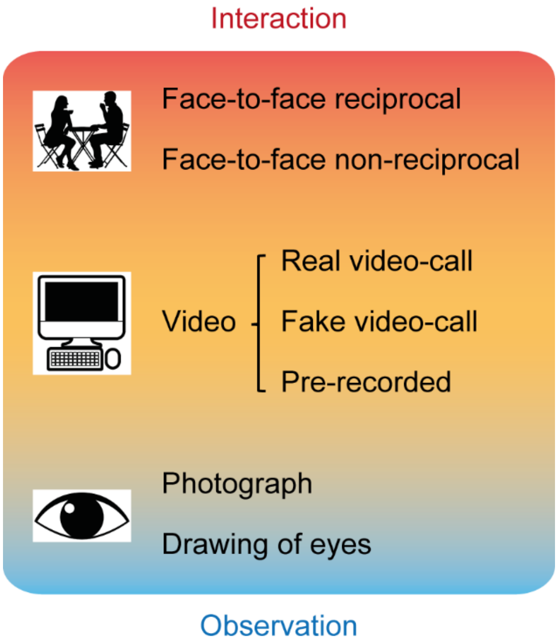

Figure 6-4. Common stimuli used in social neuroscience research represented along a spectrum of "observation" to "interaction" standpoints.

For instance, using virtual-reality avatars, Pfeiffer and colleagues (U. J. Pfeiffer, Timmermans, Bente, Vogeley, & Schilbach, 2011) employed the now widely used gaze-contingent eye-tracking paradigm (Kim & Mundy, 2012; Wilms et al., 2010) to test how joint attention modulates the perceived humanness of an avatar. In this paradigm, participants wearing an eye-tracker interact with an avatar whose gaze is controlled by the real-time gaze data collected from the participant. Results showed that avatars are perceived as more human-like if they follow the gaze of participants to achieve joint attention, and similar studies have shown that they are also perceived as more likeable (Grynszpan, Martin, & Fossati, 2017; Willemse, Marchesi, & Wykowska, 2018). Moreover, joint attention with avatars has also been linked to activation in brain areas related to processing of gaze direction (superior temporal sulcus), rewards (ventral striatum) and mental states (medial prefrontal cortex, temporo-parietal junction) (Caruana, Brock, & Woolgar, 2015; Pelphrey, Viola, & McCarthy, 2004; U. J. Pfeiffer, Vogeley, & Schilbach, 2013; Schilbach et al., 2010). This suggests that gaze following and joint attention are critical to adopt an "interaction" standpoint towards an audience. Similar manipulations could be applied on a fake video-call setting, where participants believe they are interacting with another person and the video-clips shown can be manipulated depending to participants' behaviour.

Thus, to fully understand which neurocognitive mechanisms underlie audience effects (and face-to-face interactions), future studies will need to systematically manipulate and compare different types of social stimuli and audiences. Importantly, to make sensible interpretations of their findings, such studies will also need to carefully consider where their manipulations fall in the "observation-interaction" spectrum of social stimuli.

6.4.2. Interpersonal dynamics in the brain

Another major challenge for social neuroscience research will be to understand how our brain processes and integrates the continuous and multimodal exchanges of social signals to make sense of social interactions. To do so, it will be key to use novel neuroimaging techniques such as fNIRS, which can record brain activity of two individuals while they interact face-to-face. This thesis employed fNIRS to measure brain activity of two participants and identify which *individual* brain regions are engaged in reciprocal versus non-reciprocal interactions. However, simultaneous brain recordings of two participants can also be used to compute *interpersonal* measures of brain activity, such as cross-brain coherence.

Cross-brain coherence (i.e. synchronisation of neural activity between two brains) is an indicator of interpersonal synchrony and has been found to increase during dialogue (Hirsch et al., 2018; Jiang et al., 2012) and cooperative tasks (Cui et al., 2012; Lu & Hao, 2019; Piva et al., 2017). Interestingly, several studies have shown that live mutual gaze triggers cross-brain coherence between partners. For instance, it mediates neural coupling between parents and infants (Piazza, Hasenfratz, Hasson, & Lew-Williams, 2018), and increases synchronisation of frontal and temporo-parietal brain regions between adult participants (Hirsch et al., 2017; Saito et al., 2010). These findings suggest that direct gaze acts as a signal that enhances cross-brain coherence over time (Gallotti, Fairhurst, & Frith, 2017; Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012).

It has been proposed that cross-brain coherence serves to optimise the processing of social signals exchanged between partners, thus facilitating communication (Hasson & Frith, 2016). However, the exact mechanisms how two brains synchronise with each other are not yet well-understood. Cross-brain coherence analysis computes coherence for each wavelet or frequency component within a range of interest, and it has been shown that different frequency timescales correspond to parallel neural processing of a stimulus (e.g. silent film) at different levels, such as sensory (short timescales) and semantic (long timescales) processing (Hasson & Frith, 2016; Hasson, Yang, Vallines, Heeger, & Rubin, 2008). However, it is unknown whether this is also true for social interactions: it could be that synchronising the processing of sensory and semantic information embedded in social signals allows two interacting partners to keep track of the rapid interpersonal dynamics of social interactions. Future studies will need to investigate the functional significance of cross-brain coherence and of different frequency timescales in the context of social interactions. This will be crucial to understand how we are able to successfully communicate with each other, as well as to gain further insight into the mechanisms of autistic social cognition.

6.5. Conclusion

The aim of this thesis was to investigate which cognitive and neural mechanisms underlie changes in behaviour when being watched, particularly focusing on eye gaze, facial displays and prosocial behaviour as social signals. Using ecologically valid paradigms and novel methodologies, I found evidence that eye gaze has a dual function and is coordinated with speech during communicative interactions. I also found that high-functioning autistic participants do use eye gaze as a social signal, although it is unclear whether this reflects a spontaneous behaviour or the use of compensation strategies. Moreover, I found that participants spontaneously produced more facial displays when being watched, and that spontaneous production and perception of facial displays engaged specific brain systems. This provides evidence in favour of the behavioural ecology view of facial displays, which suggests that facial displays are a tool for communication. In addition, I found mixed support for reputation management theory: depending on the identity of the audience, participants will increase (or not) prosocial behaviour to signal good reputation. Nonetheless, there was no support for the hypothesis that changes in behaviour when being watched are related to self-referential processing, although further research is needed to clarify this question. Finally, I also found that, beyond being watched, reciprocal social interactions further modulate social signals and recruit a complex brain system linked to mentalising and decision-making. In line with the second-person neuroscience approach, the findings reported in this thesis provide evidence that live communicative interactions engage specific cognitive and neural mechanisms that are not recruited in non-interactive social situations. Understanding how all of these cognitive and neural systems work together to enable real world face-to-face interactions (and to what extent they are disrupted in autism) will be the hallmark and challenge for future research on social neuroscience.

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