Mentalizing during communicative acts

Zdenko Kohút

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University of York

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Abstract

Successful communication often requires people to account for one another's mental states. Previous research has focused primarily on how this is achieved between speakers and listeners; in contrast, the issue of how listeners account for another listener's mental state has not been investigated thoroughly. In my thesis, I report a series of studies that seek to address this gap in the literature. Across four empirical studies, I investigate: a) the neural processes involved in tracking another listener's comprehension, b) the importance of task and situational demands on social language comprehension, and c) the relationship between levels of processing and social language comprehension. The results of these investigations provide insight into both the behaviour and the neurocognitive processes supporting the behaviour of co-listeners. Specifically, my results suggest that both mentalizing and simulation are important mechanisms allowing us to achieve insight into the comprehension of other listeners. Importantly, we do not automatically track everything about the experience of other listeners: low level features of language are not processed from another listener's perspective. In addition, the task demands and situational constraints in which co-listeners find themselves heavily influences whether or not perspectives will be shared. Taken together, the findings discussed in this work contribute to new models of language comprehension in social contexts.

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Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References. All of the presented work was completed under the supervision of Dr. Shirley-Ann Rueschemeyer.

The empirical work presented in Chapter 2 has been submitted for review in the following peer reviewed journal:

> **Kohút, Z.**, Majerus, N., Siklos-Whillans, J., Temudo, A., & Rueschemeyer, S. (under revision). On the neural correlates of communication: an fMRI study on the integration of social and semantic information during discourse processing. *Neuroimage.*

Part of the data analysed in Chapter 3 comes from a previously conducted study published in the following peer reviewed journal:

> Westley, A., **Kohút, Z.**, & Rueschemeyer, S. (2017). "I know something you don't know": Discourse and social context effects on the N400 in adolescents. *Journal Of Experimental Child Psychology, 164*, 45-54. doi: 10.101 6/j.jecp.2017.06.016

Part of the original data presented in Chapter 3 was presented in poster form at the following international conference:

> **Kohút, Z.**, & Rueschemeyer, S., (2016, September). *Individual differences in the social N400 effect.* Poster presented at the 22th Architectures and Mechanisms for Language Processing conference, Basque Center on Cognition, Brain and Language, Bilbao, Spain.

Chapter 1
Language in social interaction

Language is ubiquitous in ordinary human social interactions. A particular feature of language communication, recognized and highlighted by philosophers and scientists, is that what people say, that is, the words they utter, does not fully determine what they mean. This is obviously the case for tropes such as metaphor or hyperbole, but as several investigators have shown this indeterminacy pertains to a lot of ordinary literal language use as well (e.g., Grice, 1975; Clark, 1996; Wilson & Sperber, 2004; Scott-Phillips, 2018). It is by considering the context in which sentences are uttered as well as by considering interlocutors as agents with certain beliefs and desires that this indeterminacy is countered. For instance, from the perspective of language comprehension, the sentence "It is hot in here", if uttered in a room with closed windows, can be interpreted as an indirect request for the interlocutor to open the window, due to the speaker's desire for the room temperature to change. From the perspective of language production, one also has to consider this when constructing sentences that will be comprehensible to the listener. For instance, the sentence "My new computer has Windows" would be easily comprehensible for someone familiar with computers. However, such a sentence would probably not make much sense to someone unfamiliar with Microsoft software. It is therefore critical to take into consideration others' knowledge, beliefs, and desires, that is, the mental states of other people in natural communicative contexts. The present work focuses on how people use such information in order to monitor other's understanding of language stimuli.

Previous work on social interactions has focused predominantly on dyadic interactions, that is, communicative exchanges between two interlocutors. At the same time, relatively little attention has been devoted to how listeners use information about the mental states of their co-listeners. This issue is important since a co-listener is a potential future interlocutor, but a co-listener's understanding of the speaker's sentences may differ from the listener's understanding, due to different background knowledge (just as in the "My new computer has Windows" example above). Recently, Rueschemeyer and colleagues have suggested that listeners track the comprehension of other co-listeners, and they achieve this by mentally simulating comprehension of the utterance from the other's perspective (Rueschemeyer et al., 2015; Westley et al., 2017). The present work aims to extend these results further, by investigating how information about the co-listener's mental states influences language comprehension, in particular testing the veracity of the simulation proposal, as well as the properties of this newly discovered simulation, such as its relationship to joint action. Further, the current work addresses the neurocognitive correlates underlying our ability to track the perspective of other listeners during language comprehension. To this end, a series of electrophysiological (EEG), neuroimaging, and behavioural studies uncovering the neural networks engaged in social language processing will be reported.

Approaches to mentalizing and pragmatics

The present work aims to investigate the phenomena at the intersection of linguistic and social aspects of human cognition. Therefore, to approach this issue, two research traditions that historically treated these aspects rather separately - pragmatics and mentalizing - will need to be considered. Before turning to the specific findings from the empirical studies investigating pragmatic aspects of communication and mentalizing individually, as well as their intersection, this section will outline the general framework and assumptions present in both research traditions that pertain to the present investigations.

The first field of interest, pragmatics, is traditionally a linguistic discipline focused on explaining how people use contextual information in order to resolve the problem of linguistic indeterminacy. While the empirical work presented in this work is mostly based on experimental psycholinguistic works into this type of issue, the main assumption coming from this work is based on more formal linguistic observations. This assumption, reflected most predominantly in the works Grice (1975) and Clark (1996), is that communication is a cooperative endeavour, that is, speakers aim to speak in such a way as to be understood and listeners assume that speakers want to be understood. Clark (1996) further extends this by claiming that interlocutors coordinate their communicative acts with their interlocutors in order to achieve their communicative goals, hence he proposes that communication is a type of joint action. Assuming this will be helpful when considering communication with respect to mentalizing.

The second field of interest, focusing on a more general cognitive ability, mentalizing, is mainly based in psychology and cognitive neuroscience. Mentalizing (often also referred to as mindreading, theory of mind, cognitive empathy, and folk psychology) is a human ability that has over time been defined in various, although adjacent ways. For instance, Premack & Woodruff (1978) describe it as an ability to impute mental states to others (as well as to oneself), while for instance Apperly (2008) adds to this the ability to explain and predict another’s behaviour in terms of the imputed mental states. Since the present work does not aim to specifically investigate the distinction between mental state ascription and mental-state-based inferences, the broader definition of the term will be assumed.

For the purposes of the present work, it will also be helpful to consider one of the implicit assumptions present in the literature on mentalizing, challenged by some authors in recent years (McGeer, 2007; Heyes & Frith, 2014). These authors point out that research in mentalizing frames it purely in terms of interpretation of others' behaviour, where one's role is that of an independent observer. The authors suggest, however, that mentalizing is not only interpretive, but also regulative. This means that mentalizing also has a cooperative element, where people not only read others' behaviour, but also regulate their own behaviour in such way that it is rendered readable to others. Assuming this cooperative nature of mentalizing is helpful when considering communication as it parallels one of the central elements of the current pragmatics.

The broad parallel between communication and mentalizing emerges when mentalizing and pragmatic aspects of communication are considered with respect to their cooperative nature. This, in addition to the undeniably social nature of both endeavours, seems to provide a strong enough motivation for studying the convergences and divergences between the two. In the following text the relevant research into pragmatic aspects of communication, mentalizing, and the relationship between mentalizing and pragmatics will be introduced before outlining the specific research goals and hypotheses.

Common ground

Thinking about talking

Perhaps the central concept in psycholinguistic investigations into the pragmatic aspects of communication is the concept of common ground. This concept refers to the mutually shared information between interlocutors that both parties assume to be mutually shared, and hence it is not information that is only accidentally shared (Clark et al., 1983; Clark, 1996). Common ground has been proposed to be the base around which successful communication revolves. To exemplify this, one can imagine a person having bought a computer with the Windows operating system introduced at the beginning of this chapter. The way they will talk about this to, say, a colleague who is a computer scientist and their great grandfather who has never been around a computer can be assumed to be quite different. For instance, the sentence "My new computer has Windows." would be warranted in the first case, but not in the second case, as for somebody unexposed to computers such a sentence would be anomalous. Therefore, common ground seems to be the background against which communicators model and understand utterances. The opposite of the common ground is privileged ground; private knowledge that an interlocutor assumes to be unknown to the other party (e.g., Rączaszek-Leonardi et al., 2014).

The goal of psycholinguistic approaches to pragmatics is to find out how and under what conditions people use information about common ground during language comprehension and production. The most notable research programs in this area focus on how common ground is used to identify the object a speaker is referring to (e.g., Keysar et al., 2003; Brown-Schmidt & Heller, 2007; Barr, 2008; Brown-Schmidt & Hanna, 2011) and on how the introduction of a speaker with different than previously established common ground influences reference resolution (e.g., Kronmüller & Barr, 2007, Brown-Schmidt, 2009a; Kronmüller & Barr, 2015). The goal of these studies is mainly to establish in what ways people adjust their speech or comprehension process to their interlocutors, often specifically focusing on the timing of common ground use during comprehension. This is because there are two main theoretical accounts of how common ground is used in speech comprehension. The first, Perspective-Adjustment account (e.g., Keysar et al., 1998; Keysar et al., 2000; Keysar et al., 2003) challenges the assumption that common ground is always used in the process of comprehension. The account proposes that listeners are primarily egocentric (i.e., not considering others' perspective) and only use the information about the common ground when the egocentric strategy fails. The other, Constraint-Based account (e.g., Hanna et al., 2003; Hanna & Tanenhaus, 2004; Brown-Schmidt et al., 2008) proposes that information about the common ground can be used from the very beginning of utterance comprehension, but how much influence it has depends on its relative salience as compared to other cues. This account predicts that under some circumstances egocentric cues may outweigh the common ground, but it is not always the case. The evidence for these two views is briefly reviewed below for each of the two main issues approached in this area as these paradigms form one of the important sources of the present empirical investigations.

Definite reference

Studies investigating the influence of common ground on language processing have often focused on the timing of use of such information during referential communication. Many of such studies utilize paradigms constructed along the principles of so-called Director's task introduced by Keysar et al. (2000) in an eye-tracking experiment. In this task participants are seated opposite to the director with a rectangular grid shelf consisting of 16 slots containing various items placed in between them. While contents of all the slots are visible to the participant, some of them are occluded from the director. The director's role is then to request the participant to make various manipulations with the objects in the slots (e.g., *"Move the small candle."*) and the participant has to select the correct objects in line with the director's requests. In the critical trials, one of the occluded slots contains a competitor. For instance in the common ground (non-occluded slots) there is a large candle and a small candle and in the privileged ground (one of the occluded slots) there is another candle larger than the large candle from the common ground. The director then asks for the large candle, which from the participant's egocentric perspective is the largest candle placed in the occluded slot, while from the perspective of the director it is the larger of the two non-occluded candles. The results showed that in such trials the participants fixated their attention on the competitor first, before moving onto the large candle in the common ground. This effect, replicated several times (Keysar et al., 2003; Wu & Keysar, 2007; Legg et al., 2017), is in line with the Perspective-Adjustment model, since it suggests that people approach reference resolution egocentrically first, before adjusting their interpretations to the common ground. However, this interpretation of the results was challenged from the point of view of the Constraint-Based theorists on the grounds that the competitor was highly salient compared to the target object. In their studies (e.g., Hanna et al., 2003; Hanna & Tanenhaus, 2004), which otherwise followed the same logic as the Director's task in all important aspects, the private ground competitor was made less salient compared to the target object. For instance, in the critical condition in the study of Hanna et al. (2003) the target common ground object was a red triangle and the private ground competitor was also a red triangle, but occluded from the director. Here, unlike in the studies supporting Perspective-Adjustment model, the participants fixated on the target object nearly immediately, with little interference from the competitor. These results were therefore interpreted as showing that when the relative salience of the private competitor, compared to the information in common ground, is reduced, the effects of common ground can be observed from the very onset of the comprehension process.

Referential precedents

In the psycholinguistic research on pragmatic aspects of communication, the phenomenon of so-called referential precedents has also received considerable attention. The term referential precedent refers to an agreement between interlocutors to refer to a referent using a specific expression (Brennan & Clark, 1996). To consider an example from Kronmüller & Barr (2015), while the same object can be referred to as for instance a pound, a coin, a quid, or a metal object, people expect the chosen expression to stay constant throughout the course of communication throughout the discourse (Kronmüller

& Barr, 2015). Since these precedents are established with specific interlocutors, the researchers were interested in whether and how people adjust the use of referring expressions when a new interlocutor who does not share conversational history with the participant is introduced, and to how people resolve precedent broken by the new speaker, as well as by the original speaker with whom they were established.

In general, previous studies show that speakers consider the conversation history they share with their interlocutors (e.g., Clark & Wilkes-Gibbs, 1986; Wilkes-Gibbs & Clark, 1992; Brennan & Clark, 1996; Gann & Barr, 2014). For instance, in the study of Wilkes-Gibbs & Clark (1992) participants were paired with another participant (matcher), with both of them being presented with a set of abstract shapes (tangrams), which were, however, ordered differently for each. The task for the matcher was to reorder their abstract shapes so they match the order of the participant's abstract shapes. Since they could not see each other's shapes, they had to achieve this by means of verbal communication. Over the course of several trials, the descriptions of shapes grew shorter and more specific. After this phase, participants had to repeat the same task with another matcher, who was either present during the exchange with the original matcher and therefore knew the conversation history, or who was completely naive. It was shown that when the new matcher was naive, the participants provided longer descriptions of the shapes, indicating that they adjusted the referring expressions to their naivety.

Eye-tracking studies provide further insight into how people adjust to different speakers in referential communication. In such experiments participants are usually presented with an array of objects with which they interact based on a director's referring expressions. The experiments usually consist of an entrainment phase where the participants interact with one director, followed by a test phase where either a new director is introduced, or the task continues with the same director. In the test phase the director (regardless of whether they are new or not) either maintains the precedents from the entrainment phase (i.e., uses the same expression to refer to the same object) or breaks the precedents (i.e., uses a different expression to refer to the same object). Kronmüller & Barr (2015) conducted a meta-analysis of a number of studies following similar designs revealing two main effects. First, there is an early occurring same speaker advantage for maintained precedents where the probability of looking at the target object is higher for the same director than for a novel director. Then there is a later different speaker advantage for broken precedents showing that people adjust to broken precedents more quickly if they are broken by a different speaker. While it may seem that the same speaker advantage for maintained precedents is in support of Constraint-Based model as suggested by some authors (e.g., Brown-Schmidt, 2009a), literature suggests that it may be due to a simple association between a specific speaker and a referring expression (Barr et al., 2014; Horton, 2007). The later different speaker advantage for broken precedents, however, seems to be in favour of the Perspective-Adjustment model due to its later occurrence.

Overall, it seems that regardless of which of the two models is better supported by the current evidence, the research shows that people are able to adjust their language comprehension and production processes to their interlocutors. However, most of these do not include any co-listeners in their design, and those who do (e.g., Wilkes-Gibbs & Clark, 1992) are usually not interested in language processing from their perspective. The experiment presented in Chapter 5 aims to fill this gap in the literature.

Mentalizing

Thinking about thinking

Early research into mentalizing focused mainly on its developmental properties, primarily on the age at which it emerges and on what other cognitive faculties its development is connected to. While recent decades have seen a significant increase in the amount of studies focusing on cognitive and neural underpinnings of this ability in adults, perhaps the most canonical paradigm used in this line of research comes from the developmental investigations. In this paradigm called the Sally-Anne test, but usually described more generally as the false-belief task (Wimmer & Perner, 1983), participants are presented with two puppets named Sally and Anne interacting with a marble and two boxes. In the critical condition, Sally has the marble and puts it in one of the boxes (box A) in the presence of Anne. Sally then leaves the room. While Sally is gone, Anne takes the marble out of the box A and puts it in the other box (box B). Sally then comes back into the room. The participant's task is then to decide whether Sally, unaware of the change of the marble's location, will look for it in box A or B. If the participant possesses the ability to consider another's mental states then they will correctly answer that Sally will look for the marble in box A. It has been shown repeatedly that by the age of around 4 years, children are able to pass this task (e.g., Perner et al., 1989; Apperly, 2008; although see Onishi & Baillargeon, 2005; Rubio-Fernández & Geurts, 2013). The logic of the task is based on the observation that if one is tasked to judge the mental states of another with the same beliefs or perspective as they themselves hold, it is impossible to disentangle the judgements based on one's egocentric perspective (i.e., first person perspective) from the judgements based on representation of another's mental states (Dennett, 1978). However, if another holds a false or different belief, this issue disappears due to the impossibility of making inferences about another's perspective based solely on one's egocentric perspective. The false-belief task and its variations had then become a sort of a litmus test of possession of the ability to mentalize (although such a prominent role of the task has sometimes been criticized, e.g., Bloom & German, 2000).

The general rationale of the false-belief task was also often adopted by research programs in adult psychology and cognitive neuroscience. Since such a task is trivial for adults, the question in the adult research is not the one of whether they possess the ability to mentalize, but rather the question of what cognitive mechanisms they employ in the process of consideration of another's mental states. Two prominent competing theoretical frameworks have been proposed to address this issue, so-called theory-theory and simulation theory. While the relationship between the two proposals has become more complicated over the years, with some proposing hybrid accounts (e.g., Goldman, 2011) or even refusing the dichotomy altogether (e.g., Apperly, 2008), they represent the main lines alongside of which much of the thinking in the field is organized. The present work focuses predominantly on the simulation theory, although some of the aspects of the results presented in the following chapters are better interpreted by a theory-theory-like approach.

According to theory-theory, understanding other people's minds is based on the possession of an implicit scientific-like theory of how observable events and actions relate to unobservable mental states. Therefore, theory-theory proposes that people hold a model of the human mind that is defeasible and hence open for change if the predictions generated by this model do not hold true (e.g., Gopnik & Wellman, 1992, Gopnik et al., 1994; Leslie, 1987). For instance, one may possess such a theory that claims that all people who are hungry seek food. Holding this theory, all instances of seeing someone eating would be interpreted as a result of the person being hungry, and all instances of people claiming they are hungry would generate the prediction that they are seeking food. However, this simple theory may change, for instance if one encounters a person claiming they are eating because their doctor instructed them to eat at specific times, rather than because they are hungry. Such an observation would therefore lead the theory of the relationship between eating behaviour and underlying mental states to become more complex.

While there has been a lot of controversy about the specific properties of such theory-theory such as the degree of its innateness (e.g., Leslie, 1987), for the present purposes, the most important aspect of theory-theory is that it is reasoning-based and disembodied. This means that it proposes that the essence of the way people think about other people's mental states is not different from the way they think about other aspects of the world, and that this reasoning about others' mental states is different from how those mental states are experienced from the first person perspective. This is important because distinctions between reasoning based vs. non-reasoning based, and disembodied vs. embodied represent the dividing line between theory-theory and simulation theory.

Simulation theory rejects the notion that understanding of others' mental states is achieved by means of rule-based reasoning about the relationship between mind and the world. Instead, it proposes that mentalizing operates in an embodied fashion, where understanding of other people is achieved through vicarious experience - simulation. In other words, the theory proposes that understanding of another's mental states is essentially based on the same cognitive mechanism as having those mental states (Shanton & Gallese, 2010). Taking the previously introduced example of the relationship between people being hungry and eating behaviour, it is possible to illustrate the proposed workings of simulation as well. For instance, according to this theory, if someone says that they are hungry a prediction about their future behaviour can be made by simulating the state of hunger, and then based on this vicarious hunger future actions such as food seeking and other eating-related behaviours are derived as if one would be having these intentions themselves. Simulation theory therefore corresponds to the proverbial putting oneself into someone else's shoes.

Neural correlates of mentalizing

The research into the neural correlates of mentalizing revealed a network of regions responding selectively to increased mentalizing demands, consisting of regions of medial prefrontal cortex (mPFC), precuneus/posterior cingulate, and (predominantly right, but often also bilateral) temporo-parietal junction (TPJ) (e.g., Frith & Frith, 2006; Mitchell, 2009; Spreng et al., 2009; Mar, 2011; Schurz et al., 2014), with some studies also pointing to temporal poles (e.g., Gallagher & Frith, 2003; Olson et al., 2007). Activity in the regions of this network has been observed using several different types of tasks thought to require mentalizing including the false-belief task (e.g., Gallagher et al., 2000; Saxe & Kanwisher, 2003; Aichhorn et al., 2009), judgement of another's mental states or action prediction without the presence of a false belief (e.g., Villarreal et al., 2012; Walter et al., 2009), judgement of personality traits (e.g., Ma et al., 2011; Mitchell et al., 2002; Todorov et al., 2007; Modinos et al., 2011), observation of animations of abstract shapes that interact in such a way that they can be readily interpreted as intentional agents (e.g., Castelli et al., 2000; Martin & Weisberg, 2003; Tavares et al., 2007; Santos et al., 2010), or tasks where participants engage in a competitive game with another participant, as compared to competing against a computer (e.g., Gallagher et al., 2002; Krach et al., 2008). In addition, due to a degree of cross task and cross study variation, several quantitative meta-analyses were conducted in recent years as well. These analyses generally replicated the pattern of the proposed mentalizing network. For instance Bzdok et al. (2012) revealed a network consisting (among other regions) of mPFC, bilateral TPJ, precuneus, bilateral temporal pole, and the case was almost the same in the studies of Spreng et al. (2009), Mar (2011), and Schurz et al. (2014).

Regarding the debate between theory-theory and simulation theory, the neuroimaging studies so far have not been able to provide a clear answer. In line with simulation theory, it has been repeatedly shown that mPFC shows an overlap between mental state attribution to self and to similar others, but not to dissimilar others (e.g., Mitchell et al., 2005; Mitchell et al., 2006). The authors explain this as suggesting that at least in the case of similar others, mental state ascription may operate by means of simulation. However, there is an issue with such interpretation. This is because ascription of mental states to oneself may not constitute a genuine first person experience to begin with. More specifically, it is not clear whether when one is ascribing mental states to oneself, the self does not figure in such a process as an abstract other. To illustrate this in an example, simulation theory would predict that, for instance, an experience of being confused when not being able to solve a mathematical equation would be supported by the same neural substrate as observing somebody else being confused solving an equation. On the other hand, self mental state ascription seems to reflect the identification of one's confusion, rather than the experience of it, and therefore the result could also be interpreted to favour theory-theory. This ambiguity, therefore, warrants further investigation of the simulation issue using more suitable experimental designs. In the present work, a study attempting to investigate this using such a design in the context of language comprehension is presented in Chapter 2.

To conclude this section, it may be helpful to point out a parallel between the types of paradigms introduced by the researchers investigating pragmatic aspects of communication and the researchers investigating mindreading by means of the false-belief task. The parallel between the two is that in both cases, the investigations rely on the presence of an agent whose mental states need to be taken into consideration, for instance, due to them having a different access to some of the crucial task related information. In the case of the false-belief task, this is due to one of the puppets leaving the room, while the target objects change their positions. In the studies of the referential communication this is, in the case of the Director's task, due to the interlocutor having some of the potential referents occluded from view and, in the case of the studies on referential precedents, due to them not knowing the conversation history. By this parallel it seems plausible to assume that consideration of an interlocutor's knowledge may rely on mentalizing, as an interlocutor, similarly to the puppet in the false-belief task, is a being whose mental states differ from the participant's with respect to the task. While mentalizing in communication has not been studied as extensively as either of these on their own, recent years have seen an increase in interest in this topic, especially using neuroimaging approaches.

Mentalizing and acting together

Finally, the present subsection will briefly introduce the topic of joint action. Although this topic is usually not included under the umbrella of mentalizing, it is also concerned with consideration of others' mental states. The topic is also relevant to the research of communication, since as mentioned before it has been proposed that communication is a type of joint action (Clark, 1996).

In psychology, similarly to pragmatics, joint action is viewed as a coordinated action of at least two individuals, co-actors, in order to achieve a common goal (e.g., Sebanz et al., 2006a). The results of some of the studies on joint action suggest that under some conditions, people represent actions of their co-actors in the same way they represent their own actions, which seems to be in line with Simulation theory. For instance, in the study of Sebanz et al. (2003) participants were involved in a simple motor go-nogo task either alone or with a co-actor. In each trial they were presented with a picture of a hand pointing to their button or to the co-actor's button (in alone condition to an unused button). On each picture, the hand had a ring on, rendered in one of two colours. Participants were instructed to press their button as quickly as possible upon seeing one of the colours, and in the co-actor condition, the co-actor was instructed to do the same in reaction to the other of the two colours. The analysis of the reaction times showed that when the colour indicated that the participant should respond, but the finger was pointing at the other button, they were significantly slower to respond in co-actor, compared to alone condition. Further, the pattern of the results in the co-actor condition was the same as in an additional alone condition, where the participant was pressing both buttons. This was interpreted as indicating that participants were representing co-actor's actions concurrently alongside their own actions. This evidence was further corroborated in an event-related potential (ERP) study (Sebanz et al., 2006b) using a nearly identical paradigm, showing evidence of action suppression when the co-actor was prompted to act, as compared to when conducting the task alone.

Considering that communication was proposed to be a type of joint action, and that joint action seems to rely on simulation, one can be tempted to speculate that communication also has to, at least in some cases, rely on simulation. Although some studies suggesting this will be presented in the next section of the present chapter, a closer empirical link between joint action and communication has not yet been established. This issue will be approached in Chapter 3.

Mentalizing about common ground

Mentalizing network and language

The investigations into the neural correlates of communication repeatedly show involvement of the mentalizing network during language comprehension when pragmatic demands are high. For instance, a study of van Ackeren et al. (2012) revealed that resolution of indirect requests (e.g., *"It is hot here!"* as a request for a listener to open the window) engages regions of mentalizing network. Similar results were observed by Bašnáková et al. (2014, 2015) using indirect replies (e.g., *"It's hard to give a good presentation."* as an indirect reply to *"Did you find my presentation convincing?"*), as well as in studies on irony processing (Shibata et al., 2010; Spotorno et al., 2012; review see Bohrn et al., 2012). The involvement of mentalizing network was also observed during processing of communicative intentions more generally (Willems et al., 2009; Kuhlen et al., 2017; Enrici et al., 2011). Its involvement was also observed in the referential tasks introduced previously. For instance, Dumontheil et al. (2010), using a scanner adjusted version of the Director's task, showed involvement of mPFC in the critical condition (i.e., when the competitor was hidden from the director's view). Further, Bögels et al. (2015) found an involvement of mentalizing network in a referential precedents task in cases when precedents were broken by the same speaker. Interestingly, the current evidence also shows that increased pragmatic demands also lead to an increase in connectivity between mentalizing network and regions of a wider language network. This was shown for instance for the cases of indirect requests (van Ackeren et al., 2016), irony (Spotorno et al., 2012), and communicative intentions (Tettamanti et al., 2017), suggesting that language and mentalizing network work in concert in order to integrate information from the two domains.

Unfortunately, similarly to the neuroimaging studies on mentalizing generally, the experiments on mentalizing in communication were not designed to carefully test the veracity of either simulation theory or theory-theory. In addition, no neuroimaging study to date has investigated neural correlates of a co-listener's language processing, since all the present studies either focus on dyadic interactions in which the participants either participate, or observe them. Both these issues will be approached in Chapter 2.

Simulating comprehension

A more convincing evidence for mental simulation of another's language processing, comes from previous ERP studies of Rueschemeyer et al. (2015) and Westley et al. (2017). These experiments adapted some general aspects of the studies on joint action into their design, such as the one by Sebanz et al. (2003) described below. For instance the study of Rueschemeyer et al. (2015) introduced so-called Joint Comprehension task where the participants were presented, in the critical condition, with a context sentence and a context-dependent target sentence such as *"In the boy's dream, he could breathe under water"* and *"The boy had gills"*. The target sentence was therefore semantically anomalous without the context sentence. Such pairs of sentence were either presented to the participant alone, or in the presence of a co-listener who was only exposed to the target sentence (while the participant still had access to both sentences). It was shown that in the presence of a co-listener the target sentence elicited the N400-effect, a common marker of semantic anomalousness (e.g., Kutas & Federmeier, 2011), but this was not the case when the sentence was presented to the participant alone. This was therefore interpreted as indicating that people simulate their co-listener's comprehension process. The result was replicated on an adolescent sample using an improved experimental design (Westley et al., 2017), and more recently also on adult (Jouravlev et al., 2018) and infant samples (Forgács et al., 2018).

The similarity between these experiments and the studies on joint action is in the role of co-listener and co-actor. Regardless of the experiment, the participants engaged, together with another person, in a shared task, a go-nogo task in the case of joint action experiments; in the case of joint comprehension experiments they answered questions about their own and one another's understanding of the target sentences. Further, there was no direct interaction between the two parties in both types of paradigms. The results of the experiments also parallel each other, with joint action experiments suggesting that people represent the co-actor's action, and joint comprehension experiments suggesting they simulate the co-listener's comprehension process (alternatively one could also say that they represent the co-listener's experience of semantic anomaly).

Although there is an obvious parallel between the experiments on joint action and joint comprehension, it is not clear at the moment whether this parallel is merely accidental, or whether it reflects a deeper connection between joint action and joint comprehension.

This problem will be investigated in Chapter 3. Further, the phenomena observed in joint action literature, as described in one of the previous subsections of this chapter, seem to be rather low level (simple motor acts) in contrast to high, lexical integration level simulation observed in joint comprehension studies. As of yet, it is unknown whether simulation in language comprehension also occurs at lower levels of language processing. This issue will be explored in Chapter 4.

Research goals and hypotheses

The present work aims to investigate how the information about a co-listener's mental states is used by listeners during language comprehension in triadic communicative contexts. More specifically, the following work is interested in the issue of mental simulation, that is, in the questions of whether use of information about another's comprehension relies on simulation of this process (Chapter 2), and what the properties of such simulation are (Chapters 3 and 4). The present work is further interested in the question of the relationship between joint action and joint comprehension, more specifically, in whether there are aspects of the results of joint action research that can be replicated at the level of communication (Chapter 3). And finally the present work is interested in how the use of co-listener's mental states influences use of common ground (Chapter 5).

The experiment presented in Chapter 2 can be seen as a direct successor of the ERP studies on joint comprehension (Rueschemeyer et al., 2015; Westley et al., 2017; Jouravlev et al., 2018; Forgács et al., 2018). Aiming to investigate the relationship between mentalizing, language, and simulation, this experiment utilizes the experimental design from Rueschemeyer et al. (2015) for use in a MRI scanner. Each trial consists of two sentences, forming a short narrative, with the co-listener either having access to both sentences, or only to the second sentence. In line with the previous literature on mentalizing during communicative acts, it is predicted that in this experiment consideration of sentences from another's different perspective will employ the regions of mentalizing network. Further, relating to the simulation theory, it is expected that the neural pattern connected to narrative processing, in the critical context-dependent condition, will only be observed when both the participant and the co-actor have access to the entire narrative, but not when the co-listener only has access to the second sentence. The experiment will also explore the relationship between language and mentalizing networks by means of connectivity analysis, as it has been suggested previously that there is an increase in connectivity between the two when pragmatic demands are high.

Chapter 3 focuses on the relationship between joint action and joint comprehension in an ERP study. Adjusting the paradigm from Westley et al. (2017), it tests whether representation of another's mental states during language comprehension depends on the presence of a shared task, as seems to be the case in joint action research (Sebanz et al., 2003; Tsai et al., 2006). Therefore the main difference between the previous study and the present investigation is that there is an absence of shared task, with only the participant, but not the co-listener being engaged in a task. It is predicted that if communication is a type of joint action, then no evidence of the co-listener's mental state representation should be observed. If, on the other hand, such evidence is observed then this would point more towards psychological independence of communication and joint action. In addition, the study explores the individual differences between the participants' electrophysiological responses and behavioural measures of empathy and executive function.

Chapter 4 further explores the properties of mental simulation in an ERP study. Specifically, the study's main interest is whether simulation occurs at lower levels of language processing (lexical access) as compared to the simulation observed at higher compositional semantic levels observed in the previous studies (e.g., Rueschemeyer et al., 2018; Westley et al., 2017). This is tested using a novel paradigm where participants are presented first with single low and high frequency words alone, followed immediately by a presentation of the same words in the presence of a co-listener. It is predicted that upon the first presentation of the words the word frequency N400-effect will be observed with more negative deflection for low compared to high frequency words. If people simulate another's language processing at the level of lexical access, then this effect should be observed again upon the second presentation of these words in the presence of a co-listener.

Chapter 5 investigates how the use of a co-listener's mental states influences use of common ground in a behavioural paradigm. Participants, either alone or together with a co-listener, were presented with prime-target word pairs engaging in a semantic relatedness task. In the trials of interest, the prime word was always a homonym with at least two possible interpretations. In addition, the participants (but not the co-listeners, if they were present) were presented with a prime sentence that primed one of the two possible interpretations of the homonymous prime word. In the critical trials, the words in the prime-target pairs were semantically related, but the prime sentence primed such interpretation of the homonymous prime that was incongruent with the target word. It is hypothesized that in the presence of a co-listener who does not have an access to the prime sentence the participants' semantic judgements will be different. Regarding the direction of the effect it is hypothesized that the presence of the co-listener will either result in a reduction of the effect of the incongruent prime sentence as this forms the common ground between the participant and the co-listener.

The aim of Chapter 6 is to integrate and explain the results of the empirical investigations within the wider literature framework, as well as with respect to one another, in order to further the understanding of mentalizing in communicative contexts with respect to co-listeners as well as to direct interlocutors.

Chapter 2

On the neural correlates of communication: an fMRI study on the integration of social and semantic information during discourse processing

(based on: **Kohút, Z.**, Majerus, N., Siklos-Whillans, J., Temudo, A., & Rueschemeyer, S. (under revision). On the neural correlates of communication: an fMRI study on the integration of social and semantic information during discourse processing. *Neuroimage; the author led on data acquision, data analysis, and wrote the article under supervision of Dr. Shirley-Ann Rueschemeyer)*

Abstract

The primary function of language is to facilitate communication between individuals. Despite this, there is relatively little neuroimaging research into the neural networks that support social aspects of language processing. In the current fMRI study we investigated how the presence of other listeners affects language comprehension: in particular we were interested in how the brain processes sentence stimuli that are interpreted similarly by a participant and another listener (confederate) vs. sentence stimuli that are perceived to be interpreted differently by participant and confederate. The results suggest that listeners readily take the perspective of other listeners into account when jointly attending sentence stimuli, and that doing so engages parts of the mentalizing network in addition to brain areas dedicated to language processing. Furthermore, when perspectives diverge, listeners simulate language comprehension from the perspective of the other listener in order to support their understanding of the other listener's interpretation. The results provide insight into cognitive and neural mechanisms of simulation during language comprehension, and into the pattern of involvement of language and mentalizing systems in presence of increased pragmatic demands.

Introduction

As humans, we spend a great amount of time interacting and communicating with other people around us. Arguably one of the most powerful tools we have in order to facilitate social communication is language. It is clear that everyday language use requires interlocutors to both master a linguistic system and to be highly attuned to social information about the people with whom they are speaking. Information about another's interests, demographics, shared common ground and visual perspective are readily considered and used to modulate language production and comprehension (reviews see Barr & Keysar, 2006; Brennan et al., 2010; Kronmüller & Barr, 2015). Although many studies have investigated the temporal dynamics of perspective taking during language comprehension, there is comparatively less research on the cognitive mechanisms and neural underpinnings supporting social communication. The aim of the current study is to address some of the gaps in our current understanding of how social information is considered during language comprehension.

Both high-level theorizing about others (i.e., mentalizing) and simulation are likely to play a role in on-line social language comprehension. With respect to mentalizing, previous neuroimaging research has shown that social language comprehension (i.e., language comprehension in which the perspective of the speaker is important to consider) activates neural networks that are typically involved in considering the thoughts, beliefs and desires of others, as well as classical language networks (van Ackeren et al., 2012; van Ackeren et al., 2016; Bašnáková et al., 2013; Bašnáková et al., 2015). For example, van Ackeren et al. (2012) demonstrated that the mentalizing network comprising the temporo-parietal junction areas, medial prefrontal cortex and precuneus is activated by sentences that require inferencing on the part of the listener in order to derive the speaker's intended meaning. In a follow-up study, it was shown that activity within the mentalizing network drives activity within areas responsible for processing and integrating semantic content, indicating that high-level social cognition mediates semantic processing on-line during language comprehension (van Ackeren et al., 2016). Similar patterns of results have been reported for processing of indirect speech (Bašnáková et al., 2013; Bašnáková et al., 2015), and figurative language processing including irony (e.g., Spotorno et al., 2012; review see Bohrn et al., 2012), as well as the processing of communicative intention generally (Willems et al., 2009; Willems & Varley, 2010; Kuhlen et al., 2017, Enrici et al., 2011; Tettamanti et al., 2017). Taken together, this research suggests that high-level social cognitive networks involved in mentalizing work together with classical perisylvian language areas to support *social* language comprehension.

While neuroimaging work demonstrates that mentalizing aids social language comprehension more generally, electrophysiological work has shown that simulation may play a key mechanism supporting our ability to track another's perspective from one moment to the next (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Forgács et al., 2018; Jouravlev et al., 2018). Specifically, participants were presented with sentences containing semantic anomalies, as well as sentences that contained a semantic anomaly for another listener (i.e., a confederate), but which were plausible for the participant him/herself. A well-known electrophysiological marker of semantic integration difficulty, the N400-Effect (e.g., Kutas & Federmeier, 2011), was elicited by both types of sentences in comparison to sentences that were semantically congruent for both participant and confederate. Importantly, when the same sentence stimuli were presented to participants seated alone (i.e., not in the presence of the confederate) the N400-Effect was elicited only by sentences that the participant deemed semantically anomalous him/herself. This indicates (1) that listeners are sensitive to how other co-listeners comprehend language stimuli, and (2) that the cognitive processes supporting our ability to process language egocentrically are also employed in order to understand language from the perspective of someone else. Therefore, simulation of sentence comprehension from the other's perspective appears to be a key mechanism during online social language comprehension.

While the results of the electrophysiological studies provide compelling evidence that simulation is important for online social language comprehension, they provide little insight into how mentalizing and simulation work in concert. In the current study we aim to address this gap by identifying the neural areas involved in tracking another listener's ability to understand sentence stimuli. Based on the results of the neuroimaging studies reported above, we hypothesized that tracking another person's comprehension of language stimuli would elicit activity in the mentalizing network. In particular, we hypothesized that the mentalizing network works in concert with high-level language processing areas to language comprehension from the perspective of another listener. Secondly, based on the results of the electrophysiological studies reported above, we hypothesized that language stimuli that were anomalous for either another listener or oneself would be processed as high-demand language stimuli. Lastly, we hypothesized that evidence of discourse processing and sentence integration would only be seen if both listeners were able to successfully integrate the sentence into the preceding discourse. Taken together these results would provide insight into the neural areas supporting both high-level mentalizing and on-line perspective tracking during sentence comprehension.

Methods

Participants

Twenty right-handed native English-speaking participants with normal or corrected-to-normal vision were recruited from the University of York (age M = 26.3, SD = 6.5, 11 females). The study was approved by the local ethics committee of the York Neuroimaging Centre (YNIC), and all of the participants gave written informed consent before participating in the experiment.

Materials

Ninety experimental stimuli, belonging to three critical experimental conditions were created (N = 30 per condition). Experimental stimuli consisted of pairs of two sentences (S1, S2). S1 was presented as a spoken sentence; S2 was presented visually. Critical stimuli belonged to one of three Sentence conditions:

- Plausible stimuli (PLAUS) in which S2 was semantically plausible when viewed in isolation, and was also semantically plausible in the context of any additional information contained in S1.
- Implausible stimuli (IMPLAUS) in which S2 was semantically implausible when viewed in isolation, and remained implausible even in the context of any additional information contained in S1.
- Context-dependent stimuli (CONTEXT) in which S2 is semantically implausible when viewed in isolation, but is rendered semantically plausible by information contained in S1.

Stimuli were presented to participants in two Perspective conditions, resulting in six experimental conditions in total: In the Same Perspective (SAME) condition, the participant and another listener (the confederate) both heard S1 and then both read S2 together. In the Different Perspectives (DIFF) condition, only the participant heard S1 and then both the participant and the confederate read S2 together.

Task

In SAME Blocks, the participant was asked to indicate whether or not S2 was semantically plausible in the context of S1 for the confederate. In DIFF Blocks, the participant was asked to indicate whether or not their interpretation of S2 was likely to match the confederate's interpretation. The participants were told that the confederate was performing the same task outside of the scanner. Anticipated responses for each experimental condition can be seen in Table 2.1. Responses were collected via a button box in the participant's left hand.

			PERSPECTIVE	
	Spoken sentence (S1)	**Written sentence (S2)**	**SAME**	**DIFF**
PLAUS	The fishmonger prepared the fish.	The fish had gills.	Plausible	Match
IMPLAUS	The boy woke up at dawn.	The boy had gills.	Implausible	Match
CONTEXT	In the boy's dream, he could breathe underwater.	The boy had gills.	Plausible	Mismatch

Table 2.1. Examples of experimental stimuli and expected responses in each block. Experimental stimuli were made up of two sentences (S1, S2) and belonged to one of three Sentence conditions (PLAUS: S2 is semantically plausible in the context of S1, IMPLAUS: S2 is semantically implausible even in the context of S1, CONTEXT: S2 is semantically plausible only in the context of S1). Stimuli were presented in two Perspective conditions: SAME: participant and confederate have the same perspective, as both hear S1 and then read S2; DIFF: the perspective of the participant and the confederate is potentially different, as the participant hears S1 alone and then both participant and confederate read S2 together.

Stimulus Presentation

Participants were brought into the neuroimaging centre and then introduced to a confederate (a member of the experimental team who claimed to be performing the task alongside the participant outside of the scanner). The participant and the confederate were provided with task instructions, and a short practice block containing a number of trials from each experimental condition was run outside of the scanner to ensure that participants understood the task demands. Once the participant understood the task, they were brought into the scanner whilst the confederate remained in the control room.

Experimental stimuli were presented in four blocks of 15 minutes each. In SAME blocks (Blocks 2 and 3), the participant was told that spoken sentences (S1) were being played aloud in the control room, and that the confederate could hear anything that the participant heard. Therefore, the participant and confederate were privy to identical information. In DIFF Blocks (Blocks 1, 4) the participant was told that the speakers had been turned off in the control room, and that confederate therefore could not hear any spoken information during the trial. This resulted in the participant and the confederate having potentially different background knowledge about a given trial. The order of blocks was the same for all participants. An instruction screen describing whether the confederate could hear S1 initiated each block. The participant was asked to acknowledge this information by pressing a button.

Each trial began with the presentation of a spoken sentence (S1), followed by a blank screen (200 ms). A second sentence (S2) was then presented several words at a time across three screens lasting 1000 ms, 1000 ms, 2000 ms respectively (4000 ms in total). Following the final S2 screen, a question mark appeared in the centre of the screen, prompting participants to respond to the task question, which differed across the two perspective blocks (please see Table 1). In order to reinforce the belief that the confederate was participating in the task, an asterisk was presented for 500 ms on the screen at a random interval 0-2000 ms after the participant's response had been recorded. This signalled to the participant that the confederate's response had also been recorded. A jittered 4-6 second ISI was inserted (blank screen) between the trials. In addition, 15 null events (blank screen, 6 seconds) were interspersed throughout each block. Sentences from the three Sentence conditions and null events were presented during each block in a pseudo-randomized order in such a way that no more than two trials from the same condition would be presented consecutively.

fMRI data acquisition

Functional Magnetic Resonance Imaging (fMRI) data acquisition was performed using a 3T GE HDx Excite MRI scanner at the York Neuroimaging Centre, University of York, using an 8-channel, phased-array birdcage coil. A gradient-echo echo-planar imaging (EPI) sequence was used to collect data from 34 contiguous bottom-up interleaved slices (TR = 2000 ms, TE = 18.9 ms, matrix size = 64 x 64, FOV = 192 x 192 mm, slice thickness = 3 mm, flip angle = 90°). Each functional scan lasted 15 minutes and consisted of 450 volumes. Following functional scanning, a high-resolution T1-weighted anatomical image was acquired for each participant (TR = 7800 ms, TE = minimum full, matrix size = 256 × 256, FOV = 290 x 290 mm, slice thickness = 1 mm, flip angle = 20°, number of slices = 176) to serve as an anatomical reference.

fMRI preprocessing

The raw MRI data were preprocessed and analysed using FSL-FEAT version 6.0, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl, Jenkinson et al., 2012; Smith et al., 2004; Woolrich et al., 2009). Brains were extracted from the raw images using FSL-BET (Smith, 2002). Images were normalized to a standard EPI template centered in

Montreal Neurological Institute space and resampled at an isotropic voxel size of 2mm. The first 3 volumes were discarded to reduce T1 equilibration effects. Slice timing correction was applied by using sinc interpolation to shift each time-series of the TR to the middle of the TR period. The normalized images were smoothed with an isotropic 8 mm FWHM Gaussian kernel and temporal high-pass filter (sigma = 100 ms) was applied.

Whole brain GLM analysis

The preprocessed fMRI time series for each block were analyzed on a subject-by-subject basis using an event-related approach in the context of the general linear model. Regressors for each Sentence condition (PLAUS, IMPLAUS, CONTEXT), as well as button presses, were entered into the first-level analysis. Only correctly answered trials were included in the regressor for each condition. The BOLD response was modelled for each regressor with the double-gamma canonical hemodynamic response function and its temporal derivative. The response function was time locked to the onset of the final word of S2, with a duration of 2 seconds (length of word presentation). Button presses were modelled from the onset of the button press with a duration of 0 (stick function). Blocks from each Perspective condition (SAME, DIFF) were combined using fixed-effects modelling in a second-level analysis for each participant. This resulted in a single design matrix with six conditions belonging to two Factors: three Sentence conditions (PLAUS, IMPLAUS, CONTEXT) and two Perspective conditions (SAME, DIFF). For each participant contrast images were calculated representing (1) the main effect of having shared vs. different perspectives (DIFF > SAME, SAME > DIFF), (2) the main effect of processing high-demand vs. low-demand sentences, i.e., semantically incongruent and context-dependent sentences, vs. semantically plausible sentences ((IMPLAUS + CONTEXT) > PLAUS) and (3) the main effect of processing specific types of high-demand sentences (i.e., CONTEXT > IMPLAUS, IMPLAUS > CONTEXT). The effects of having shared vs. diverging perspectives on high-demand sentence stimuli was assessed in the direct contrast between high-demand stimuli within each Perspective Condition (SAME: CONTEXT > IMPLAUS, DIFF: CONTEXT > IMPLAUS, SAME: IMPLAUS > CONTEXT, DIFF: IMPLAUS > CONTEXT). Single participant contrast images were entered into a third-level random effect analysis for the critical contrasts of interest. The group analysis consisted of a one-sample t-test across the contrast images of all subjects that indicated whether observed differences between conditions were significantly different from zero. Activations that exceeded a voxel level threshold of $Z > 2.6$ ($p < .005$) and a cluster corrected threshold of $p < .05$ are described.

Regions of Interest (ROI) analysis

The role of shared perspective in processing stimuli was explored in a regions of interest (ROI) analysis. Regions that were selectively sensitive to context-dependent sentences in general (CONTEXT > IMPLAUS) were selected as ROIs. This contrast was selected, because only context-dependent sentences generate different interpretations for participant and confederate across the two Perspective Blocks.

			ROI centre MNI coordinates		
	Cluster	ROI radius	x	y	z
Left angular gyrus	1	6 mm	-56	-54	-42
Left MTG	2	6 mm	-64	-50	-10
Left amygdala	3	6 mm	-22	-6	-22

Table 2.2. ROI coordinates based on CONTEXT > IMPLAUS contrast. There was one ROI per cluster. All regions' centre was located at the location of the peak voxel within the respective cluster as a sphere with 6 mm radius.

A set of three spherical ROIs with 6 mm radiuses were generated for left angular gyrus (AG), left middle temporal gyrus (MTG), and left amygdala (see Table 2.2 for coordinates). The centre of three of the regions of interest (left AG, left MTG, left amygdala) was the local maximum with the largest z-value from the three significant clusters identified in the contrast. Percent signal change from these ROIs was then extracted for all levels of Sentence and Perspective factors. To correct for different baselines, the mean signal change from PLAUS condition was subtracted from the mean signal change in IMPLAUS and CONTEXT conditions in both Perspective conditions separately. The data were then entered into 2x2 repeated measures ANOVA with factors Sentence (IMPLAUS, CONTEXT) and Perspective (DIFF, SAME).

Generalized psychophysiological interaction (gPPI) analysis

To determine whether functional connectivity between areas involved in processing high demand language stimuli and the rest of the brain differed between the two levels of Perspective condition, a generalized psychophysiological interaction (gPPI) analysis (McLaren et al., 2012) was carried out. To this end, the left and right inferior frontal gyrus (IFG) clusters from (IMPLAUS + CONTEXT) > PLAUS contrast were selected as a seed and connectivity between the seed region and the rest of the brain was examined as a function of Sentence and Perspective. To do this, the three level GLM analysis described above was replicated for each region with several important differences. For the first-level analysis, individual time series from the seed region were extracted serving as the physiological regressor. There were three psychological regressors, one for each Sentence condition (PLAUS, IMPLAUS, CONTEXT). Three gPPI regressors were then added, each coding for interaction between each of the three psychological regressors and the physiological regressor. For each participant the four blocks (two from each of the Perspective conditions) were combined using fixed-effects modelling in a second-level analysis. This resulted in six additional conditions each encoding for connectivity between the seed and the rest of the brain in each experimental condition. For each participant, contrast images were calculated representing the difference between the SAME and DIFF conditions at each level of Sentence (i.e. DIFF > SAME and SAME > DIFF calculated for PLAUS, IMPLAUS, CONTEXT, separately). As in the whole brain GLM analysis, single participant contrast images were entered into a third-level random effect analysis for the critical contrasts of interest. The group analysis consisted of a one-sample t-test across the contrast images of all subjects that indicated whether observed differences between conditions were significantly different from zero. Activations that exceeded a voxel level threshold of Z > 2.6 (p < .005), and a cluster corrected threshold of p < .05 are described.

Results

Behavioural

Performance rates (% correctly answered trials) were entered into a 3x2 repeated measures ANOVA with the factors Sentence (PLAUS, IMPLAUS, CONTEXT) and Perspective (DIFF, SAME); see Table 2.3 for the descriptive statistics.

	PLAUS		**IMPLAUS**		**CONTEXT**	
	Mean	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
DIFF	29.45	.256	21.35	1.545	27.10	.593
SAME	29.45	.185	26.35	.549	28.00	.453

Table 2.3. Performance in the behavioural task. Mean number of correctly answered task questions per condition (N = 30) and standard error of the mean (SEM).

There was a main effect of Sentence, $F(2, 38) = 31.25$, $p < .001$, $\eta_p^2 = .62$, which indicates that performance differed across the Sentence conditions. The main effect of Perspective was also significant, $F(2, 38) = 14.77$, $p < .001$, $\eta_p^2 = .44$, demonstrating that participants made more errors when perspectives potentially diverged (DIFF) than when perspectives were shared (SAME). The interaction between Sentence x Perspective was also significant, $F(2, 38) = 10.44$, $p < .001$, $\eta_p^2 = .36$, indicating that participants responded to the Sentence stimuli differently in each Perspective Block.

Post hoc analyses revealed that the main effect of sentence reflected more accurate responses to PLAUS sentences than to either IMPLAUS, $t(19) = 6.65$, $p < .001$, $d = 1.49$, or CONTEXT sentences, $t(19) = 4.83$, $p < .001$, $d = 1.08$, and that responses to CONTEXT sentences were more accurate than to IMPLAUS sentences, $t(19) = 4.45$, $p < .001$, $d = 1$. Resolution of the significant Sentence x Perspective interaction revealed a significant difference between performance in the SAME and DIFF Blocks in response to IMPLAUS sentences, SAME>DIFF: $t(19) = 3.70$, $p = .002$, $d = .83$, but no difference between Blocks for PLAUS or CONTEXT trials (all *ps* > .1).

fMRI: Whole-brain Analysis

The results of the whole-brain analyses (co-ordinates, Z-max, extent) are summarized in Tables 2.4 and 2.5.

Areas sensitive to the task of monitoring another’s perspective were identified by looking at the direct contrast between the two social perspective blocks. The effect of explicitly processing another’s perspective vs. not explicitly needing to monitor the other’s perspective (DIFF > SAME) revealed three significant clusters in the precuneus, the right middle frontal gyrus, and in the right supramarginal gyrus. The reverse contrast (SAME > DIFF) revealed no significant differences.

Areas sensitive to higher processing demands during language comprehension were identified by looking at the direct contrast between high demand stimuli (CONTEXT + IMPLAUS) and comparing these to low demand stimuli (PLAUS). This contrast yielded three clusters showing significantly more activity for high vs. low demand stimuli: one each in the left and right IFG, and a smaller cluster spanning the right superior frontal gyrus and the right paracingulate cortex. Voxels within the bilateral IFG showing increased activity in this contrast were used as a seed region in a subsequent PPI analysis (see below).

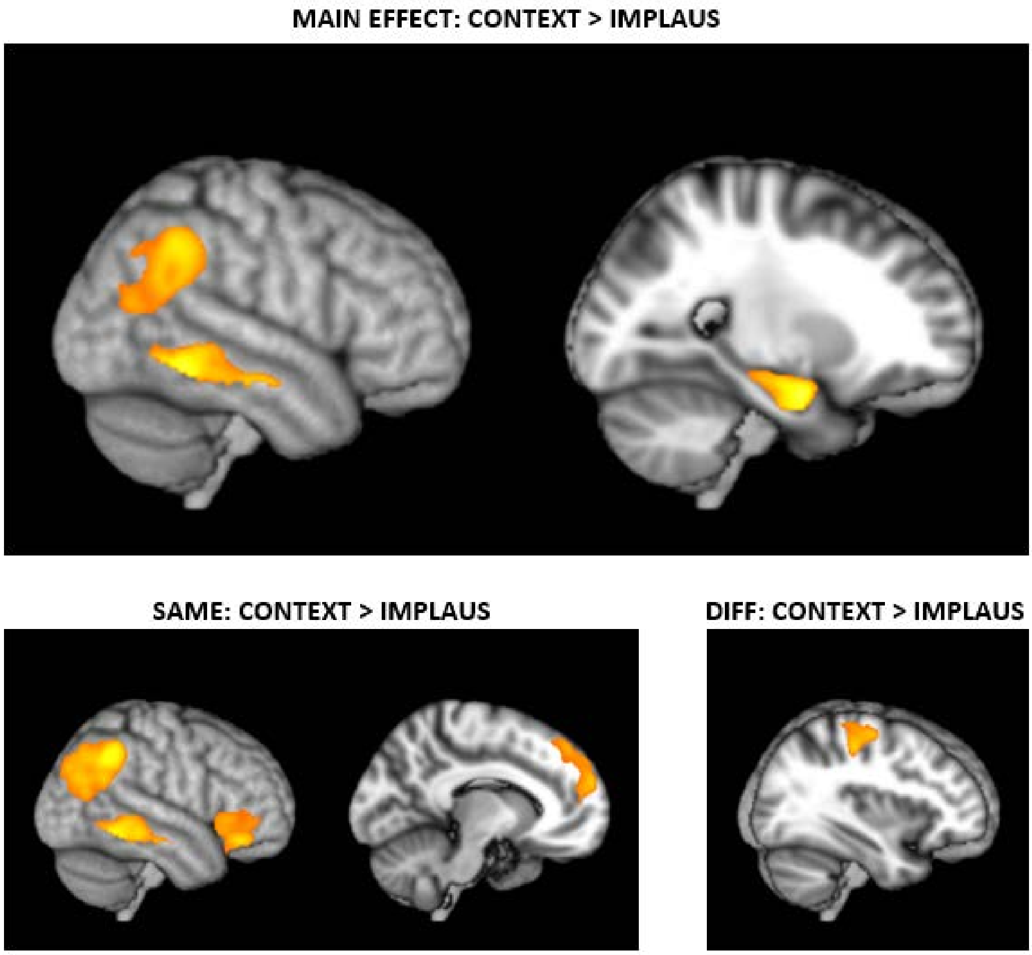

Figure 2.1. Results from the univariate analysis showing an increase in activity in CONTEXT over IMPLAUS Sentence condition. Top: MAIN EFFECT: CONTEXT > IMPLAUS, bottom left: SAME: CONTEXT > IMPLAUS, bottom right: DIFF: CONTEXT > IMPLAUS overlaid on a standard brain (voxel $p < .005$, cluster $p < .05$).

Areas selectively responsive to the processing of coherence in narrative were identified by looking at the direct contrast between the two high demand language stimuli: context-dependent vs. semantically implausible stimuli. Narrative coherence (compared to semantic implausibility) elicited increased activity in three clusters located in the left hemisphere: a large posterior cluster covering angular and supramarginal gyri, extending to lateral occipital cortex, a cluster in middle temporal gyrus, and a smaller cluster spanning amygdala and hippocampus (see Figure 2.1). These areas were used as Regions of Interest (ROIs) in a subsequent analysis (see below). The reverse contrast (IMPLAUS > CONTEXT) revealed no significant differences.

				MNI coordinates		
Brain Region	**Cluster**	**Extent (voxels)**	**Z-value**	**x**	**y**	**z**
Main effect DIFF > SAME						
Precuneus	1	1145	4.75	2	-62	50
Right middle frontal gyrus	2	857	4.17	34	2	58
			3.76	36	20	52
			3.17	42	36	26
			3.03	44	42	18
			2.99	38	36	36
Right supramarginal gyrus/angular gyrus	3	770	4.13	46	-44	48
			2.91	60	-28	46
			2.71	40	-38	32
Main effect (IMPLAUS + CONTEXT) > PLAUS						
Left orbitofrontal cortex/insula extending to left inferior frontal gyrus	1	4139	4.66	-32	22	-8
			4.58	-52	22	24
			4.34	-40	12	24
			4.19	-50	32	-4
			3.95	-50	22	2
			3.52	-38	8	2
Right orbitofrontal cortex/insula extending to right inferior frontal gyrus and middle frontal gyrus	2	2590	4.86	34	24	-6
			4.34	52	26	18
			4.30	46	22	20
			3.64	40	14	30
			3.43	54	28	-18
			3.30	52	20	6
Right superior frontal gyrus extending to right paracingulate gyrus	3	1351	4.10	4	32	46
			3.80	6	18	46
Main effect CONTEXT > IMPLAUS						
Left angular gyrus extending to left supramarginal gyrus and left lateral occipital cortex	1	1222	3.58	-56	-54	42
			3.55	-58	-50	38
			3.31	-56	-60	28
			3.12	-52	-72	18
			2.84	-44	-68	40
Left middle temporal gyrus	2	984	3.99	-64	-50	-10
			3.53	-62	-22	-18
			3.51	-58	-16	-16
			3.43	-58	-12	-18
			2.66	-60	-60	4
Left amygdala extending to left hippocampus	3	785	4.13	-22	-6	-22
			3.31	-26	-24	-16

Table 2.4. Clusters of activity for main effects of Perspective and Sentence condition. Cluster size in voxels, local maxima‘s z-values, and coordinates in MNI space are listed. Local maxima were identified using FSL’s *cluster* algorithm.

Lastly, areas that were sensitive to the processing of high demand stimuli for which the participant and confederate had mismatching vs. matching interpretations were investigated by looking at the direct contrast between the two high demand stimuli (CONTEXT vs. IMPLAUS) within each social block (SAME, DIFF). During blocks in which the participant’s and the confederate’s perspectives were shared (SAME), four significant clusters showed increased activity for narrative coherence compared to semantic implausibility: a large posterior cluster covering left angular and supramarginal gyri, extending to lateral occipital cortex, left inferior frontal gyrus/orbitofrontal cortex, left middle temporal gyrus, and left medial prefrontal cortex (mPFC). During blocks in which perspectives were not shared (DIFF), the same contrast yielded activity only in the left Precentral and Postcentral gyri (see Figure 2.1). The reverse contrasts (SAME: IMPLAUS > CONTEXT, DIFF: IMPLAUS > CONTEXT) showed no significant differences.

				MNI coordinates		
Brain Region	**Cluster**	**Extent (voxels)**	**Z-value**	**x**	**y**	**z**
DIFF: CONTEXT > IMPLAUS						
Left central sulcus extending to left precentral and postcentral gyri	1	852	3.46	-34	-26	48
			3.45	-40	-14	58
			3.41	-42	-26	54
			3.34	-40	-24	60
			3.3	-26	-20	56
			2.99	-34	-30	64
SAME: CONTEXT > IMPLAUS						
Left angular gyrus extending to left lateral occipital cortex	1	2246	3.96	-56	-54	42
			3.39	-52	-58	26
			3.37	-48	-76	26
			3.35	-44	-68	40
			3.26	-38	-80	34
Left orbitofrontal cortex extending to left Inferior frontal gyrus	2	1329	3.63	-38	36	-16
			3.12	-56	28	-2
			3.12	-56	24	-2
			3.09	-52	22	-8
			2.96	-48	42	-4
			2.93	-50	38	-8
Left middle temporal gyrus	3	1156	3.82	-62	-52	-12
			3.52	-64	-34	-10
			3.34	-60	-22	-18
Left superior frontal gyrus	4	987	3.4	-12	60	24
			3.4	-16	44	44
			3.01	-8	54	40

Table 2.5. Clusters of activation for main effects of CONTEXT > IMPLAUS sentences per Perspective condition. Cluster size in voxels, local maxima‘s z-values, and coordinates in MNI space are listed. Local maxima were identified using FSL’s *cluster* algorithm.

ROI analysis

The areas showing selective response to the processing of coherence in narrative, based on CONTEXT > IMPLAUS contrast (see above) were further analysed, in order to explore whether the activity in these areas differed based on differences in perspective. Mean BOLD activity from the three spherical regions of interest centered around the three clusters' peaks was extracted. Each subject's mean signal from PLAUS condition was subtracted from the signal in CONTEXT and IMPLAUS conditions prior to the analysis. The data were then entered into three separate 2x2 repeated measures ANOVAs, one per ROI. The results are depicted in Figure 2.2.

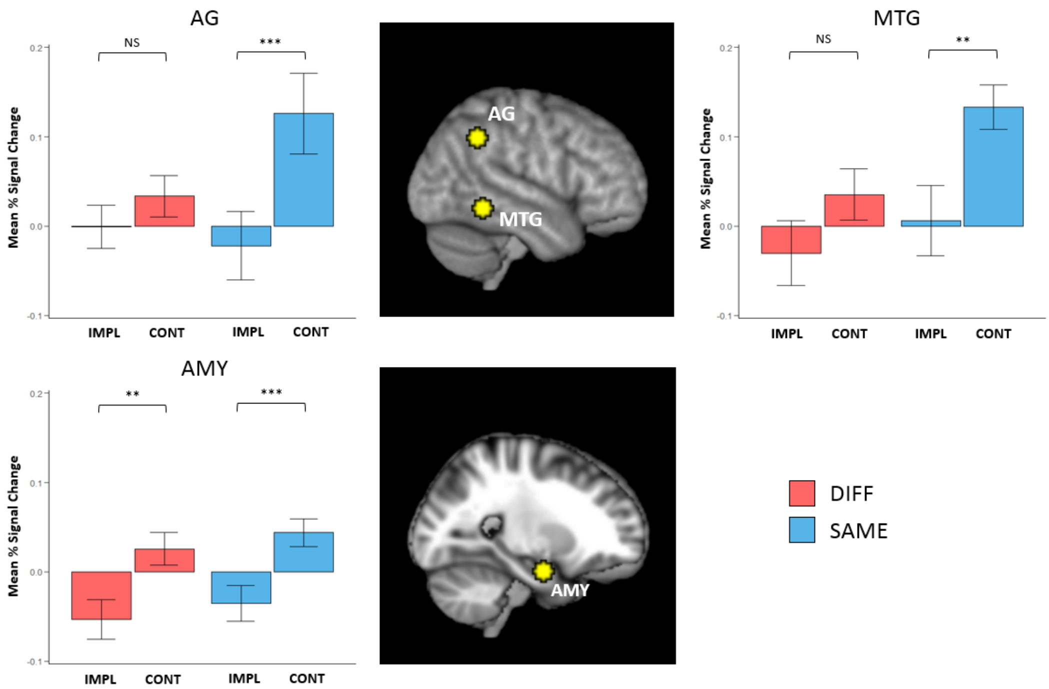

Figure 2.2. Mean signal change (±SEM) from the three regions of interest. Data for DIFF (red) and SAME (blue) are depicted separately for the two analysed sentence conditions (IMPLAUS - IMPL, CONTEXT - CONT). (*** p < .001; **p < .01; * p < .05; NS > .05; the p-values are corrected for 2 comparisons). AG – left angular gyrus, MTG – left middle temporal gyrus, AMY – left amygdala.

In the left AG a significant main effect of Sentence, $F(1, 19) = 23.38$, $p < .001$, $\eta_p^2 = .552$, was observed with the signal larger for CONTEXT sentences (M = .080, SEM = .024) than for IMPLAUS sentences (M = -.011, SEM = .016). An interaction of Sentence and Perspective, $F(1, 19) = 21.72$, $p < .001$, $\eta_p^2 = .55$, was also observed. The main effect of Perspective was not significant, $F(1, 19) = .46$, $p > .1$, $\eta_p^2 = .03$. To resolve this interaction the difference between CONTEXT and IMPLAUS sentences was tested for both Perspective conditions separately using paired t-tests. This analysis showed that in DIFF condition there was no significant difference between CONTEXT and IMPLAUS sentences (*M* = .034, *SEM* = .023), *t*(19) = 1.52, *p* = .145, *d = .34*. In SAME condition, however, there was a significant difference between the two types of sentences (*M* = 1.48, *SEM* = .022), *t*(19) = 6.62, *p* < .001, *d = 1.48*, with the signal magnitude larger in CONTEXT sentences (*M* = .044, *SEM* = .016) compared to IMPLAUS sentences (*M* = -.036, *SEM* = .020).

Left MTG showed only a significant main effect of sentence, *F*(1, 19) = 16.51, *p* = .001, η_p^2 = .47, with larger activity in CONTEXT condition (*M* = .084, *SEM* = .023) compared to IMPLAUS condition (*M* = -.012, *SEM* = .023). Main effect of Perspective and the interaction of the two factors were not significant (*ps* > .05).

Similarly, left amygdala also showed only a significant main effect of Sentence, *F*(1, 19) = 26.48, *p* < .001, η_p^2 = .58, with larger activity in CONTEXT condition (*M* = .035, *SEM* = .0125) compared to IMPLAUS condition (*M* = -.045, *SEM* = .015). Main effect of Perspective and the interaction of the two factors were not significant (*ps* > .05).

gPPI analysis

The results of the gPPI analyses showing significant differences between the conditions (co-ordinates, Z-max, extent) are summarized in Table 2.6.

Areas showing increased connectivity with the left and right IFG were identified for each condition in a generalized psychophysiological interaction (gPPI) analysis. The seed regions in the left and right IFG were identified as the clusters showing sensitivity to higher language processing demands as identified by (CONTEXT + IMPLAUS) > PLAUS contrast (see above). Patterns of connectivity between the seed regions and the rest of the brain were calculated for each condition separately and then compared between the two Perspective conditions (i.e., PLAUS: SAME vs. DIFF, IMPLAUS: SAME vs. DIFF, CONTEXT: SAME vs. DIFF).

In the left IFG the comparisons revealed a significant increase in connectivity in DIFF condition compared to SAME condition for IMPLAUS and CONTEXT Sentence conditions (i.e., IMPLAUS: DIFF > SAME, and CONTEXT: DIFF > SAME). In IMPLAUS condition this was observed in two clusters, covering bilateral Putamen and Caudate Nucleus, extending to frontal regions such as the left orbitofrontal cortex and the right IFG, and in the left hemisphere to Insula as well. In CONTEXT condition, this increase was observed in two clusters as well (Figure 2.3), an anterior cluster peaking in mPFC and surrounding subcortical regions, and a posterior cluster located in the precuneus. There was no increase in connectivity for SAME compared to DIFF condition for neither Sentence condition.

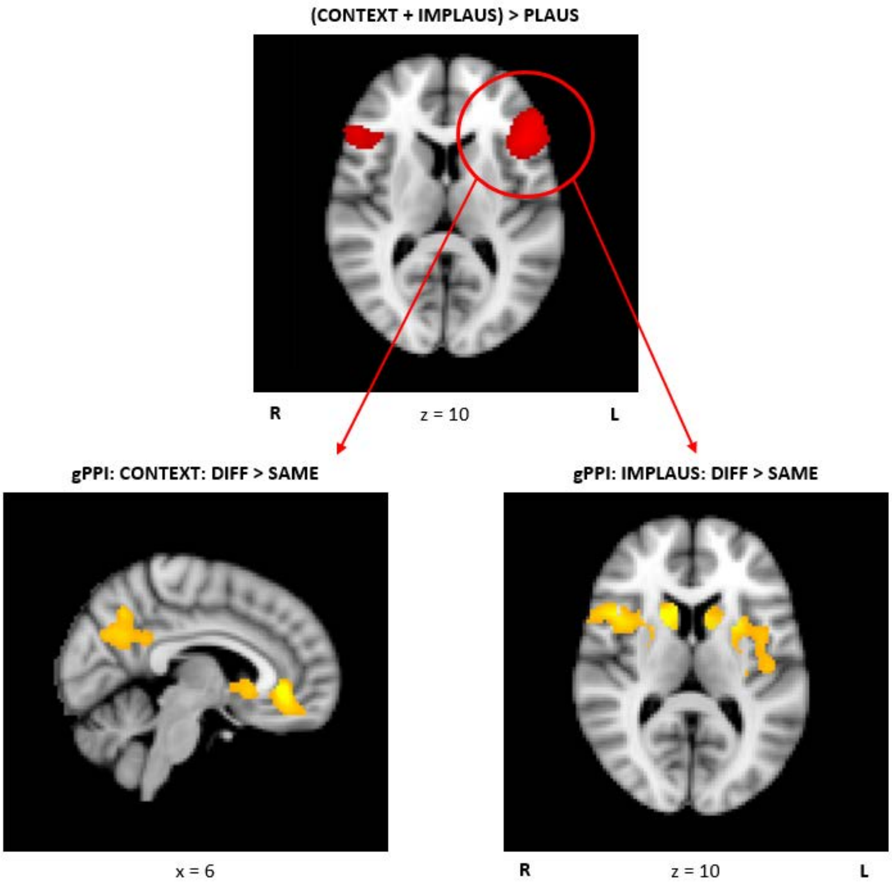

Figure 2.3. Regions showing a significant increase in connectivity with the left IFG in DIFF over SAME Perspective condition. The signal from the left IFG cluster from (CONTEXT + IMPLAUS) > PLAUS contrast served as the physiological regressor (top; encircled). The regions showing an increase in connectivity in DIFF over SAME condition are depicted separately for CONTEXT and IMPLAUS Sentence conditions (bottom left and bottom right, respectively), overlaid on a standard brain (voxel $p < .005$, cluster $p < .05$).

In the right IFG the analysis revealed a significant increase in connectivity in DIFF compared to SAME condition for CONTEXT Sentence condition only (i.e., CONTEXT: DIFF > SAME). This increase in connectivity was observed in several right hemispheric regions spanning Caudate Nucleus, Insula, and a small portion of mPFC. No other significant differences in connectivity were observed for right IFG.

Brain Region	Cluster	Extent (voxels)	Z-value	MNI coordinates x	y	z
gPPI left IFG IMPLAUS DIFF > SAME						
Left putamen extending to left caudate, Insula, and orbitofrontal cortex	1	1194	3.93	-26	8	8
			3.81	-14	22	4
			3.67	-16	14	4
			3.64	-36	12	-12
			3.36	-34	30	-2
			3.30	-28	24	2
Right caudate extending to right putamen, inferior frontal gyrus, frontal operacular cortex, and insula	2	717	4.45	18	14	10
			4.20	10	18	8
			4.12	22	10	8
			3.86	46	14	10
			2.95	32	26	6
			2.81	26	-4	10
gPPI left IFG CONTEXT DIFF > SAME						
Right cingulate gyrus extending to left putamen, insula, and caudate, and to right nucleus accumbens	1	2635	4.90	8	36	-6
			4.19	-30	6	6
			4.18	-34	6	6
			4.02	-18	20	-4
			3.84	-42	8	6
			3.52	12	20	-8
Left precuneus extending to right precuneus	2	1431	3.92	-14	-68	28
			3.88	14	-62	26
			3.49	-8	-60	48
			3.45	12	-50	36
			3.39	6	-58	42
			3.36	4	-60	28
gPPI right IFG IMPLAUS DIFF > SAME						
-	-	-	-	-	-	-
gPPI right IFG CONTEXT DIFF > SAME						
Subcallosal gyrus extending to right caudate, cingulate gyrus, frontal opercular cortex, and insula	1	1219	4.04	2	12	-2
			3.96	8	18	4
			3.79	8	36	-6
			3.78	50	2	10
			3.63	34	10	0
			3.62	32	14	2

Table 2.6. Results of the gPPI analysis of differences in connectivity for DIFF > SAME with seed in the left IFG and right IFG, respectively. Cluster size in voxels, local maxima‘s z-values, and coordinates in MNI space are listed. Local maxima were identified using FSL’s *cluster* algorithm. The reverse contrasts (SAME > DIFF) did not show any significant differences, and hence are not listed in the table.

Discussion

The aim of the present study was to examine patterns of neural activity associated with tracking another listener’s ability to understand sentence stimuli on-line. To this end, we presented participants with language stimuli that varied in narrative coherence (i.e., whether a sentence makes sense in the context of previous discourse). Additionally, we manipulated the ability of a jointly attending co-listener to make sense of the same sentence by controlling whether or not the co-listener had access to the full discourse context. The results demonstrate that listeners do track other listeners’ interpretation of language stimuli, even if the interpretation diverges from what the participant’s own interpretation. Further, neural responses suggest that understanding what others understand in a multi-party conversation relies on simulation of language comprehension from the perspective of other listeners. Lastly, processing language stimuli in social contexts relies on co-activation and connectivity between classical language and mentalizing networks.

Behavioural responses to experimental stimuli indicate that participants were able to process and reflect upon both their own and another person’s interpretation of a sentence, even if interpretations diverge. Response accuracy in both Blocks (SAME, DIFF) were high for all stimuli, and there was no difference in response accuracy for sentences that were plausible for both (PLAUS) and sentences that were plausible for the participant, but not for the confederate (Context-dependent). Small, but significant differences in performance were seen between the Blocks in response to sentences that were implausible for both participant and confederate. Specifically, participants made very few errors in identifying semantic anomalies in the Same Perspective Block, but they made more errors indicating that their perspective matched the confederate‘s if both parties should have interpreted the sentence as anomalous. This is likely to reflect the difficulty for the participant has in making a positive response (i.e., “match”) to a semantically anomalous stimulus. Taken together, the behavioural results demonstrate that participants are attuned to both information from discourse context, and to the potential that their own interpretation of a sentence diverges from another listener’s perspective if access to discourse context is not consistent.

The current study further suggests that understanding what co-listeners can understand in a multi-party conversation relies on simulating language comprehension from the perspective of other listeners. Specifically, on trials in which odd sentences were rendered coherent in the context of discourse narrative, participants showed increased activity in the Extended Language Network (ELN) including mPFC, left IFG, left MTG and left AG. The ELN is known to be activated by the processing of coherent narratives and stories, for example, discourse extending over multiple sentences (Ferstl et al., 2008; 2018; Mar, 2011). Critically, in the current study, the ELN was only activated during trials in which both the participant and the confederate could process narrative coherence (e.g., when both had access to the context sentence); it was absent in coherence trials in which the confederate would have been unable to process the narrative coherence. This suggests that participants gained access to the confederate's interpretation by simulating language comprehension from their perspective (e.g., in this case simulating lack of coherence). This finding is in line with electrophysiological work from our own and other labs demonstrating that participants simulate the comprehension processes of other co-listeners during social language comprehension (Rueschemeyer et al., 2015; Westley et al., 2017; Forgács et al., 2018; Jouravlev et al., 2018).

The results of the current study also provide insight into how neural networks supporting mentalizing and language processing interact to support social language comprehension more generally. With respect to mentalizing, when participants were faced with sentence stimuli that could have been interpreted differently by the co-listener, increased levels of activity were seen in parts of the mentalizing network, namely within the precuneus and posterior cingulate cortex. These brain regions have been shown to be consistently activated across a wide range of mentalizing tasks (e.g., Schurz et al., 2014; Mar, 2011; Saxe, 2006; Mitchell, 2008). The specific role of the precuneus in mentalizing is not clear, but some studies have suggested that it plays a role in representing third-person perspectives by showing its involvement in task requiring, for example, consideration of another's action, attribution of agency to another, or in taking another's spatial reference frame (e.g., Ruby & Decety, 2001; Farrer & Frith, 2002; Vogeley et al., 2004; Cavanna & Trimble, 2006). In the current study, posterior cingulate was activated only in blocks in which the participant and confederate had access to a different amount of background information (i.e., perspectives were potentially, but not always, different). We suggest that this region supports participants in representing the potentially diverging perspective of the confederate. It should be noted that other parts of the mentalizing network, such as mPFC and temporo-parietal junction regions, were not differentially activated by the different social conditions in our experimental paradigm. One explanation for this may be that the perspective of the other listener was relevant in both Different and Same Perspective blocks: in other words, there was always another listener present (no block tested sentence comprehension in the absence of another listener). Therefore, the critical difference between the blocks was whether or not the participant's and the confederate's interpretation of sentence stimuli matched. For this reason, the larger mentalizing network is likely to be involved in both Same and Different Perspective blocks, and the contrast between the social conditions highlights those portions of the network that are sensitive to a potential mismatch between self and other.

With respect to language processing, sentences with relatively higher processing demands (i.e., sentences requiring context integration, semantically anomalous sentences) elicited greater activity in the bilateral IFG than sentences with lower processing demands (i.e., semantically coherent sentences). Bilateral IFG is known to be activated by high semantic demands, including semantic violations (Friederici et al., 2003; Rüschemeyer et al., 2006; Zhu et al., 2009; Vigneau et al., 2011; Mar, 2011; Bilenko et al., 2009) (review see Hagoort & Indefrey, 2014). In particular, the left IFG has been shown to be integral to higher level aspects of semantic processing, such as semantic integration (Hagoort, 2016) and semantic control (Jefferies, 2013). In the current study, we suggest that IFG activity reflects the generally increased demands associated with processing local semantic anomalies. In the case of context-dependent sentence stimuli, the local semantic anomaly is rendered plausible if the sentence is considered in the context of the previous discourse; in the case of pure semantic anomalies, no re-interpretation is possible. In both cases, the IFG is an active component in searching for and integrating new information in the service of comprehension.

While both context-dependent and semantically anomalous sentences activated the bilateral IFG significantly more than semantically coherent sentences, connectivity between the IFG and other regions in the brain differed systematically across the language and social conditions. Specifically, when the participant believed their own interpretation of the sentence differed from the confederate's (i.e., context dependent condition in the Different Perspectives Block), the left IFG showed stronger connectivity to portions of the mentalizing network, including medial prefrontal and posterior cingulate cortex, than when the participant believed their interpretation and the confederate's were aligned (i.e., context-dependent condition in the Same Perspectives Block). This pattern of connectivity between the IFG and the mentalizing network was not seen if the participant believed that they and the confederate shared their final interpretation of the sentence (i.e., semantically anomalous condition in the Different Perspectives vs. Same Perspectives block). This suggests that the IFG may support the integration not just of different linguistic cues during language comprehension, but may also be involved in integrating linguistic cues with information about a conversational partner's background knowledge, beliefs and desires (see also van Ackeren et al., 2016).

Previous studies have demonstrated partial overlap between discourse processing and mentalizing networks in the past (e.g., Ferstl, 2018; Mar, 2011; Lavoie et al., 2016; Lin et al., 2018), leading researchers to suggest that the overlap is either because discourse processing often requires mental state inferences (e.g., Mar, 2011), due to the domain general functionality of the regions of overlap (e.g., Ferstl, 2008; Mar, 2011), or due to the overlapping regions serving different cognitive processes during discourse and mental state processing, respectively (Lavoie et al, 2016). The present study contributes to this ongoing debate as both mentalizing and discourse processing demands were manipulated independently. Specifically, although mentalizing was necessary in all conditions in the current study (i.e., the co-listener perspective was always present), parts of the larger network (left IFG, left MTG, left AG, dorsal mPFC) were shown to be selectively responsive to coherent narrative processing above and beyond mentalizing demands. On the other hand, other parts of the network (precuneus, ventral mPFC), were observed to be selectively sensitive to increased mentalizing demands (i.e., when the participant's perspective differed from the co-listener's perspective). The results therefore suggest that while there is a well-documented overlap between mentalizing and narrative processing networks (Mar, 2011; Lavoie et al., 2016; Lin et al., 2018), parts of these networks show selective sensitivity to narrative processing and others to the processing of different perspectives.

One of the possible concerns one could have regarding the present study relates to the nature of the experimental task. In the present study the task differed based on whether the perspective of the participant and the co-listener was the same or different. While in the Same Perspective Blocks participants were only asked to judge whether the final sentence is plausible to the co-listener, in Different Perspective Blocks they were asked to judge whether their own and the co-listener's plausibility judgements of the final sentence matched (see Table 2.1). The potential issue with such design is that it may result in decreased ability of the experiment to isolate the phenomenon of interest – brain processes connected to perspective difference processing – by invoking undesired task-specific processes. For instance, in Different Perspective Blocks the task required the participants to compare between two interpretations of the target sentence. This was not the case in Same Perspective Blocks where only a single interpretation was considered. It is then possible that the significant differences observed between the perspective blocks partly reflect such aspects of the task differences. An improved experimental design adjusting for this issue presented here was later introduced and is presented in Chapter 3 in an EEG study (also in Westley et al., 2017). Utilizing such design in a future fMRI study could help to pinpoint the neural correlates of simulation with more confidence.

Overall, the present results are broadly in line with previous research on pragmatics in dyadic contexts suggesting the involvement of the mentalizing network during pragmatic language processing (van Ackeren et al., 2012; Bašnáková et al., 2013; Bašnáková et al., 2015; Spotorno et al., 2012; Bohrn et al., 2012; Willems & Varley, 2010; Kuhlen et al., 2017), as well as integration of the mentalizing network with semantic regions of the brain during such processing (Enrici et al., 2011; van Ackeren et al., 2016; Tettamanti et al., 2017). The current results are in line with the literature showing that specific parts of the overlapping Extended Language and metalizing networks can be dissociated from one another: the precuneus in particular is activated by diverging perspectives above and beyond baseline activity seen for discourse processing. In contrast, middle temporal and angular gyri show a selective response to narrative discourse processing that goes beyond what is elicited by mentalizing. More importantly, the present study extends the previous findings by clearly demonstrating that people are sensitive to the comprehension process of the co-listeners' in triadic communicative contexts, as evidenced by the task performance as well as the neuroimaging evidence. The results also expand on the previous studies on simulation of co-listener's comprehension process (Rueschemeyer et al., 2015; Westley et al., 2017; Forgács et al., 2018; Jouravlev et al., 2018) by providing evidence suggesting that simulation of processing from another's perspective can be achieved by suspension of the cognitive processes based on private information, that is, in this case coherent narrative processing.

Chapter 3

A failure to replicate the Social N400-effect in absence of a shared task

Abstract

Communication has been previously described as a type of joint action. However, to this date, there is no empirical evidence explicitly linking the phenomena observed in research on joint action and joint comprehension. The present study investigated whether such a link exists using the electrophysiological Social N400-effect, previously connected to simulation of another's mental states in communicative contexts. Based on the previously made observations that similar simulation-like phenomena in the joint action domain are only observed if both actors are engaged in a shared task, the present study aimed to establish whether the Social N400-effect can also only be observed when both listeners are engaged in such a task. To this end, a version of so-called Joint Comprehension paradigm from a previous experiment on the Social N400-effect was adapted and utilized. Unlike in the original experiment, in the current version the participants were not engaged in a shared task with another listener (confederate). It was hypothesized that if communication is a type of joint action, the Social N400-effect should not be observed in absence of the shared task. The analysis of electrophysiological responses supports this prediction, showing no evidence of the Social N400-effect. The results contribute to the literature on cognitive and neural underpinnings of communication by providing an empirical link between the phenomena observed in joint action and joint comprehension literature.

Introduction

Human communication is a complex process during which speakers with different background, knowledge and perspectives aim to coordinate with one another in order to achieve their communication goals, that is, they participate in a form of joint action (Clark, 1996). Previous electrophysiological research framing language comprehension in social settings (e.g., Rueschemeyer et al., 2015; Westley et al., 2017) found that people represent their co-listener's comprehension process, which parallels how physical actions are processed in the presence of a co-actor (Sebanz et al., 2006b). Despite these similarities, it is not clear from the present evidence whether the effect observed in the two experiments depends on the participants' involvement in an explicit joint action (i.e., a shared task), or whether it is more independent and occurs due to mere presence of another listener. The present experiment addresses this issue.

Previous research on joint action provides an important window into how humans process social information. One of the major findings is that, when conducting tasks jointly with another actor, people form so-called shared representations; meaning that they mentally represent not only their own actions, but also the actions of their co-actors, that is, they co-represent their actions (e.g., Sebanz et al., 2005; Sebanz et al., 2006a; Atmaca et al., 2008). Neuroscientific evidence supports this notion, for instance, in an event-related potential (ERP) study, Sebanz et al. (2006b) provide evidence of action suppression when the co-actor, but not the participant, was prompted to act. No such effect was observed in absence of a co-actor. This suggests that the participants formed a representation of the co-actor's action, the outcome of which then had to be suppressed. Since language has been proposed to be a type of joint action (Clark, 1996; Pickering & Garrod, 2004) similar logic was used to test the comprehension process in joint settings. In the studies testing this (e.g., Rueschemeyer et al., 2015; Westley et al., 2017), a well-known ERP marker of semantic integration difficulty, the N400-effect, was utilized (e.g., Kutas & Federmeier, 2011). Both experiments showed that a co-listener's experience of semantic difficulty elicited the N400-effect, even when the participant themselves were not experiencing it. This vicariously experienced or simulated N400-effect was therefore termed the Social N400-effect. This phenomenon is in agreement with the literature on joint action as it shows that in both cases people do represent the mental states of their action and communication partners.

Nevertheless, the conditions under which the Social N400-effect occurs have not been studied before. In both experiments on Social N400-effect, the participant and the co-listener were simultaneously engaged in an explicit task requiring them to answer questions about their own and their partner's understanding of the presented sentences. It is not clear whether such shared task requiring joint action is necessary to elicit the Social N400-effect; although behavioural and ERP evidence would suggest so, since it has been shown that co-representation effects disappear when the other participant is not engaged in an explicit shared task (Sebanz et al., 2003; Tsai et al., 2006). Therefore, the most parsimonious hypothesis is that, if language is a type of joint action, then the presence of the Social N400-effect depends on the presence of a shared task. However, there are reasons why such straightforward generalization should be taken with caution: the evidence in the previous literature on joint action relies on simple motor tasks, a domain quite different from language. It is not clear at this point, even if one assumes that language is a type of joint action, which aspects of joint action translate across domains, and which of them are motor action specific. It is then also possible that co-listeners' mental states are considered regardless of the presence of a shared task because, while motor acts are often performed in isolation, language is primarily a social tool. Due to the social nature of language, people may be more prone to consider another's mental states in communicative contexts than in motor action contexts. Since such doubts can be cast on the cross-domain translatability of the previous literature on joint action, the issue warrants an empirical investigation.

In the present experiment, the question of whether the Social N400-effect relies on the presence of a shared task was explored. To do this, a version of the Joint Comprehension task from one of the previous studies on Social N400-effect (Westley et al., 2017) was used in a slightly adjusted version. The participants were presented with short stories consisting of five sentences. The first four sentences were read by the participant alone, while the final sentence was read together with a co-listener unexposed to the previous sentences. Similarly to the previous experiment, in the two conditions of interest, all five sentences were either semantically plausible on their own, as well as with respect to each other, or semantically implausible on their own, but still plausible with respect to each other (i.e., in both cases the five sentences formed a coherent narrative). Crucially, the present experiment differs from the original study in the way co-listener is engaged in the task. While in Westley et al. (2017) both the participant and the co-listener answered questions about their own and each other's understanding at the end of each trial, in the present case, only the participant was engaged in the task, while the co-listener was merely a passive reader. To explore the question more quantitatively, the data from the present study were also directly compared with the data from Westley et al. (2017).

The rationale for the use of the between study comparison described in the previous paragraph instead of collecting new data for such comparison as a part the present sample stems from the original aim of the present study. The present study's goal was originally to explore the individual differences in the Social N400-effect using a number of behavioural measures (this goal was retained and is further described below). However, in the process of data collection an error was spotted in the experimental setup – the absence of a shared task. Despite this not being originally intended, in light of the literature on joint action the data collection was resumed assuming the theoretical framework described above.

In line with the original experiment, it was predicted that during the alone part of the stories, at the first sentence position, semantically implausible sentences would, in comparison to semantically plausible sentences, elicit larger N400; reflecting the canonical N400-effect. At a later fourth sentence position in the stories, this effect would disappear since the anomalous sentences would be embedded in a meaningful discourse context and hence not be processed as anomalies (Nieuwland & Van Berkum, 2006). For the final sentence, read by both the participant and the confederate unexposed to the preceding context, there were two possible outcomes. If people simulate another's comprehension process more autonomously regardless of the presence of a shared task, then, similarly to the original experiment, the Social N400-effect should be observed. However, if joint action is a necessary requirement for such vicarious language processing, no evidence of the Social N400-effect should be observed. From these possible outcomes follow the hypotheses for the direct comparison of the present data with the data from Westley et al. (2017). No difference between the two studies was predicted during the alone part of the stories and, if people do simulate another's comprehension regardless of the presence of a shared task, then there should also be no difference between the two studies at the position of the final sentence. Nonetheless, if the presence of a shared task is a necessary condition for occurrence of the Social N400-effect, the amplitude of the signal should be significantly reduced at the final sentence position compared to Westley et al. (2017).

In addition, the relationship between the Social N400-effect and two other cognitive faculties, empathy and executive function, was explored. While the latter has been investigated previously in the context of perspective taking in dyadic settings (Brown-Schmidt, 2009b; also see Lin et al., 2010), with Brown-Schmidt (2009b) showing that individual differences in inhibition positively correlate with one's ability to suppress utterance interpretations irrelevant to the interlocutor, this has not yet been explored in triadic contexts. One of the aims of the current experiment is, therefore, to assess whether the amplitude of the Social N400-effect correlates with executive function, as estimated by the classical Stroop task (Stroop, 1935). The exploration of empathy in relationship to the Social N400-effect was motivated by the fact that, like empathy, the Social N400-effect seems to rely on consideration of another's mental states. For the purposes of the present study, empathy was considered, in terms of Baron-Cohen & Wheelwright, as the ability to, "... tune into how someone else is feeling, or what they might be thinking" (Baron-Cohen & Wheelwright, 2004). In line with this, Empathy Quotient (EQ) questionnaire (Baron-Cohen & Wheelwright, 2004) was used to estimate individual empathic ability. Still, since EQ relies on self-assessment, the Reading the Mind in the Eyes test, which is a more objective measure of empathy, was administered as well (Baron-Cohen et al., 2001).

The individual differences in the two abilities and the Social N400-effect size were explored even though it was possible that no significant Social N400-effect would be observed at the group level. This is because, even if null effect would be observed, inter-individual differences can co-vary with the amplitude of an effect that is not significant at the group level. Therefore, regardless of the hypotheses about the presence of the Social N400-effect, it was hypothesized, in line with Brown-Schmidt (2009b), that executive function, as measured by the Stroop task, would be positively correlated with the amplitude of the Social N400-effect. Positive relationship between empathy estimates and the Social N400-effect was expected, since both these abilities seem to rely on consideration of another's mental states.

Methods

Participants

Fifty-five participants aged 18-25 years (M = 19.87, SD = 1.31; 32 females) were recruited through the University of York in exchange for course credits or payment. All participants were native English speakers. Each participant conducted the experiment together with a confederate who was a member of the experimental team. The confederates were native English, German, Iranian, and Slovak speakers. The study was approved by the ethics committee of the Department of Psychology, University of York. All participants provided informed consent before participating in the experiment. Data from 13 participants were removed, due to the participant passing out during the session (1 case), being hungover (1 case), constant sneezing (1 case), constant hand movement (1 case), excessive blinking (1 case), or excessive noise in the signal (less than 50 % data remaining; 8 cases).

Stimuli

A set of 115 short stories consisting of 5 sentences was created (examples in Table 3.1), 90 of which belonged to one of the two main experimental conditions (N = 45). In Plausible condition (PLAUS), the presented stories were semantically plausible and all five constituent sentences were plausible on their own. In Implausible condition (IMPLAUS), the stories were semantically plausible, but none of the constituent sentences were plausible on their own, that is, the sentences were only plausible when read in the context of the story. There were three sentences of interest in each story, the first, the fourth, and the fifth sentence (S1, S4, and S5, respectively). In the case of these three sentences, it was always the final word that determined whether the sentence would be PLAUS or IMPLAUS (underlined in Table 3.1).

In addition, 15 'catch' trials were created, each belonging to one of 3 'catch' conditions (N = 5). These conditions were introduced in order to keep the participants attending to all sentences in the two main conditions, otherwise it would have been possible to guess the plausibility of S4 and S5 based solely on S1. In these 'catch' conditions, semantically plausible and implausible sentences were mixed in the following way (examples in Table 1):

- Catch 1 - The first four sentences were plausible as a story as well as on their own. The last sentence was anomalous and therefore inconsistent with the preceding sentences;
- Catch 2 - The first four sentences were implausible on their own, but plausible as a story. The last sentence was plausible on its own, but inconsistent with the preceding sentences;
- Catch 3 - The first four sentences were implausible on their own, but plausible as a story. The last sentence was implausible on its own, but inconsistent with the preceding sentences.

Procedure

Participants were seated in front of and to the centre of a computer screen. A confederate (a member of the experimental team) was seated next to them and was presented as another participant. Both the participants and the confederate were fitted with an EEG cap. The participant and the confederate were then presented with the task instructions and a short practice run consisting of 8 trials. During this practice run they were encouraged to ask questions if anything was unclear to them and were provided feedback on their responses by a member of the experimental team. This was followed by the main part of the experiment.

	P alone				P + C		
	S1			**S4**	**S5**	**Q1**	**Q2**
PLAUS	The man sat in the train.	The man was visiting his mum.	The man reserved a seat.	The man showed his tickets.	The man looked out of the window.	Yes	Yes
IMPLAUS	The book was written by banana.	The banana became famous.	The banana earned a lot of money.	People followed the banana.	A reported interviewed the banana.	No	Yes
Catch 1	The boy polished the guitar.	The guitar was brand new.	The boy adored the guitar	The boy played rock on the guitar.	The guitar was made of cheese.	No	No
Catch 2	The woman baked for guitar.	The guitar liked the snacks.	The woman baked the biscuits.	The woman ate with the guitar.	The boy practisised the guitar.	Yes	No
Catch 3	The violin applied for the job.	The job was well-paid.	The job was in sales.	The violin wanted the job.	The violin was served with custard.	No	No

Table 3.1. Examples of experimental stimuli in the two main conditions (PLAUS, IMPLAUS) and in the three 'catch' conditions (Catch 1-3). The underlined target words in PLAUS and IMPLAUS condition were examined in the EEG analyses. The first four sentences (S1 - S4) were read by the participant alone (P alone), the fifth sentence (S5) was read together with a confederate (P + C). At the end of each trial, participants had to indicate whether S5 was comprehensible for the confederate (Q1) and whether it was in line with the previous four sentences (Q2).

Each trial began with a screen prompting the confederate to close their eyes. Upon seeing this, the confederate closed their eyes and covered their face with both hands in order to make it ostensive that they could not see the screen. The participant then pressed a button and the first four sentences were presented (S1 to S4). Each sentence was split into three parts and presented across three screens. The first two screens each contained 2 to 4 words and were presented for 1000 ms each. The last screen presented a single word in isolation for a duration of 2000 ms. This is because at this position the critical word was presented (at S1, S4, and S5), disambiguating whether the sentence would be anomalous or not (underlined in Table 1). After S4, another prompt appeared instructing the confederate to open their eyes. When the participant was satisfied that the confederate's eyes were open, the participant pressed a button and S5 was presented to both the participant and confederate.

After all 5 sentences were presented, participants were tasked to answer two questions (in the following order): “Do you think the last sentence was plausible for your partner?” and “Was the last sentence consistent with the previous sentences?”. Participants responded ‘yes’ or ‘no’ using keyboard. After every five trials a pause screen was presented giving participants the option to rest between the trials. The experiment was then resumed after a button press.

There were 115 trials in total. Trials were presented in a pseudorandomized manner, with no more than two trials from the same condition being presented consecutively. The catch trials were interspersed throughout the length of the experimental runs. Only the data from correctly answered trials from the two main conditions (PLAUS, IMPLAUS) were considered in the EEG analysis. The experiment was scripted and presented using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com).

EEG data processing

Continuous EEG was recorded using 32-channels placed in a five percent electrode system montage (recording reference = left mastoid, ground = forehead, VEOG and HEOG included, electrode impedances < 10 kΩ). The signal was pre-processed using BrainVision Analyzer 2 (re-reference to average of mastoids, segmentation = -200 to + 1000 ms around target word onset, baseline correction = -200 ms, semi-automatic artefact rejection for eye movements, performance-based trial rejection, electrode drifting, and EMG artefacts). In total 15.98 % (*SD* = 8.12 %) of the data was discarded. The percentage of trials excluded per condition was S1 PLAUS: *M* = 14.76, *SD* = 9.34 ; S1 IMPLAUS: *M* = 18.15, *SD* = 8.37 ; S4 PLAUS: *M* = 14.97, *SD* = 6.40 ; S4 IMPLAUS: *M* = 17.09, *SD* = 8.99 ; S5 PLAUS: *M* = 14.29, *SD* = 7.64 ; S5 IMPLAUS: *M* = 16.61, *SD* = 7.46.

Canonical N400-effect

To identify the precise time course of the canonical N400 component in this sample, signals from PLAUS and IMPLAUS conditions at S1 were compared using paired two-tailed cluster mass permutation t-test, using a family-wise alpha level of .05 (Bullmore et al., 1999), using Mass Univariate ERP Toolbox (Groppe et al., 2011). All time points from the 0 to 800 ms window following the onset of the target word were considered at all 30 scalp channels. Any channels within approximately 5.44 cm of one another were considered spatial neighbours. Repeated measures t-tests were performed for each comparison using the original data and 10000 random within-participant permutations of the data. For each permutation, all t-scores corresponding to uncorrected p-values of .01 of less were formed into clusters. The sum of the t-scores in each cluster is the "mass" of that cluster and the most extreme cluster mass in each of the 10001 sets of tests was recorded and used to estimate the time window and distribution of the null hypothesis.

Differences in N400-effect across sentence conditions

The size of the N400-effect was further examined across the three sentence conditions. To do this, mean amplitude was calculated for each Sentence, and Plausibility condition (i.e., S1, S4, S5 for PLAUS and IMPLAUS) from the interval showing significant difference at S1 (365-515 ms as determined by the cluster mass permutation t-test, see Results section) in the cluster mass permutation t-test. The data were then entered to 3x2 Repeated measures ANOVA with factors Sentence (S1, S4, S5) and Plausibility (PLAUS, IMPLAUS). The results were further examined using three planned paired t-tests comparing the difference between PLAUS and IMPLAUS at each level of Sentence (S1, S4, S5). These t-tests were therefore Bonferroni corrected for 3 comparisons.

Comparison with Westley et al. (2017)

The amplitudes from the present experiment were compared with amplitudes from a previously published study on Social N400-effect (Westley et al. 2017) following nearly identical experimental design (N = 16). Unlike the present adult sample, these data come from an adolescent sample (*Age M* = 12.42, *SD* = 1.58 years). The analysis window was different in the previous experiment due to a somewhat different result of the permutation t-test on S1 (365-630 ms). In order to make the comparison as equal as possible, the interval showing significant difference at S1 in the present experiment (i.e., 365-515 ms) was used as an analysis window for both datasets. The data from the two studies were then entered to 3x2x2 mixed ANOVA, with within subject factors Sentence (S1, S4, S5) and Plausibility (PLAUS, IMPLAUS) and a between subject factor Task (Shared, NotShared), with Shared referring to data from the Westley et al. (2017) study and NotShared referring to the present data.

Individual differences

In order to test whether individual differences in empathy and executive function are connected to individual differences in the Social N400, these abilities were estimated using behavioural measures. To measure empathy, the Empathy Quotient (EQ) questionnaire (Baron-Cohen & Wheelwright, 2004), and Reading the Mind in the Eyes task (RMiE) (Baron-Cohen et al., 2001) were administered. To measure executive function, the classical Stroop task was used (Stroop, 1935).

EQ is a commonly used measure of empathy in psychological research. The questionnaire consists of 60 items, 40 of which are related to empathy with 20 filler items interspersed throughout. Each item has a form of a declarative sentence expressing a statement about one's behaviour (e.g., "I find it easy to put myself into somebody else's shoes"). The participant's task is to indicate their agreement with each statement on a 4 point Likert-like scale (with options: strongly agree, slightly agree, slightly disagree, strongly disagree). Depending on the answer, participants can score 0, 1, or 2 points for each of 40 empathy related items. The sum of these points is one's EQ. The questionnaire was administered at the beginning of the experimental session, while the experimenter was setting up the participants with the EEG. Although this measure is very popular in psychological research, the obvious drawback is that it relies on self-reports. For this reason, RMiE was introduced as it does not rely on self-report.

RMiE (Baron-Cohen et al., 2001) is a measure of mentalizing, where participants are in each trial presented with a picture of eyes and 4 words describing specific emotions (e.g., 'playful', 'comforting', 'irritated', 'bored'). The participant's task is to select the word that they think describes the emotional state expressed by the picture. The participant's score is the sum of correctly answered questions. The task starts with a description of the task and a single test trial, followed by 36 experimental trials. The task was administered in a separate session, taking place after the EEG session, and was administered using a custom-made computer-based questionnaire.

In the Stroop task (Stroop, 1935) participants were presented with a series of single words presented to the centre of the computer screen. In the critical trials, one of three colour words was presented - 'RED', 'GREEN', 'BLUE'. The colour of the letters in which the words were depicted depended on the condition. In Congruent condition, the colour of the letters corresponded to the colour referred to by the word (e.g., the word 'RED' written with red coloured letters). In Incongruent condition, the colour of the letters did not correspond to the colour referred to by the word (e.g., the word 'RED' written with blue coloured letters). A third, Nonword condition, was introduced, where participants were presented with a nonword consisting solely of consonants (e.g., 'PXFS') rendered in one of the three colours. Each trial began with a fixation cross presented to the centre of the screen for 200 ms, followed by presentation of the stimulus word or nonword. The task required participants, using a button box, to indicate as quickly and as accurately as possible what the colour of the letters was, regardless of the colour referred to by the word. Each participant was presented with 36 trials from Congruent, 12 trials from Incongruent, and 12 trials from Nonword conditions, totalling 60 trials. The experiment was split into 2 blocks with 30 trials, with half of the trials from each condition being presented per block. Between the blocks, participants were offered an opportunity to take a short break or to follow with the task immediately. The task was administered in a separate session together with RMiE. The task was scripted and presented using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). For the analysis, Stroop effect was calculated for each subject by subtracting the average reaction time in Congruent condition from the average reaction time in Incongruent condition. The data from Nonword trials were not considered.

The data for EQ were collected for every participant in the sample (N = 42); for RMiE and the Stroop task, due to one participant not showing up for the second session, the sample was one participant short (N = 41). The EEG data from this participant were therefore excluded from the analysis of individual differences for the two respective tasks.

The scores from the three tasks (EQ, RMiE, Stroop) were analysed with respect to the amplitude of the signal at S5. To do this, the difference between mean signal PLAUS and IMPLAUS conditions from 365-515 ms window was analysed against EQ score, RMiE score, and Stroop effect in correlation analysis using Pearson's correlation coefficient. If at least one of the variables was not normally distributed, Spearman's Rho was used instead. In addition, the same analysis was conducted for each behavioural measure at S1 as well. This was done in order to control for whether, in case there is a significant correlation between S5 and one of the behavioural measures, this correlation is specific to S5 or correlates with the N400-effect in general. Since each behavioural measure was tested across both S1 and S5, all p-values were Bonferroni corrected for two comparisons.

Results

Behavioural

On average, the proportion of correct responses showed near perfect performance for both test questions and plausibility conditions (Q1-PLAUS: M = 97.9, SD = 4.7; Q1-IMPLAUS: M = 98.8, SD = 2.3; Q2-PLAUS: M = 98.4, SD = 4.3; Q2-IMPLAUS: M = 98.2, SD = 4.3). This was further examined using 2x2 repeated-measures ANOVA with factors Question (Q1, Q2) and Plausibility (PLAUS, IMPLAUS). No significant effect of

Question (F(1, 41) = .021, p > .1, $\eta_p^2 = .001$), Plausibility (F(1, 41) = .49, p > .1, $\eta_p^2 = .01$), or interaction of the two factors (F(1, 41) = 1.53, p > .1, $\eta_p^2 = .04$) were observed. The results therefore indicate that the participants had sufficient understanding of the task, and that difficulty did not vary across questions or conditions.

Canonical N400-effect

The cluster mass permutation revealed a significant cluster in 365-515 ms window (p < .001). The cluster was distributed centro-parietally, with its amplitude and spatial extent (i.e., the number of electrodes in the cluster) peaking at 400 ms post stimulus. Regarding the direction of the effect, the cluster showed a more negative going deflection in IMPLAUS compared to PLAUS condition. The direction as well as topography of the effect are therefore in line with canonical N400-effect (see Fig. 3.1). In line with the previous study (Westley et al., 2017), three central electrodes (C3, Cz, C4) from the cluster were used for analyses across the three sentence conditions.

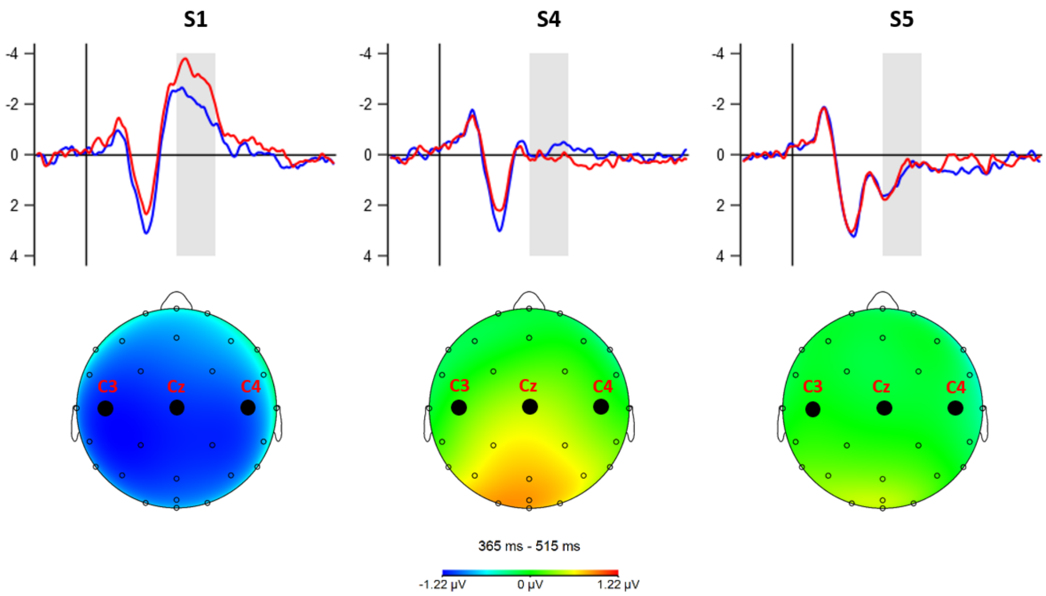

Figure 3.1. Event related potentials and average topographies from the analyzed window (grey region; 365-515 ms). Time courses depict average from three central channels (C3, Cz, C4) for PLAUS (blue) and IMPLAUS (red) conditions across three analysed sentences (S1, S4, S5). Y-axis represents amplitude in µV. The only significant difference between IMPLAUS and PLAUS can be seen at S1.

Differences in N400-effect across sentence conditions

Amplitudes from the three central electrodes were averaged across the interval defined by the N400-effect as observed at S1 (365-515 ms) for each of the six conditions (S1, S4, and S5, each for both PLAUS and IMPLAUS). These values were entered into a 3x2 repeated measures ANOVA with factors Sentence (S1, S4, S5) and Condition (PLAUS, IMPLAUS). The analysis showed a significant main effect of Sentence (F(2, 82) = 83.03, p < .001, η_p^2 = .70) as well as of Condition (F(1, 41) = 5.53, p = .024, η_p^2 = .12). The interaction of the two factors was significant as well (F(2, 82) = 8.35, p = .001, η_p^2 = .17). Paired t-tests comparing between the two levels of Condition at each level of Sentence revealed a significant difference between PLAUS and IMPLAUS on S1 (*M* = 1.13, *SEM* = 1.54; *t*(41) = 4.76, *p* < .001, *d* = .73), but not on S4 (*M* = -.27, *SEM* = 1.63; *t*(41) = -1.07, *p* > .1, *d = .17*) nor S5 (*M* = .07, *SEM* = 1.59; *t*(41) = .30, *p* > .1, *d = .05*).

Additional analysis of these data was conducted using a clustering approach, and is reported in Appendix 1. The aim of this analysis was to explore whether a subset of the sample shows the Social N400-effect, as this seemed to be the case based on visual inspection of the data. While the analysis shows evidence of a negative going signal deflection in a subset of the sample, there are several issues relating to whether such approach is appropriate for the present data and the research question.

Task Sharing

Further, the amplitudes from the 365-515 ms window were compared between the current experiment and a previous experiment which used a shared task (see Figure 3.2). Similarly to the above analysis, average amplitudes from the three central electrodes were entered in 3x2x2 mixed ANOVA with within subject factors Sentence (S1, S4, S5) and Plausibility (PLAUS, IMPLAUS), and a between subject factor Task (Shared, NotShared). The analysis revealed a significant main effects of Sentence (F(2, 112) = 84.96, p < .001, η_p^2 = .60), Plausibility (F(1, 56) = 40.53, p < .001, η_p^2 = .42) and Task (F(1, 56) = 7.95, p = .007, η_p^2 = .12); as well as an interaction of Sentence and Plausibility (F(2, 112) = 8.53, p < .001, η_p^2 = .13). Task showed a two-way interaction with both Sentence (F(2, 112) = 13.45, p < .001, η_p^2 = .19) and Plausibility (F(1, 56) = 24.05, p < .001, η_p^2 = .30). The three-way interaction of Task Sentence Plausibility was also significant (F(2, 112) = 3.30, p = .04, η_p^2 = .06).

To disentangle the three-way interaction, three independent samples comparisons were ran comparing the size of the N400-effect, estimated as the difference between PLAUS and IMPLAUS, between the two studies at each level of Sentence variable. Due to the unequal variances between the two groups, a non-parametric Mann-Whitney U Test was used. The p-values were Bonferroni corrected for 3 comparisons. The results show that the N400-effect was significantly smaller in NotShared compared to Shared condition at S1 (*Mdn Shared* = 3.57, *Mdn NotShared* = 1.06; U = 492.00, z = 2.71, p = .021, r = .36) as well as at S5 (*Mdn Shared* = 3.43, *Mdn NotShared* = -0.0012; U = 480.00, z = 2.51, p = .036, r = .33). There was no difference between NotShared and Shared conditions at S4 (*Mdn Shared* = 0.46, *Mdn NotShared* = -0.06; U = 399.00, z = 1.10, p > .1, r = .14).

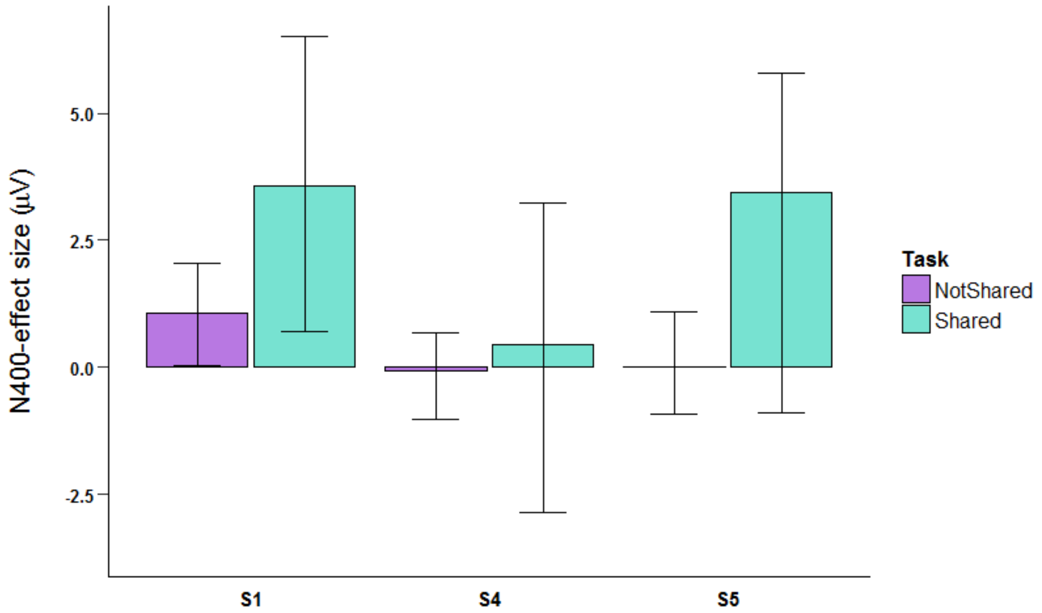

Figure 3.2. Median N400-effect size (error bars: Q1, Q3) for S1, S4 and S5 for NotShared and Shared task conditions. N400-effect size is calculated as the difference between the signal from PLAUS and IMPLAUS conditions from 365-515 ms time window. The data for NotShared condition come from the present study, while the data for Shared condition come from Westley et al. (2017) on an adolescent sample.

Individual differences

Next, the relationship between the amplitude of the signal at S5 and S1 and the measures of empathy (EQ, RMiE) and executive function (Stroop) was analysed. To do this, the difference between mean signal PLAUS and IMPLAUS conditions from 365-515 ms window at S1 and S5, respectively, was analysed against EQ score and Stroop effect in a correlation analysis using Pearson's correlation coefficient. In case of RMiE, the same analysis was conducted using Spearman's Rho since RMiE scores were not normally distributed, $D(41)$ = .14, p = .038.

The analysis revealed no significant correlation between EQ and either S1 (r = -.26, n = 42, p > .1) or S5 (r = -.03, n = 42, p > .1), and the same was the case for Stroop (S1: r = .13, n = 41, p > .1; S5: r = -.14, n = 41, p > .1). In case of RMiE, there was no significant correlation at S1 (r_s = -.16, n = 41, p > .1), and a marginally significant correlation at S5 (r_s = -.32, n = 41, p < .1).

Discussion

The present study aimed to test whether the previously observed marker of simulation of others' comprehension process, the Social N400-effect, is elicited regardless of the presence of a shared task. In other words, the study tried to elucidate whether simulation of a co-listener's mental states requires both attendees to participate in a joint action or whether simply jointly attending to the stimuli is sufficient. To explore this the paradigm from previous study on Social N400-effect (Westley et al., 2017) was adapted and slightly altered to fit the purposes of the present investigation. The main difference between the two experiments was that, in the present experiment, the co-listener was only passively reading the presented sentences, whereas in the previous experiment they were engaged in a shared task with the participant.

In line with the hypotheses and the previous study (Westley et al., 2017), the two baseline effects were replicated. When participants were reading the sentences alone, semantically anomalous sentences showed larger N400-effect compared to semantically plausible sentences (S1). This effect was completely attenuated as the discourse developed further (S4). More importantly, however, the Social N400-effect was not replicated in this experiment, as there was no difference between the signal for semantically implausible and plausible sentences read in presence of a co-listener (S5). Direct comparison with the data from the previous study also showed that the observed effect at S5 was significantly smaller compared to Westley et al. (2017). Consequently, the data suggest that in the absence of a shared task people do not simulate another's comprehension process.

The present result is in line with the literature on joint action as it has been previously shown that people represent actions of their co-attendees only if they are involved in a shared task (Sebanz et al., 2003; Tsai et al., 2006); therefore, the present experiment extends the previous studies on mental simulation of language comprehension (e.g., Rueschemeyer et al., 2015; Westley et al., 2017) by strengthening the link between joint comprehension and joint action, as it shows that these share another property: dependence on a shared task. It is thus possible to speculate that, at least to an extent, joint comprehension operates under similar rules as joint action. The results of the experiment then also seem to provide some validity to the common assumption that communication is a form of joint action.

Interestingly, the task performance showed ceiling effects suggesting that, although no evidence of mental simulation was found, the participants were still able to perform the task without any problems. On one hand, this may be due to the experimental task being relatively simple, and it seems possible that propositional rules, detached from embodied representation of another's mental states, could be used to infer the correct answers based solely on the analysis of the semantic plausibility of the sentences. On the other hand, this begs the question of causal significance of mental simulation in the process of making inferences about mental states of others. The lack of evidence of mental simulation accompanied by unimpaired performance seems to suggest that Social N400-effect could be an epiphenomenon, rather than a process necessary for consideration of others' mental states.

The lack of Social N400-effect accompanied by unimpaired performance seems to parallel the work on the role of mirror neurons in action understanding. It has been long assumed that these motor neurons, which show an increase in activity both when one performs an action and when they observe another performing an action (thus effectively simulating another's action), are crucial for action understanding (e.g., Rizzolatti & Craighero, 2004). Recently, this view has been contested on grounds of several lines of research showing that, for instance, damage to the regions of the mirror neuron system regions does not impair action understanding, or that there are actions that cannot be simulated, such as certain non-human species actions but can be readily understood; and several others (Hickok, 2009). Mahon & Caramazza (2008) instead suggest that action understanding can be achieved through more abstract, high level representations, while mirror neuron activity is either merely reflexive – based on association between action and motor system activity – or that it perhaps provides some enrichment to such higher-level processing. Turning back to the Social N400-effect, the pattern of the results seems to be similar, since lack of simulation does not seem to predict impaired performance. One could therefore speculate that the simulation phenomena, namely mirror neurons and Social N400-effect may generally have a less central role in understanding of other agents.

This suggests that, at least in paradigms such as the one presented currently, mentalizing may be better explained in terms of a more abstract, disembodied approach. This seems to be supported by the results of the fMRI study presented in Chapter 2, showing involvement of regions such as precuneus and medial prefrontal cortex in a similar task. These regions are activated across a variety of different mentalizing tasks (e.g., Aichhorn et al., 2009; Villarreal et al., 2012; Ma et al., 2011; Castelli et al., 2000; Gallagher et al.,

2002) suggesting they store high level abstract representations. In addition, they seem, at least roughly, to correspond to a subset of transmodal regions on the unimodal to transmodal cortical gradient (Margulies et al., 2016), which were suggested to be responsible for more abstract aspects of cognition. It then seems plausible to suggest that consideration of others' mental states relies primarily on abstract representations; with lower level, more domain-specific simulation of others' comprehension process having a more specific role (what exactly this role might be will be discussed in Chapter 6).

Conversely, there are a several limitations to the current experiment that might have influenced the results. First, in the previous experiments (Rueschemeyer et al., 2015; Westley et al., 2017; Jouravlev et al., 2018), the co-listener was always a native English speaker. In the present study, only about a third of the participants were paired with a native speaker, while the rest were paired with second language English speakers with detectable foreign accents (German, Iranian, and Slovak). It has been shown previously, using neuroimaging techniques, that when making social judgements, neural resources are utilized differently depending on how dissimilar the judged person is (Mitchell et al., 2005; Mitchell et al., 2006). Behavioural work also shows that people tend to project their mental states to similar others more often than to dissimilar others (Ames, 2004). It is therefore possible that the absence of Social N400-effect might be a result of increased dissimilarity of the co-listeners compared to the previous experiments, rather than an effect of the absence of a shared task. To fully elucidate that the observed absence of Social N400-effect was not an effect of increased co-listener dissimilarity, the present result needs to be replicated with native English co-listeners.

It is also worth noting that the comparison between the data from Westley et al. (2017), where the participants were engaged in a shared task, and the present data where the shared task was absent, may partly reflect a developmental change in the N400-effect amplitudes rather than effects of task sharing only. This is because, as mentioned previously, the current data come from an adult sample, while in the case of Westley et al. (2017) the sample were adolescents. As shown in previous developmental studies, the size of the N400-effect decreases with age (Holcomb et al., 1992; Cummings et al., 2008). This age difference seems to be present in the reported comparison as well, since the size of the canonical N400-effect was significantly smaller in the adult compared to the adolescent sample. While this does not invalidate the current conclusion, because the absence of a significant Social N400-effect was shown in the analysis of current data alone, it makes it somewhat difficult to disentangle the effect of the presence of shared task from the effect of age in the direct between-study comparison. Importantly, the absence of evidence of the Social N400-effect in the present study cannot be attributed to the age differences, since the effect was observed in adult samples previously (Rueschemeyer et al., 2015; Jouravlev et al., 2018). These previous studies, however, utilized a different experimental design not allowing for direct comparison with the present results.

The interpretability of the experiment, however, relies on the assumption that the canonical N400-effect is observed at S1. While this is true of both the current adult sample, as well as of the adolescent sample, and despite what was mentioned in the previous paragraph, the canonical N400-effect size may seem unusually small upon visual inspection of Figure 3.2. This impression may partially be a result of the fact that the figure depicts median together with Q1 and Q3, with the actual mean difference being above 1 microvolt and not as dispersed (*M* = 1.13, *SEM* = .24). The few studies that provide explicit information about the observed N400-effect size suggest that the size of the adult canonical N400-effect was not outside of the usual range, with for instance Filik & Leuthold (2008) reporting a reliable N400-effect of a size as small as 1.03 μV (and a slightly larger effect of 1.43 μV in a later study; Filik & Leuthold, 2013).

In addition, individual differences in terms of executive function and empathy were explored with relationship to Social N400-effect in the present study. The correlation analyses showed no significant effects (although, in the case of RMiE task this would be significant if not corrected for multiple comparisons). This may be simply due to the lack of a significant Social N400-effect in the present experiment, suggesting that even the participants with better executive function or empathic abilities were not more prone to show the effect in the absence of a shared task than the participants with smaller scores in these estimates. This suggests that absence of a shared task eliminates the Social N400-effect regardless of individual executive function or empathic abilities.

Overall, the present experiment does not show any evidence of simulation of others' comprehension process in absence of a shared task, as demonstrated by the lack of Social N400-effect. This suggests that joint comprehension operates under similar rules as joint action. The result of this study thus presents an empirical evidence for the long assumed relationship between language and joint action. However, the results also open the question of whether such simulation is truly a core mechanism utilized in pragmatic inference-making or merely an epiphenomenon. Further studies will be needed to elucidate this question.

Chapter 4

No evidence of mental simulation of lexical access

Abstract

Previous literature on simulation in non-language domains shows, across various paradigms, that people are able to simulate low level cognitive phenomena. However, in case of language communication this issue has not yet been explored, with previous studies showing evidence of mental simulation in language comprehension only at the high level of lexical integration within sentential context. In the present experiment a novel paradigm was constructed to test whether low level language phenomena can be simulated on an example of lexical access. In each trial participants were presented with single high and low frequency words, each presented first to them alone, followed by the presentation of the same word in the presence of a confederate unexposed to the first presentation of the word. The analysis of electrophysiological responses revealed the canonical word frequency N400-effect, with more negative signal deflection for low compared to high frequency words upon the first presentation of the words. This effect was not repeated upon the second presentation of the word in the presence of another listener. Therefore, the results do not provide evidence of mental simulation at the level of lexical access. Possible explanations for the absence of evidence of simulation are discussed, together with a proposal of an alternative paradigm that could help in providing of a more conclusive answer.

Introduction

Previous electrophysiological (e.g., Rueschemeyer et al., 2015; Westley et al., 2017), as well as fMRI evidence (Chapter 2) suggests that people simulate co-listener's comprehension process in triadic communicative contexts. This evidence, however, only demonstrates simulation at the level of lexical integration within a sentence context. This is a higher level phenomenon in the hierarchy of language comprehension processes and, as of yet, it remains unclear whether simulation also occurs at lower levels of this hierarchy. The present study aims to investigate whether simulation also occurs at lower levels, at an example of lexical access.

Language comprehension is ordinarily thought to proceed across several levels of representation roughly constituting a hierarchy. This hierarchy begins with pre-lexical stages of processing (e.g., phoneme and syllable level processing) followed by a lexical retrieval stage where meaning of an individual item is retrieved from memory and is then, at the highest level, integrated within the sentence and narrative context (e.g., Hickok & Poeppel, 2007; Hickok, 2012). While these different levels of representation have been extensively studied in the individual branches of linguistics and psycholinguistics, the recent literature on simulation of others' language processing has not yet sufficiently considered them.

The previous studies showing evidence of such simulation (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2), while using different imaging modalities and employing slightly different paradigms, only focus on one level of processing: lexical integration. In all three previous studies, participants were presented with a context sentence and a target sentence. In the critical condition, the target sentence was constructed in such way that it was semantically anomalous when presented in isolation, but was rendered meaningful in light of the context sentence. Critically, while participants were presented with both the context and the target sentences, the co-listener was presented with the target sentence only, therefore, the target sentence was anomalous for the co-listener but not for the participant. All three experiments suggest that, when this is the case, the participants processed the target sentence as if they were not exposed to the context sentence, that is, from the perspective of the co-listener. From the cognitive point of view, this can be interpreted as requiring inhibition of the context in order to process the target sentence in isolation. This in effect renders the target sentence's lexical items anomalous due to a lack of sensible context to be integrated with. While integration of a lexical item into a sentence context can be considered to be at a high level in the language processing hierarchy, it remains an open question whether simulation occurs at this more abstract level only, or whether it is an outcome of simulation at lower processing level, such as the level of lexical access.

There is some evidence in the previous literature on visuospatial perspective taking suggesting that mentalizing abilities can operate at simpler processing levels. For instance, a study of Frischen and colleagues (2009) demonstrated in a joint selective attention paradigm that people represent their co-actors' distractors – locations of certain colour on a computer screen – although these were irrelevant to their task. Similarly, a study of Böckler and colleagues (2011) showed that people take another's perspective during an object mental rotation task. The study showed that reaction times were reduced when an object required rotation at a large angle from their own perspective, but there was a co-actor present from whose perspective the angle was small (and vice versa if the angle was large for the co-actor; the reaction times increased although the angle was small for the participant), demonstrating that mental rotation of an object is a subject to perspective taking. In a somewhat different domain, number magnitude judgement, a similar picture arises (Surtees et al., 2016). In this experiment participants were seated opposite to a co-actor and were required to judge whether single numbers are larger of larger magnitude than 7 or not. The perspective for the co-actor was flipped and therefore certain numbers would require the opposite judgement from the alternative perspective (e.g., 6 appears as 9 when reversed). The study showed that the interpretation of the numbers from the co-actor's perspective interfered with the participant's judgement, suggesting they spontaneously adopted their perspective. Altogether, these studies and several others (e.g., Tversky & Hard, 2009; Kessler & Thomson, 2010; Griffiths & Tipper, 2012) show that even relatively lower level cognitive operations such as simple distractor inhibition, mental rotation of an object, or number magnitude judgement are subject to perspective taking abilities. This leaves the possibility that language information could also be processed at lower levels during perspective taking open.

The literature on dyadic verbal interactions also highlights pragmatic effects at lower processing levels. For example, the influential interactive-alignment account of conversation (Pickering & Garrod, 2004) suggests that interlocutors' mental representations align at all levels of processing, including the low levels. However, the account only describes this alignment as the result of a simple priming mechanism operating automatically. The authors propose that speakers are primed to use, for instance, similar referring expressions and syntactic structures because the interlocutor uses them. In other words, due to the nature of priming, certain semantic items or syntactic structures (and other constituents of language, e.g., morphemes) become more readily accessible. A somewhat similar idea can be found in the literature on so-called referential precedents, which are referring expressions established in the course of a conversation, implicitly agreed to by the interlocutors. It has been shown that if such precedents are broken and an alternative referring expression is used, listeners are quicker to adjust to the alternative expression if the precedent was broken by a novel speaker with whom it was not established (Kronmüller & Barr, 2007; 2015). Overall, the literature on dyadic verbal interactions shows that pragmatic effects at lower levels (e.g., reference resolution) can be achieved by simple mechanisms such as priming, or by consideration of the speaker's identity. Nevertheless, it is not possible to extrapolate these interactive approaches from the domain of dyadic interaction to the triadic contexts of the sort presented in the previous studies on simulation (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3). This is simply because in such contexts there is no direct interaction between the co-listeners.

The aim of the present study is to test whether mental simulation occurs at a lower level of linguistic processing: at the level of lexical access. To achieve this, a paradigm was devised utilizing, similarly to the previous electrophysiological studies on mental simulation at the sentence level (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 3), the N400-effect. Targeting the same event related potential may at first seem paradoxical since the target cognitive phenomenon was different from the previous studies. However, evidence shows that the N400-effect can index processing at multiple levels of language comprehension (Kutas & Federmeier, 2011), and even extends to the non-linguistic domains (e.g., Balconi & Caldiroli, 2011), showing that the effect is of a more general nature. In the previous experiments on simulation, the N400-effect was used as an index of semantic anomalousness, since this potential shows a more negative deflection for words semantically anomalous within the context of a sentence (e.g., 'the boy had gills') compared to semantically plausible words (e.g, 'the boy had toys'). In the present case, the effect was used as an index of lexical access difficulty due to its sensitivity to the frequency of word usage. The frequency N400-effect shows more negative signal deflection for low frequency words, compared to high frequency words (Rugg, 1990; Van Petten & Kutas, 1990). Since word frequency effects are in behavioural research usually assumed to reflect lexical access (e.g., Rubenstein et al., 1970; Segui et al., 1982), the frequency N400-effect can be thought of as reflecting lexical access level of processing as well (Lau et al., 2008); especially when no additional context allowing lexical integration level processing is present.

In this study, participants were presented with series of high and low frequency words, with each word presented to them alone first, followed immediately by presentation of the same word, either in the presence of a co-attendee, or alone again. As a baseline hypothesis, it was predicted that upon the first presentation of the word, during which the participant was alone, a classical frequency N400-effect would be observed. More crucially, it was predicted that if mental simulation of others' comprehension process operates at multiple levels, for the second presentation of the words in the presence of a co-attendee, this effect would be observed as well. These hypotheses were tested across two experiments. In Experiment 1, the participants did not know in advance whether the co-attendee would be presented with the word or not; in Experiment 2, they were informed about this in advance in every trial.

Experiment 1

Methods

Participants

Twenty-five participants (*Age M* = 20.9, *SD* = 1.6; 19 females) were recruited through the Department of Psychology at the University of York. Each participant was paired with a confederate who was a member of the experimental team. All participants and confederates were native English speakers. The study was approved by the ethics committee of the Department of Psychology, University of York. All participants provided informed consent before participating in the experiment.

Stimuli

A set of 240 single high frequency (HF) and low frequency (LF) words, 120 for each frequency group, was sampled from an online Corpus of Contemporary American English (www.wordfrequency.info). The HF group consisted of commonly occurring words such as 'family' or 'tool', while the LF group consisted of less common words such as 'burrow' or 'yarn'. An independent samples t-test showed that the difference between mean corpus frequency of the words in HF group (M = 5647.89, SD = 55758.59, range: 15877 - 470401) and LF group (M = 794.16, SD = 253.65, range: 114 - 1353) was significant, $t(119.005) = 10.94$, $p < .001$, $d = 2.02$. The two frequency groups were also matched for word length, with the average word length being 5.6 letters.

Procedure

Participants were seated in front of a computer screen, facing the centre of the screen. To their right side a co-attendee was seated. The co-attendee pretended to be another participant, unfamiliar with the experiment. While the co-attendee was looking at the screen from an angle, they could still see it clearly. The experiment began with a short practice run; the responses from this run were not registered. The practice run was followed by the experimental run.

There were three experimental conditions (see Figure 4.1), with two of these serving as a control. Trials in all three conditions were structured around two temporal segments: the initial part (T1) that did not vary across the conditions, and the later part (T2) that varied across the conditions. In all conditions, the co-attendee was first instructed to close their eyes and to cover their face with their hands so that it was ostensive that they could not see. The participant then pressed a button and the trial began. Following the button press, an empty screen was presented for 200 ms, followed by presentation of HF or LF word for 1500 ms (T1). From this point on the three conditions varied:

1. In Open eyes condition (OPEN), the word stayed on the screen for another 2000 ms (T2), while a 600 Hz sine tone was presented during the first 250 ms of this period instructing the co-attendee to open their eyes.

2. In Control condition 1 (Control1), the word stayed on the screen for another 2000 ms (T2), while a 300 Hz sine tone was presented during the first 250 ms of this period instructing the co-attendee to keep their eyes closed.

3. In Control condition 2 (Control2), following T1, the word disappeared and was replaced by a mask ('####') for 500 ms. After this the word re-appeared for another 2000 ms (T2), while 300 Hz sine tone was presented for the first 250 ms of this period instructing the co-attendee to keep their eyes closed.

There were 240 experimental trials in total, with 80 trials for each of the three conditions (i.e. OPEN, Control1, Control2). Half of the words presented in each condition were LF words while the other half were HF words.

To keep the participants engaged in reading, 24 'catch' trials were added, 8 per experimental condition. In these trials, presentation of a word was followed by a forced yes/no question about the meaning of the preceding word (e.g. 'hamster' was followed by 'Was the previous word something furry?'). Both the participant and the co-attendee had to answer these before moving to the next trial. The responses were made by pressing a button and the performance was calculated as the sum of correctly answered questions. Since the frequency of these words was not considered when constructing these 'catch' trials, the signal from these was not considered in the EEG analysis.

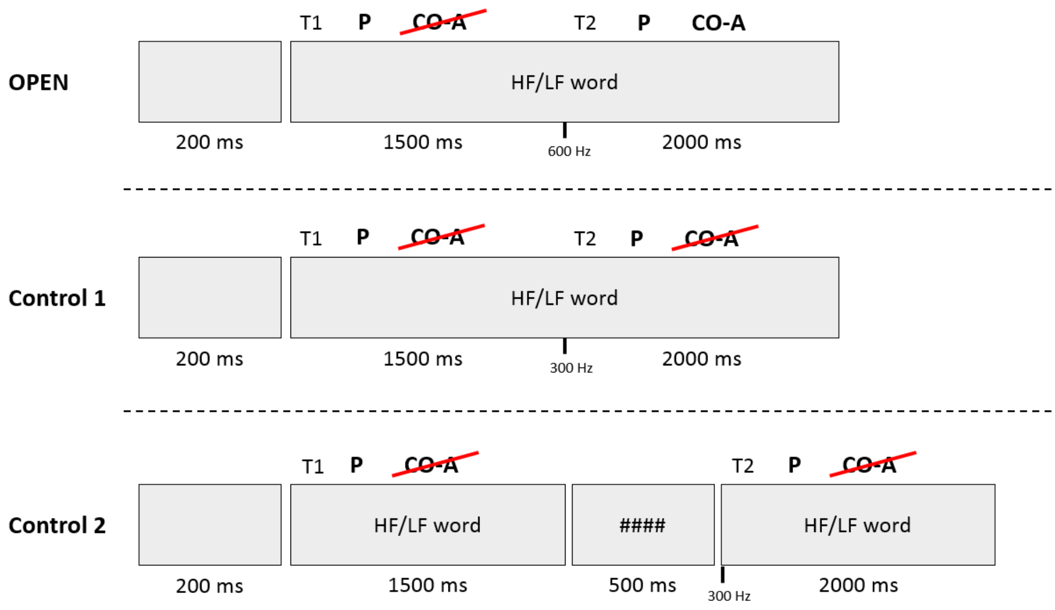

Figure 4.1 Experimental trial scheme in OPEN, Control 1, and Control 2 conditions. P - Participant, CO-A co-attendee. Crossed CO-As indicate segments when co-attendees had their eyes closed.

The trials were presented in a pseudo-randomized order in such way that no more than two trials from the same condition or three trials with a word from the same frequency group would be presented consecutively. The 'catch' trials were interspersed throughout the entire experimental run. The experiment was scripted and presented using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com).

EEG recording

Continuous EEG was recorded using 32-channels placed in a five percent electrode system montage (recording reference = left mastoid, ground = forehead, VEOG and HEOG included, electrode impedances < 10 kΩ). The signal was pre-processed using Brain Vision Analyzer (re-reference to average of mastoids, segmentation = -200 to + 1000 ms around target word onset, baseline correction = -200 ms, ocular ICA (Infomax), semi-automatic artefact rejection for eye movements, electrode drifting and EMG artefacts). In total 9.3 % (*SD* = 6.2 %) of the data was discarded. The percentage of trials excluded per condition excluded was OPEN_T1_HF: *M* = 9.3, *SD* = 6.3 ; OPEN_T1_LF:

M = 9.3, *SD* = 6.2 ; OPEN_T2_HF: *M* = 7.7, *SD* = 5.4 ; OPEN_T2_LF: *M* = 8.6, *SD* = 5.3 ; Control1_T1_HF: *M* = 9.1, *SD* = 6.7 ; Control1_T1_LF: *M* = 11.6, *SD* = 8.4 ; Control1_T2_HF: *M* = 8.3, *SD* = 5.6 ; Control1_T2_LF: *M* = 8.6, *SD* = 5.7 ; Control2_T1_HF: *M* = 10.8, *SD* = 6.7 ; Control2_T1_LF: *M* = 8.6, *SD* = 5 ; Control2_T2_HF: *M* = 9.9, *SD* = 5.5 ; Control2_T2_LF: *M* = 9.2, *SD* = 5.4.

Data analysis

In line with the previous literature (e.g. Elston-Güttle & Friederici, 2007; Debruille et al., 2008; Filik & Leuthold, 2008), the amplitude of the N400-effect was estimated by averaging the signal from 350-550 ms post stimulus-onset window across the average of three central channels C3, Cz, and C4. For OPEN and Control1 conditions, the stimulus-onset for T2 was considered the onset of the sounds indicating the co-attendee to either open their eyes or not.

The reason to use an a priori determined analysis window rather than determining it using a permutation test as in Chapter 3 is that using the permutation method to estimate the N400-effect window from T1 would either: a) very likely result in three different analysis windows if analysis window for T2 in each condition would be determined by the permutation test at T1 in the respective condition, or, to avoid this, b) the T1 signal from the three conditions would have to be pooled. A priori window was therefore used because it results in the same analysis window across the conditions while allowing the signal from T1 to be analysed separately for each condition, which is important in order to establish that the baseline effect was present at T1 in all conditions.

Mean amplitudes were then entered into a 3x2x2 repeated measures ANOVA with factors Social (OPEN, Control1, Control2), Frequency (HF, LF), and Time (T1, T2).

Results

The results from the catch trials showed ceiling performance with participants correctly answering on average 23 out of the 24 questions (*SD* = .7).

Averaged signal from C3, Cz, and C4 electrodes was entered into 3-way 3x2x2 repeated measures ANOVA with factors Social (OPEN, Control1, Control2), Frequency (HF, LF), and Time (T1, T2). The descriptive statistics for each level of the three factors are reported in Table 4.1; the time series are depicted in Figure 4.2. The analysis revealed significant main effect of Social, $F(2, 48) = 5.30$, $p = .008$, $\eta_p^2 = .181$, and Frequency, $F(1, 24) = 12.79$, $p = .002$, $\eta_p^2 = .35$, but not of Time, $F(1, 24) = .73$, $p = .40$, $\eta_p^2 = .03$.

In addition, there was a significant interaction of Time and Frequency, $F(1, 24) = 10.48$, $p = .004$, $\eta_p^2 = .30$, indicating different effects of Frequency at T1 and T2, as well as a significant interaction of Social and Time, $F(2, 48) = 4.41$, $p = .017$, $\eta_p^2 = .16$. The other two interactions, Social*Frequency and Social*Frequency*Time were not significant, *Fs* < .7, *ps* > .5.

	Mean	SEM		Mean	SEM		Mean	SEM
OPEN_HF_T1	-1.80	0.71	C1_HF_T1	-1.76	0.70	C2_HF_T1	-2.08	0.66
OPEN_LF_T1	-3.20	0.70	C1_LF_T1	-3.02	0.76	C2_LF_T1	-3.26	0.77
OPEN_HF_T2	-0.85	0.41	C1_HF_T2	-2.05	0.47	C2_HF_T2	-2.47	0.61
OPEN_LF_T2	-0.79	0.46	C1_LF_T2	-1.99	0.38	C2_LF_T2	-3.07	0.57

Table 4.1. Mean (±SEM) signal amplitude (in µV) from 350-550 ms window across the three analysed factors. OPEN - Open eyes condition, C1 – Control1, C2 – Control2, HF - high frequency, LF - low frequency, T1 - time 1, T2 - time 2.

To resolve the significant interaction of Time and Frequency, two paired sample t-tests comparing the effect of Frequency at T1 and T2 separately were ran (Bonferroni corrected for 2 comparisons). These revealed a significant difference at T1, with LF words showing more negative signal deflection compared to HF words ($M = 1.28$, $SEM = .31$), $t(24) = 4.16$, $p < .001$, $d = .83$, but no significant difference at T2 ($M = .16$, $SEM = .22$), $t(24) = .74$, $p = .93$, $d = .15$.

To examine the interaction of Social and Time, two 1-way repeated measures ANOVAs with factor Social (OPEN, Control1, Control2) were ran for T1 and T2 separately. At T1, there was no effect of Social, $F(2, 48) = .59$, $p = .56$, $\eta_p^2 = .03$, but at T2, the effect of Social was significant, $F(2, 48) = 5.73$, $p = .006$, $\eta_p^2 = .19$. Three paired sample t-tests (Bonferroni corrected for 3 comparisons) comparing signal between all pairs of conditions indicates that signal in OPEN condition was significantly more positive in comparison to Control1 ($M = 1.20$, $SEM = .22$, $t(24) = 5.45$, $p < .001$, $d = 1.09$) as well as Control2 ($M = 1.95$, $SEM = .68$, $t(24) = 2.86$, $p = .024$, $d = .57$). There was no significant difference between Control1 and Control2 ($M = .75$, $SEM = .71$, $t(24) = 1.06$, $p = .90$, $d =$

.21). This difference is attributable to the fact a tone of different frequency was presented in the OPEN condition (600 Hz) compared to the two control conditions (300 Hz).

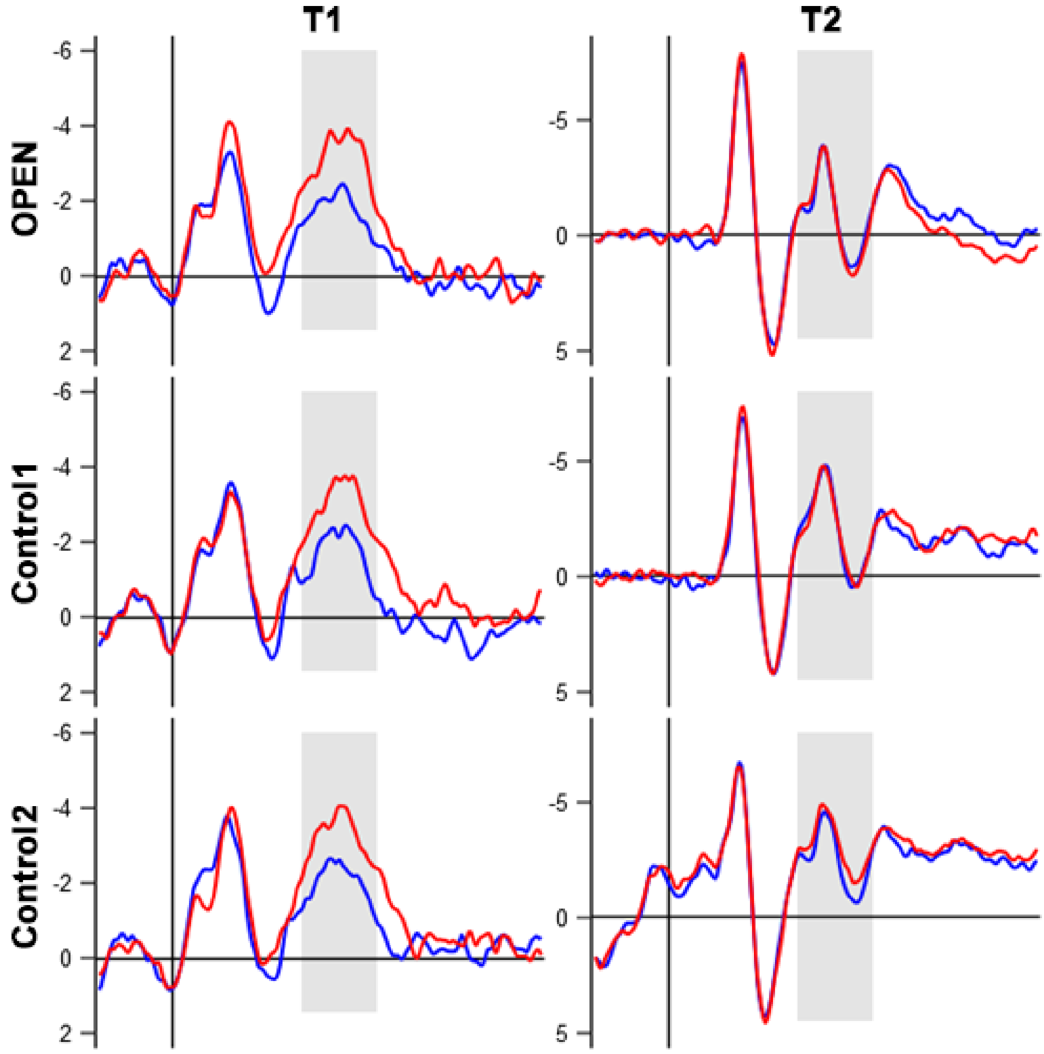

Figure 4.2 Event related potentials from Experiment 1. Each row depicts data from one Social condition (OPEN, Control1, Control2, respectively). The signal at T1 is depicted on the left side and at T2 on the right side. Significant difference between low (red) and high (blue) frequency words has only been observed at T1 in all three conditions, but in neither condition at T2. Gray region depicts the analysis window (350-550 ms). Y-axis represents signal amplitude in µV.

Interim discussion

In line with the predictions, the N400-effect was observed at T1 regardless of Social condition. However, contrary to the main hypothesis, no evidence of an N400-effect was observed at T2 regardless of whether the words were presented in presence of a co-attendee (i.e., in OPEN condition), or not (i.e., in Control1, and Control2 conditions). One reason for the effect to be lacking in OPEN condition at T2 might be that the participants did not know in advance whether the confederate would be prompted to open their eyes or not. Since there is evidence that perspective taking is an executively demanding process (Brown-Schmidt, 2009b) and it may not always be employed immediately after receiving the stimulus (Keysar et al., 2000), it is possible that the comprehension system was not 'simulation ready' on such short notice. To account for this issue, a follow up experiment was devised adjusting for it. In Experiment 2, an instruction screen was presented between the first and the second presentation of the word, prompting the participant to tell the co-attendee to open their eyes or to keep them closed. Therefore, similarly to the previous Social N400 experiments (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 3), the participant knew in advance whether the confederate would see the following stimulus or not. No other substantial changes were made to the experimental design. The hypotheses were the same as in Experiment 1: a) as a baseline measure, it was expected that upon the first, alone, presentation of the word the frequency N400 effect would be observed, b) as the main hypothesis it was predicted that the N400 effect would also be observed upon the second presentation of the word in presence of co-attendee.

Experiment 2

Methods

Participants

Twenty-three participants (*Age M* = 21.9, *SD* = 1.9; 15 females) were recruited through the Department of Psychology at the University of York. Each participant was paired with a confederate who was either a member of the experimental team, or an unrelated person recruited ad hoc. All participants and confederates were native English speakers. The study was approved by the ethics committee of the Department of Psychology, University of York. All participants provided informed consent before participating in the experiment.

Stimuli

The same set of 240 HF and LF words that was sampled for Experiment 1 was used.

Procedure

The experimental setup was identical to Experiment 1; nonetheless, the experiments differed in the experimental design.

There were two experimental conditions (see Figure 4.3), one of them serving as a control condition. Similarly to the first experiment, the trials were structured around two temporal segments: the initial part that was the same in both conditions (T1), and the later part that varied between the conditions (T2). In both conditions, the co-attendee was first instructed to close their eyes and to cover their face with their hands. After the participant made sure the co-attendee had their eyes closed, they pressed a button and the trial began. Subsequent to the button press, an empty screen was displayed for 200 ms, followed by presentation of a single HF or LF word to the centre of the screen for 1000 ms (T1). After this blank screen was presented for another 200 ms. At this point, the two experimental conditions diverged in this way:

1. In the Open eyes condition (OPEN), a screen with the phrase “OPEN EYES” was presented to the centre of the screen. Upon seeing this, participants instructed the co-attendee to open their eyes. The trial then continued after a button press once the participant made sure the co-attendee had their eyes open. An empty screen was presented first for 500 ms, followed by a presentation of a HF or LF word for 1000 ms (T2). The word presented at T2 was always the same word as the one presented at T1.

2. In the Closed eyes condition (CLOSED), a screen with the phrase “KEEP CLOSED” was presented to the centre of the screen. Upon seeing this, participants followed to the next part of the trial by a button press, leaving the co-attendee with their eyes closed. An empty screen was then presented for 1500 ms. The empty screen was presented for one second longer than in OPEN condition in order to keep the interval between presentation of T1 and T2 roughly equal. The reason for this is that it was calculated, when constructing and testing the experimental script, that the time it takes for a participant to instruct the co-attendee and for the co-attendee to open their eyes is around 1 second on average. The empty screen was followed by a presentation of HF or LF word for 1000 ms (T2). The word presented at T2 was always the same word as the one presented at T1.

It total, there were 240 experimental trials, with 120 trials for each of the two conditions (i.e., OPEN, CLOSED). Half of the words presented in each condition were LF words while the other half were HF words. The number of trials per condition was higher than in Experiment 1 simply because the same set of words was presented across two instead of three conditions.

Similarly to Experiment 1, participants were presented with 24 ‘catch’ trials, 12 per experimental condition. The items used were the same as in Experiment 1, and the signal from these was not considered in the EEG data analysis.

The trials were presented in a pseudo-randomized order, in such way that no more than three trials from the same condition or with a word from the same frequency group, would be presented consecutively. The ‘catch’ trials were interspersed throughout the entire experimental run. The experiment was scripted and presented using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com).

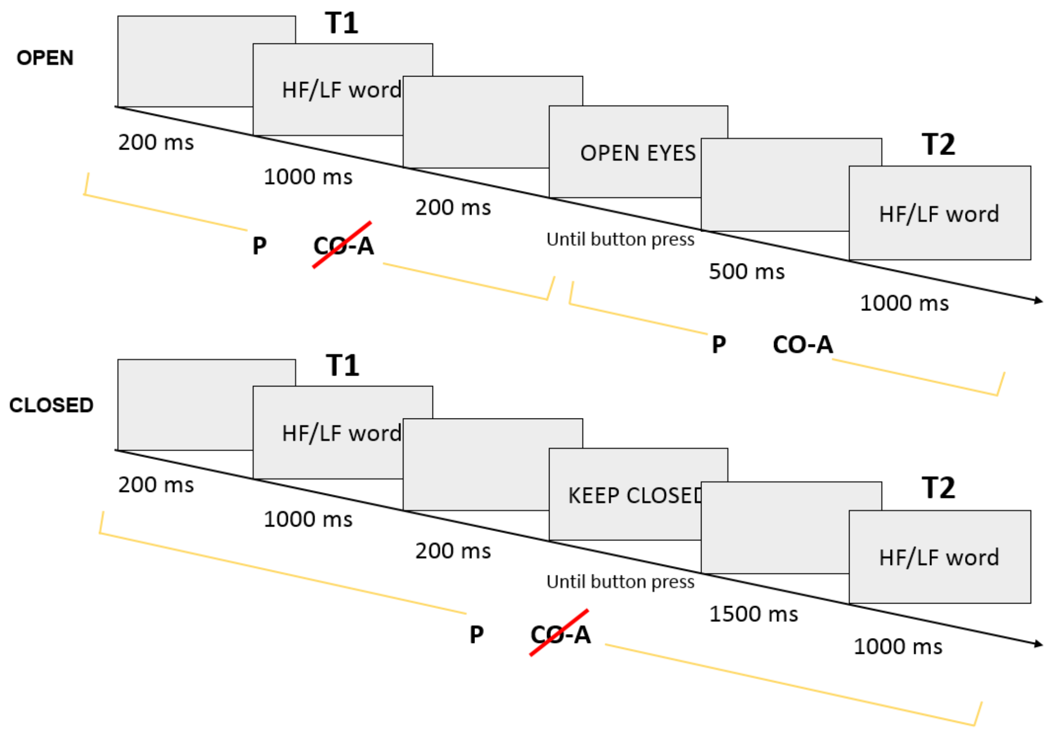

Figure 4.3. Experimental trial scheme in OPEN and CLOSED conditions. P - Participant, CO-A confederate. Crossed CO-As indicate segments when co-attendees had their eyes closed.

EEG recording

Continuous EEG was recorded using 32-channels placed in a five percent electrode system montage (recording reference = left mastoid, ground = forehead, VEOG and HEOG included, electrode impedances < 10 kΩ). The signal was pre-processed using Brain Vision Analyzer (re-reference to average of mastoids, segmentation = -200 to + 1000 ms around target word onset, baseline correction = -200 ms, semi-automatic artefact rejection for eye movements, electrode drifting and EMG artefacts). Data from 5 participants were excluded – from one participant, they were excluded due to a recording issue; for the additional four it was due to a large amount of blinking and skin potential artefacts (more than 50% of trials excluded). For the remaining 18 subjects 22.0 % (*SD* = 9.2 %) of the data was discarded. The percentage of trials excluded per condition was: OPEN_HF_T1: *M* = 26.4, *SD* = 10; OPEN_HF_T2: *M* = 21.8, *SD* = 10.5; OPEN_LF_T1: *M* = 23.4, *SD* = 8.7; OPEN_LF_T2: *M* = 20.6, *SD* = 8.5; CLOSED_HF_T1: *M* = 21.7, *SD* = 9.7; CLOSED_HF_T2: *M* = 20.5, *SD* = 6.9; CLOSED_LF_T1: *M* = 22, *SD* = 9.0; CLOSED_LF_T2: *M* = 19.7, *SD* = 7.2.

Data analysis

Similarly to Experiment 1, the amplitude of the N400-effect was estimated by averaging the signal from 350-550 ms post stimulus-onset window across the average of three central channels C3, Cz, and C4. Mean amplitudes were then entered into a 2x2x2 repeated measures ANOVA with factors Social (OPEN, CLOSED), Frequency (HF, LF), and Time (T1, T2).

Results

The results from the catch trials showed ceiling performance with participants correctly answering on average 22.7 out of the 24 questions (*SD* = 1.2).

	Mean	SEM		Mean	SEM
OPEN_HF_T1	-3.33	0.62	CLOSED_HF_T1	-3.51	0.80
OPEN_LF_T1	-4.47	0.78	CLOSED_LF_T1	-4.53	0.81
OPEN_HF_T2	0.75	0.63	CLOSED_HF_T2	1.34	0.56
OPEN_LF_T2	0.55	0.68	CLOSED_LF_T2	1.04	0.46

Table 4.2. Mean (±SEM) signal amplitude (in μV) across the three analysed factors. OPEN - open eyes condition, CLOSED - closed eyes condition, HF - high frequency, LF - low frequency, T1 - time 1, T2 - time 2.

Averaged signal from C3, Cz, and C4 electrodes was entered into 3-way 2x2x2 repeated measures ANOVA with factors Social (OPEN, CLOSED), Frequency (HF, LF), and Time (T1, T2). The descriptive statistics for each level of the three factors are reported in Table 4.2; the time series are depicted in Figure 4.4. The analysis revealed significant main effect of Frequency $F(1, 17) = 10.95$, $p = .004$, $\eta_p^2 = .39$, and Time $F(1, 17) = 44.93$, $p < .001$, $\eta_p^2 = .73$. There was no main effect of Social, $F(1, 17) = .30$, $p = .59$, $\eta_p^2 = .02$.

In addition, there was a significant interaction of Time and Frequency, $F(1, 17) = 5.50$, $p = .031$, $\eta_p^2 = .24$, indicating different effects of frequency at T1 and T2. No other interaction was significant (*ps* > .3). To examine the interaction of Time and Frequency, two paired t-tests were conducted, testing for the effect of Frequency at T1 and T2 separately (Bonferroni corrected for 2 comparisons). This revealed a significantly more negative signal for LF compared to HF at T1, $t(17) = 4.07$, $p = .002$, $d = 0.96$, but no difference at T2, $t(17) = .90$, $p = .76$, $d = .21$.

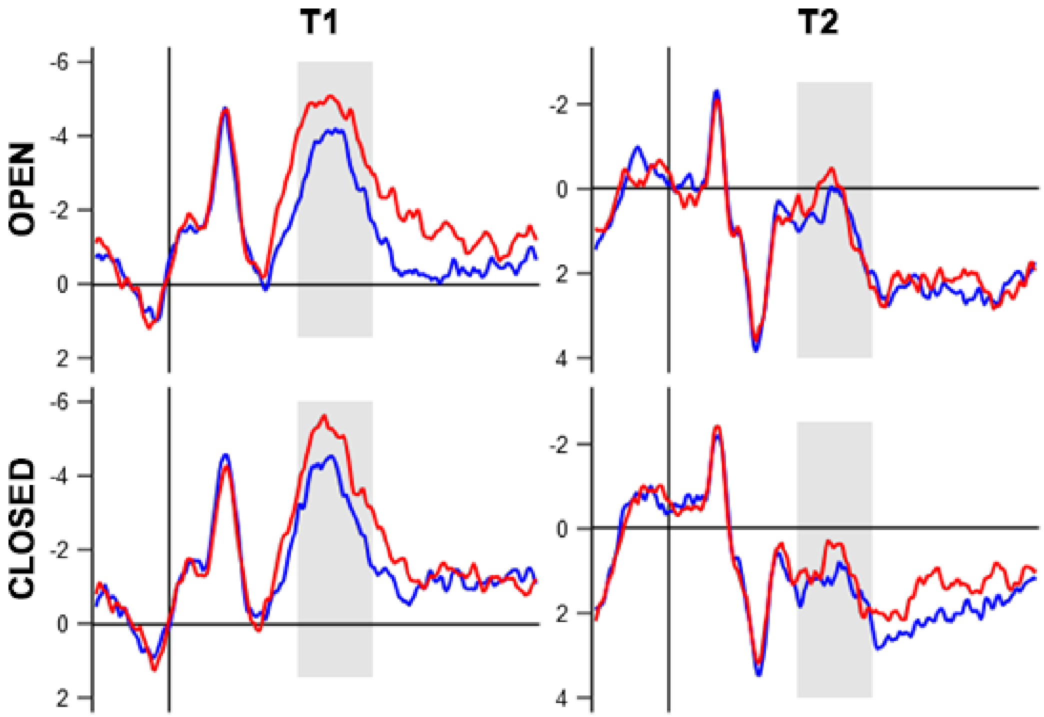

Figure 4.4 Event related potentials from Experiment 2. The top row depicts data from OPEN Social condition, the bottom row from CLOSED Social condition. The signal at T1 is depicted on the left side and at T2 on the right side. Significant difference between low (red) and high (blue) frequency words has only been observed at T1 in both conditions, but in neither condition at T2. Gray region depicts the analysis window (350-550 ms). Y-axis represents signal amplitude in μV.

Discussion

The aim of the present study was to investigate whether simulation of another's comprehension process occurs at the level of lexical access. This is because, while the previous studies showed evidence of such simulation, it was restricted to the level of lexical integration (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3). To test this, a paradigm was devised utilizing sensitivity of the N400-effect to word frequency (Rugg, 1990; Van Petten & Kutas, 1990). Participants were presented with series of single low and high frequency words. Each word was first presented to the participants alone, followed immediately by presentation of the same word to the participant as well as to a nearby seated co-attendee. In line with the baseline hypothesis, the frequency N400-effect, where low frequency words elicit more negative N400 compared to high frequency word, was replicated for the initial alone presentation on the words. However, upon the second presentation of the words, in the presence of a co-attendee, there was no evidence of the N400-effect. This indicates that simulation does not occur at the level of lexical access, at least in the given scenario. The same result was observed regardless of whether the participant knew in advance if the co-attendee would be presented with word upon the second presentation (Experiment 2) or not (Experiment 1). Consequently, the absence of the hypothesized effect was not modulated by the hypothesized need to adjust the comprehension system prior to simulation. The results are discussed below.

The absence of evidence of simulation observed in the current study indicates that simulation of co-attendee’s comprehension process in triadic communicative contexts does not occur on the level of lexical access, but, as shown in the previous experiments (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3), only on the level of lexical integration. This is somewhat at odds with the research on dyadic interactions (Pickering & Garrod, 2004; Kronmüller & Barr, 2007; 2015), where pragmatic effects were shown to operate at lower levels of processing. This literature shows that people can align their mental representations with their interlocutors so that they for instance adopt and use the same referring expressions, grammatical structures or phonological representations (Pickering & Garrod, 2004); or that people can couple specific referring expressions with specific interlocutors (Kronmüller & Barr, 2007; 2015). These studies, however, pronounce that such effects are either a result of simple priming mechanisms (Pickering & Garrod, 2004), or at least do not base these effect on explicitly outlined cognitive processes such as simulation (Kronmüller & Barr, 2007; 2015). Thus, there seems to be a difference between the cognitive mechanism proposed to underlie such low level pragmatic effects in the mentioned literature and the one tested in the present study. This is because simulation of another’s language processing is presumably a more complicated cognitive process that simple priming or coupling of a speaker with use of certain expressions. It is then possible that while low level pragmatic effects may be achievable by such simple mechanisms, simulation does not operate at such low levels of language processing.

On the other hand, the literature from non-linguistic domains presents evidence of perspective taking at lower levels of processing that could be more readily interpreted in terms of simulation (e.g., Frischen et al., 2009; Böckler et al., 2011; Surtees et al., 2016). This is because these experiments suggest that people consider lower level aspects of the surrounding environment from another's perspective. For example, the studies show they take into account the spatial locations that constitute a distractor for another, although these locations are not a distractor for themselves (Frischen et al., 2009), or that the angle of rotation of an object from another's perspective interferes with mental rotation from their own perspective (Böckler et al., 2011). These effects can be taken to suggest that people model the environment from another's perspective at lower levels of processing. There are, however, several possible reasons why this was not the case in the present study.

The first reason why an effect of simulation might not have been observed relates to the lack of novelty of the words at the time when simulation was hypothesized to occur: in both current experiments, every word was first presented to the participant alone, followed by a repeated presentation of the same word in presence of a co-attendee (i.e., every item was presented at two times, T1 and T2). It is presumable that each lexical item was accessed and retrieved upon the first presentation of the word (i.e., at T1), as demonstrated by the presence of the canonical frequency N400-effect. The lack of such N400-effect upon the repeated presentation of the word (i.e., T2) is in line with the previous literature showing reduction and disappearance of frequency effects for repeated words (e.g., Forster & Davis, 1984; Kinoshita, 1995; Rugg, 1990). It suggests that lexical item accessed and retrieved nearly immediately before was not considered anew again, simply because it was already processed from the participant's egocentric perspective. It is important to note that such lack of novelty of the stimulus at the time when it is presented to the co-attendee was not present in the previous EEG studies on simulation (e.g., Rueschemeyer et al., 2015; Westley et al., 2017), as in these the critical item was always novel for both the co-attendee and the participant at the time when the effect of simulation was observed.

The second possible reason for the absence of an effect of simulation stems from another difference between the current study and the previous experiments on simulation (e.g., Rueschemeyer et al., 2015; Westley et al., 2017). In all these experiments, participants were in each trial engaged in a task that explicitly required them to focus on the mental states of the co-attendee, that is, in each trial they were probed about whether they thought the stimulus was comprehensible from the co-attendee's perspective or not. Although in the present case both the participant and the co-attendee were engaged in a joint task, there was no explicit incentive for them to focus on one another's mental states. Since the evidence from Chapter 3 suggests that it might be the joint commitment to a shared task that is the crucial factor determining whether another's comprehension is simulated or not, absence of an explicit mental state task may not be an issue. This is corroborated by the fact that, in the previously mentioned non-linguistic experiments on perspective taking at lower processing levels, the effects of perspective taking were observed while no such explicit mental state task was present either (e.g., Frischen et al., 2009; Böckler et al., 2011; Surtees et al., 2016).

Finally, and more speculatively, simulation of language processing from another's perspective may not occur for phenomena such as the one explored in the present study due to the usual lack of conscious access to the to-be simulated aspect of the stimuli (word frequency) or the cognitive operation (lexical access) from the egocentric perspective. In other words, when listening to continuous speech or reading a coherent text, one does not consciously realize the frequency of use of every word; neither does one focus their attention on the process of accessing the meaning of each word. There are exceptions to this, for instance, upon encountering an archaic word, one may realize that it is a low frequency word, but it seems plausible to suggest that these are fairly rare. This is at odds with the previous studies on simulation (e.g., Rueschemeyer et al., 2015; Westley et al., 2017) where the target phenomenon, semantic incongruence, was a phenomenon that ordinarily is consciously realized, that is, one is usually conscious of a sentence being semantically anomalous. Similarly, in the mentioned studies on perspective taking in non-linguistic domains, the aspects of the stimuli that were shown to be considered from another's perspective, such as spatial locations serving as task targets and distractors (Frischen et al., 2009) or cognitive operations such as mental rotation (Böckler et al., 2011), are ordinarily consciously accessed; therefore, one can suggest that perspective taking was observed in the previous studies because of the target phenomena being ordinarily accessed from the egocentric perspective, and consequently participants being able to consider them from another's perspective as well, while in the present study the opposite was the case.

Due to the novelty issue, the results of the present experiment call for further investigation into the simulation at the level of lexical access in order to validate the present conclusion. An alternative paradigm can be proposed, utilizing a previously observed interaction between lexical and sentence processing levels on the N400-effect, showing that sentence context can supersede lexical level processing effects such as word frequency effects (Van Petten & Kutas, 1990; Van Petten & Kutas, 1991; Van Petten, 1993; Kutas & Federmeier, 2011). This means that two plausible sentences, one containing a high frequency word and the other containing a low frequency word – for example ‘The man dined with his family’ and ‘The rabbit was hiding in a burrow’ –, if compared, should not elicit a frequency N400-effect at the position of the final word. To extend this to the domain of perspective taking, an experimental set up can be introduced where the participant would be presented with such sentence, while a nearby seated co-attendee would be presented with the sentence-final word only. If people simulate others’ processing at the level of lexical access, then in the presence of such co-attendee the frequency N400-effect should not be superseded by the sentence context, that is, the frequency N400-effect should be observed at the position of the sentence-final words.

In summary, the present study failed to provide any evidence of simulation of the co-attendee’s lexical access in triadic verbal communicative contexts. This seems to imply, in conjunction with the previous experiments on simulation, that language is simulated only at the higher level of lexical integration. However, due to a possible influence of the lack of stimulus novelty in the conditions of interest mentioned above, further experiments are required in order to determine the validity of the present results.

Chapter 5

Presence of an active co-attendee increases privileged ground priming effects

Abstract

The present study aimed to explore, utilizing the phenomenon of lexical ambiguity, how different perspective of another listener influences one's language processing. In a behavioural experiment, participants were presented with prime-target word pairs consisting of an ambiguous prime word and unambiguous target word (e.g., "bank" – "river"). These were, in the critical condition, preceded by a context sentence priming incongruous interpretation of the ambiguous word (e.g., "He deposited his monthly wage at the local bank.", priming the interpretation of the word "bank" as a financial institution). The stimuli were presented either to the participant alone, or in the presence of a co-listener, who did not have an access to the context sentence. The task was for both to judge whether the words in the prime-target pairs were semantically related or not. The analysis of responses showed that in presence of a co-listener, participants judged related word pairs as unrelated more often compared to when conducting the task alone. Therefore, the incongruous context sentences had greater effect on the relatedness judgements when the task was conducted with a co-listener. This result suggests that, at least under some conditions, the presence of a co-listener with a different perspective can result in an increased focus on the private information, compared to commonly observed increased focus on the shared information. The results are interpreted with respect to the private information having more potential to be relevant in future exchanges between the listeners, compared to the shared information.

Introduction

Previous literature shows that people consider information about others' perspectives during language processing and that this may result in changes in the way shared language input is processed (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3). Although the previous chapter suggests that these effects occur only at a higher level of language processing, the finding is not well generalizable as the positive evidence for such changes comes from studies manipulating semantic plausibility only. The purpose of the present behavioural study is to investigate whether processing of shared language input is altered in a joint setting using another higher level aspect of language processing: context-based lexical ambiguity resolution.

Lexical ambiguity is a natural language phenomenon where a word has two or more possible interpretations (e.g., MacGregor et al., 2015). This phenomenon seems to be rather common, with as many as 84 % words with frequency larger than 10 per million having more than one dictionary entry (Rodd et al., 2002). One of the ways in which lexical ambiguities are resolved is the use of contextual information. A classic example of such ambiguity is the word "bank", which can be used to refer to both a financial institution and the land above an edge of a river, depending on the context in which it is framed. This means that interpretation of an ambiguous word may vary between listeners depending on what contextual information they are exposed to. While a lot of research has been devoted to the cognitive and neural mechanisms of lexical ambiguity resolution in isolation (e.g., Glucksberg et al., 1986; Swaab et al., 2003; Rodd et al., 2005), the influence of social factors such as perspective difference has not been investigated. The present study aims to fill this gap in the literature by investigating how one's own interpretation of an ambiguous word is influenced by the presence of a co-attendee holding a conflicting interpretation of such word.

Lexical ambiguity, despite not having received attention in pragmatic literature, is an ideal phenomenon for the study of perspective taking. This is because the interpretation of an ambiguous word can vary depending on what context a listener was exposed to, making it possible to induce different interpretation of the same stimulus in co-listeners. It is important to note, however, that perspective taking has been widely investigated using a different type of ambiguity in language, referential ambiguity (e.g., Keysar et al., 2000; Hanna et al., 2003; Barr, 2008). In general, these studies modelled a situation where the speaker produces a referring expression to a physical object. This expression was rendered ambiguous to the listener due to the presence of competitor referents from their visual perspective while these competitors were not present in the speaker's perspective. Using the eye tracking method, these studies focused on the time course of ambiguity resolution that required suppression of such competitors, as these could not be referred to from the speaker's perspective. This approach produced two prominent accounts of how perspective information is used in real time comprehension process. First, the Perspective-Adjustment account (e.g., Keysar et al., 1998; Keysar et al., 2000; Keysar et al., 2003) claims that listeners are egocentric first and only use the information about the speaker's perspective if the egocentric strategy fails. The Constraint-Based account (e.g., Hanna et al., 2003; Hanna & Tanenhaus, 2004; Brown-Schmidt et al., 2008) proposes that information about the speaker's perspective is just one of many types of cues that can influence reference resolution and, if this information is salient enough among the competing cues, it can take a detectable effect from the very onset of processing. While resolution of this issue remains an open question, it demonstrates that listeners do take the speaker's perspective into consideration when they are presented with ambiguous referential expressions. This is however only a single case of ambiguity in language and it is not obvious whether listeners also use information about another's perspective in cases where an expression is interpreted differently due to the presence of lexical ambiguity. Furthermore, the mentioned studies on referential ambiguity focused solely on dyadic interactions, and as of yet it is unclear whether listeners consider the perspective of their co-listeners when the presented language stimuli are ambiguous.

Importantly, there are several types of lexical ambiguity that need to be considered when investigating this phenomenon. On the most general level, the distinction exists between homonymy and polysemy. Homonymy refers to such ambiguity where the alternative interpretations of a word are distinct and not related in any obvious manner, such as in the above-mentioned case of the word "bank". Interpretations of polysemous words on the other hand show some degree of semantic relatedness (e.g., Weinreich, 1964; Klepousniotou, 2002). For instance, the metonymous word "crown" can, beside its literal referent, be used to refer to a king or a queen. Previous research has shown that homonymy and polysemy are psychologically and neurally different (e.g., Klepousniotou et al., 2012; Klepousniotou, 2002; Beretta et al., 2005; Rodd et al., 2002). Overall this research suggests that the distinct meanings of homonymous words are associated with distinct mental representations or separate lexical entries, while the different but related senses of polysemous words rely on a single lexical entry (Beretta et al., 2005); therefore, it is possible to say that homonymy is a more clear-cut example of lexical ambiguity. Precisely because of this, the present study is focused on homonymy only.

In addition, one of the often highlighted properties of homonymous words is their bias. A biased homonym is such a homonym where one of the interpretations has a higher frequency of occurrence than the alternative, i.e., it has a dominant and a subordinate interpretation. On the other hand, interpretations of a balanced homonym do not show frequency difference (e.g., Meade & Coch, 2017). Many studies had explored the differences between processing of biased and balanced homonyms (e.g., Duffy et al., 1988; Martin et al., 1999; Klepousniotou et al., 2008), showing that under some conditions homonym bias exerts processing differences. For this reason, this aspect of the stimuli was factored in the analyses on a general level (i.e., distinguishing only between biased and balanced homonyms, but not considering other parameters such as direction of bias etc.). However, since homonym bias was only considered after the data collection and some preliminary analyses, this variable is considered as an exploratory one and the statistical analyses are reported without it as well.

The present study aims to investigate perspective taking abilities in a triadic communicative context with the aim of testing whether presence of a co-listener, involved in a shared task with the participant but holding a different interpretation of an ambiguous word, influences the way one processes the same word. The main reason why this might may be the case was seen in the previous studies on mental simulation (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2): people do take into consideration the co-listener's perspective in triadic context. As was shown in Chapter 3, it seems to be the case that involvement in a shared task is a mechanism determining whether co-listener's perspective is considered. Therefore, the present study aims to investigate perspective taking in such shared context.

To that end, the current experiment investigates whether and how the presence of a co-attendee holding a certain interpretation of an ambiguous word is used to resolve one's own conflicting interpretation of such word. To do this, participants and co-attendees were, in the critical conditions, presented with prime-target word pairs consisting of a homonym and a semantically related target word (e.g., "bank"-"duck"). In addition, participants (but not co-attendees) were also presented with private contextual information priming an interpretation of the homonym consistent with the prime-target pair (e.g., a sentence priming "bank" as an edge of a river) or inconsistent with the prime-target pair, priming the opposite interpretation of the ambiguous word instead (e.g., a sentence priming "bank" as a financial institution). The task was for both to indicate whether the words in the prime-target pairs were semantically related, regardless of the context. Since the previous experiments on triadic interactions (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3) highlight increased use of the common ground in the presence of a co-listener, it was hypothesized that the effect of an inconsistent private context prime should be reduced in the presence of a co-listener unexposed to such context prime, as compared to when the task is performed without a co-listener. Alternatively, if presence of a co-listener would not result in different effect of private context, this could rather suggest that perspective taking does not operate or have influence in such cases as studied here. The third possible result is that the presence of a co-listener would result in an increased effect of private context prime. This would indicate that while another's perspective factors in language comprehension, it does not necessarily result in a more common ground restricted processing.

Methods

Participants

Forty participants were recruited for the experiment (*Age M* = 19.7, *SD* = 1.5, 4 males) in exchange for payment or a course credit. The participants were randomly assigned to either Alone (*N* = 22) or Joint condition (*N* = 18). For every participant in the Joint condition, another subject was recruited to perform the experiment jointly with them (*N* = 18, *Age M* = 19.7, *SD* = 1.6, all females). The experiment was approved by the local ethics committee at the Department of Psychology, University of York. All participants provided informed consent prior to participating in the experiment.

Materials

There were five types of trials, two of which were the conditions of interest, one control condition and two additional conditions used for counterbalancing (examples in Table 5.1).

To construct the trials for the two main conditions, a set was created consisting of 100 ambiguous prime words (e.g. "bank"), 200 unambiguous target words semantically related to the prime words (e.g. "money" and "river"; two target words per prime word), and 200 auditory sentences, one of which primed the first meaning of the ambiguous prime word (e.g., "The accountant had his savings in the bank"), and the other of which primed the other meaning (e.g., "The ducks were sitting at the bank"). These sentences were combined to form the stimuli in the two main conditions in the following way (see Table 1 for examples):

Congruent condition (CONG) - each ambiguous prime word was paired with a target word and an auditory sentence that primed the interpretation of the prime word congruent with target word.

Incongruent condition (INCO) - each ambiguous prime word was paired with a target word and an auditory sentence that primed the interpretation of the prime word incongruent with target word.

	N of items	Context Prime	Prime	Target	Related
CONG	50	He deposited his monthly wage at the local bank.	Bank	Finance	Yes
INCO	50	The canoe entered shallow waters and struck the bank.	Bank	Finance	Yes
UNREL	50	The workers spontaneously joined the protest march.	Bonnet	Hamster	No
FILL_REL	50	The people studied the structure of a hydrogen ion.	Ion	Electron	Yes
FILL_UNREL	100	The army were rarely used but regularly trained.	Army	Camera	No

Table 5.1. Examples of experimental trials. The 'N of items' column lists the number of items per condition and the 'Related' column indicates whether the prime-target pairs were semantically related or not. Note that while the word 'Bank' is mentioned in both CONG and INCO in this example, participants were presented with each word only once. Abbreviations: CONG - Congruent, INCO - Incongruent, UNREL - Control Unrelated, FIL_REL - Filler Related, FIL_UNREL - Filler Unrelated.

There were 50 trials per each of these conditions. Each prime word was presented in only one of these conditions; therefore, there was not repetition of the ambiguous primes.
There were three additional conditions, one control and two filler conditions (see Table 1 for examples). For Control Unrelated condition (UNREL), an additional set was created consisting of 50 homonymous primes paired with semantically unrelated target words and auditory prime sentences congruent with one of the possible interpretations of the homonymous prime word. Stimuli for Filler Related condition (FILL_REL) consisted of 50 unambiguous prime words paired with semantically related target words and auditory

prime sentences congruent with the prime-target pair. In a similar fashion, the stimuli for Filler Unrelated (FILL_UNREL) condition consisted of 100 unambiguous prime words paired with semantically unrelated target words and auditory sentences congruent with the prime word but not the target word. In total, there were 300 trials per experimental session, with 150 trials with semantically related prime-target pairs and 150 trials with semantically unrelated prime-target pairs. Half of all the stimuli contained an ambiguous prime word, while the rest of the primes were unambiguous.

The list of ambiguous prime words together with their unambiguous associates (i.e., the stimuli for CONG and INCO conditions) consisted in part of stimuli created and kindly shared by another researcher and in part was constructed in cooperation with an undergraduate research assistant who is a native British English speaker (the latter was the case for the rest of the conditions as well).

Homonym bias

The prime-target pairs from the two conditions of interest (CONG, INCO) were tested for biasedness after the main run of the experiment. An independent group of native English speakers participated in exchange for a course credit or a payment (N = 63, *Age* M = 19.4, 3 males). Two online questionnaires were created to accomplish this. Each homonymous prime word used in CONG and INCO conditions (e.g., “bank”) was tested against the two semantically related target words on a 7-point Likert-type scale with polar values representing either of the two associated words (e.g. 1 - river, 7 - money) and the middle value (number 4 on the scale) representing equal association. The participants were asked to indicate to what degree they consider meaning of one of the pair words to be associated with target word more than the other, or whether they consider them equally associated. Two online questionnaires were created (Questionnaire 1: N = 33, Questionnaire 2: N = 30), with each prime word being presented in one of the questionnaires together with either the two associates used in the experiment (e.g., “bank” with “river” and “finance”) and in the other questionnaire with only one of the associates and a semantically unrelated filler (e.g., “bank” with “river” and “father”). Each questionnaire consisted of 100 questions, with 50 questions containing both target words from the experiment and 50 questions with an unrelated filler. The questionnaires were administered using Qualtrics platform (Qualtrics, Provo, UT).

The average biasedness score for each prime word, based on the ratings in the trials containing both target words, was calculated using the ratings’ absolute difference from the middle value. One sample t-test testing the average biasedness (M = 1.01, SD = .69) against zero showed that on average the homonyms were biased toward one of the alternative meanings ($t(99) = 14.66$, $p < .001$, $d = 1.47$). To elucidate the possible effect of bias, this was considered as a factor in further analyses. The stimuli were split into two groups, Balanced and Biased, based on the following criterion: all homonyms with an average rating falling within 1 point away from the middle value were assigned to the Balanced group, the rest of the homonyms were assigned to the Biased group. This resulted in exactly 50 homonyms per group. Independent samples t-test comparing biasedness between the two groups showed that the homonyms' biasedness was significantly higher in Biased ($M = 1.62$, $SD = .36$) compared to Balanced group ($M = .41$, $SD = .28$; $t(98) = 18.61$, $p < .001$, $d = 3.75$).

Procedure

Upon their arrival to the laboratory and after providing informed consent, participants were asked to read the instructions and were encouraged to ask the experimenters questions if anything was unclear. Those in the Alone condition conducted the experiment with only an experimenter in the room. The participants in the Joint condition were paired with a co-attendee who was recruited as another participant. The co-attendees' responses were not collected, but they were not informed about this.

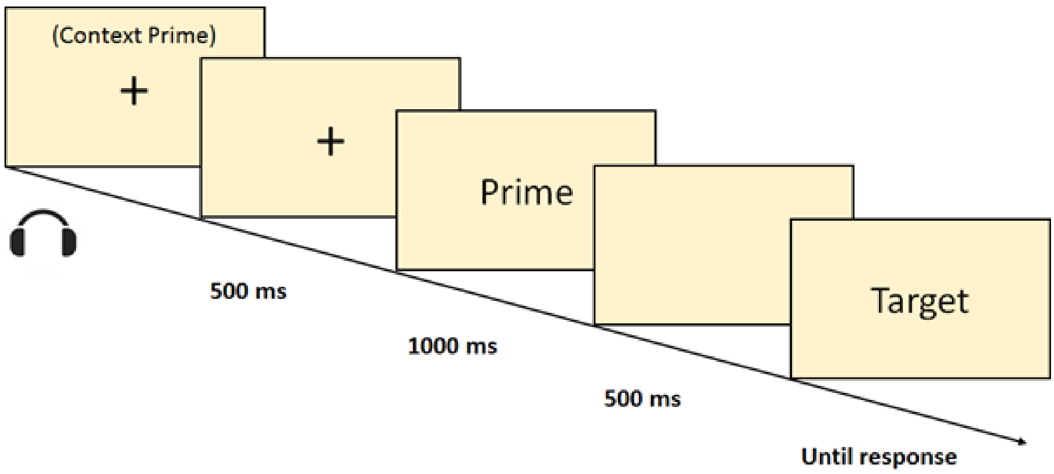

Figure 5.1. Scheme of an experimental trial. The context prime sentence was first presented auditorily through headphones to the participant in both conditions, but not to the co-attendee in the Joint condition while the fixation cross was on the screen. This was followed by another 500 ms of fixation cross. The prime word was presented for 1000 ms, followed by 500 ms of blank screen. After this, the target word was presented and stayed on the screen until the participant (and the co-attendee in the Joint condition) responded.

In both the Alone and the Joint set-up, the participant was seated in front of a computer screen, facing the centre of the screen; he/she was provided with a set of headphones, through which auditory stimuli were presented. In the Joint condition, the co-attendee was seated on the right-hand side of the participant and was very obviously given no headphones through which to hear auditory stimuli. This procedure was adopted in order to make it apparent that the co-attendee was unable to hear the auditory prime sentences.

Each participant completed 300 trials, as well as three practice trials which were not registered. The experiment was scripted and presented using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). Prior to the experiment, the stimuli for CONG and INCO conditions were organized into four lists so that each homonymous prime would be presented in both these conditions with the auditory prime sentences supporting both alternative meanings of these words. Each participant was then presented with stimuli from only one of these four lists, and the four lists were rotated across the experimental sessions so that each list would be presented to roughly the same number of participants. The stimuli for the other three conditions were the same for each participant. The order of the presentation of the stimuli was pseudo-randomized for each participant in such way that no more than two trials from the same condition were presented consecutively.

In the Joint condition, each trial began after both participant and co-attendee pressed the down arrow button on the keyboard. In each trial, the context sentence was first presented through the headphones to the participant. This sentence was not audible to the co-attendee. While the context sentence was being played, a fixation cross was presented in the centre of the screen. The fixation cross stayed on the screen for 500 ms after the offset of the context sentence. The prime word was presented in the centre of the screen for 1000 ms, followed by an empty black screen for 500 ms. Following this, the target word was presented until both the participant and the co-attendee responded with a button press (see Figure 5.1). Both the participant and the co-attendee were asked to indicate as quickly and as accurately as possible whether they considered the prime and the target words semantically related (left arrow button) or semantically unrelated (right arrow button). The subjects were instructed to respond using their index finger only, and to keep it on the down arrow button throughout the trials.

In the Alone condition, the procedure was the same except for the absence of the co-attendee. The only difference was therefore that the trials commenced and ended based on the participant's responses only. The context sentences were still presented through the headphones in order to keep the two conditions matching as closely as possible.

Prior to the statistical analysis, response rates were transformed using a sensitivity measure, meaning that the proportions of correct 'related' responses (i.e., hit rate) from CONG and INCO conditions were adjusted to the proportion of incorrect 'related' responses in UNREL condition (i.e., false alarm rate). To accomplish this, a non-parametric alternative to the popular d' measure, A', was used (Stanislaw & Todorov, 1999). This measure was chosen because in numerous cases extreme values 1 and 0 were present in the dataset. A' was calculated for each participant using the formula reported in Stanislaw & Todorov (1999; formula (2)). The A' scores were then entered into a 2x2 mixed ANOVA with a within-subject factor Congruence (CONG, INCO) and a between-subject factor Presence (Alone, Joint). To explore the effects of bias, the A' scores were also analysed using a 2x2x2 mixed ANOVA with within-subject factors Congruence (CONG, INCO) and Bias (Balanced, Biased), and a between-subject factor Presence (Alone, Joint). Since A' is not a widely used sensitivity estimate, an analysis using untransformed response rates is included in Appendix A2. This analysis is conducted using the same 2x2x2 mixed ANOVA as mentioned here, but the dependent variable is correct response rate, instead of A'.

Reaction times were calculated as the average time from the onset of the presentation of the target word until the response. Only the data from the correctly answered trials were entered into the average, that is, in case of CONG and INCO conditions, the data came from the trials where participants gave 'related' response, while in UNREL condition it was from the trials with 'unrelated' answer. The reaction times from CONG, INCO and UNREL condition were then entered into 3x2 mixed ANOVA with a within-subject factor Congruence (CONG, INCO, UNREL) and a between-subject factor Presence (Alone, Joint). To explore the effects of homonym bias, the reaction times from the CONG and INCO conditions only (as only these stimuli were tested for homonym bias) were analysed using 2x2x2 mixed ANOVA with within-subject factors Congruence (CONG, INCO) and Bias (Balanced, Biased), and a between-subject factor Presence (Alone, Joint).

Results

The data from participants whose mean correct response rate was more than 1.5 interquartile ranges above the first quartile or below the third quartile from the group mean were discarded as outliers. This resulted in exclusion of 4 participants, 2 from Alone condition and 2 from Joint condition. The analysis was therefore based on the data from 20 participants in Alone and 16 participants in Joint condition.

To analyse the responses, A' scores were entered into a 2x2 mixed ANOVA with within-subject factors Congruence (CONG, INCO) and a between-subject factor Presence (Alone, Joint). The A' data are depicted in Figure 5.2, and, in addition, the average proportions of the correct responses across the conditions are depicted in Appendix 2 (Figure A2). The analysis reported in Appendix 2, shows the same pattern of the results as the analyses reported here.

The analysis revealed a significant main effect of Congruence, $F(1, 34) = 71.09$, $p < .001$, $\eta_p^2 = .68$, with the performance being worse in INCO ($M = .94$, $SEM = .0062$) compared to CONG condition ($M = .98$, $SEM = .0022$). The main effect of Presence was not significant $F(1, 34) = 2.50$, $p > .1$, $\eta_p^2 = .07$, but more importantly the interaction of the two factors was significant, $F(1, 34) = 6.90$, $p = .013$, $\eta_p^2 = .17$. To resolve this interaction, two independent samples t-tests were run comparing the A' scores between Joint and Alone Presence groups for each Congruence condition separately. These showed that while there was no significant difference between the two groups in CONG condition, $t(34) = -.78$, $p = .44$, $d = .27$, the difference was significant in INCO condition, $t(34) = 2.17$, $p = .037$, $d = .74$, with the scores being higher in Alone ($M = .95$, $SEM = .0064$) compared to Joint group ($M = .92$, $SEM = .011$).

In order to explore the effects of lexical bias, an additional 2x2x2 mixed ANOVA was conducted with inclusion of Bias (Balanced, Biased) as a within-subject factor. Similarly to the analysis above, Congruence (CONG, INCO) and Presence (Alone, Joint) were included as within- and between-subject factors, respectively. The analysis revealed a significant main effect of Congruence, $F(1, 34) = 71.11$, $p < .001$, $\eta_p^2 = .68$, with worse performance in INCO ($M = .94$, $SEM = .0063$) compared to CONG condition ($M = .98$, $SEM = .0022$). The main effect of Bias was also significant, $F(1, 34) = 14.43$, $p < .001$, $\eta_p^2 = .34$, with worse performance for Biased ($M = .95$, $SEM = .0045$) compared to Balanced words ($M = .97$, $SEM = .0034$). The main effect of Presence was not significant, $F(1, 34) = 2.52$, $p = .12$, $\eta_p^2 = .07$. Similarly to the analysis above, there was a significant interaction of Congruence and Presence, *F*(1, 34) = 6.92, *p* = .013, η_p^2 = .17. To resolve this interaction, two independent samples t-tests were run comparing the A' scores between Joint and Alone Presence groups for each Congruence condition separately. These showed that while there was no significant difference between the two groups in CONG condition, *t*(34) = -.79, *p* = .44, *d* = .27, the difference was significant in INCO condition, *t*(34) = 2.17, *p* = .037, *d* = .74, with the scores being higher in Alone (*M* = .95, *SEM* = .0064) compared to Joint group (*M* = .92, *SEM* = .0073). The interaction of Congruence and Bias was also significant, *F*(1, 34) = 11.43, *p* = .002, η_p^2 = .25. To resolve this interaction, two paired samples t-tests were run comparing between Biased and Balanced words for each Congruence condition separately. This analysis revealed that while there was no significant difference between Biased and Balanced words in CONG condition, *t*(35) = 1.16, *p* = .25, *d* = *.19*; in INCO condition, the performance was significantly better for Balanced (*M* = .95, *SEM* = .0063) compared to Biased words (*M* = .92, *SEM* = .0073), *t*(35) = 4.51, *p* < .001, *d* = .75.

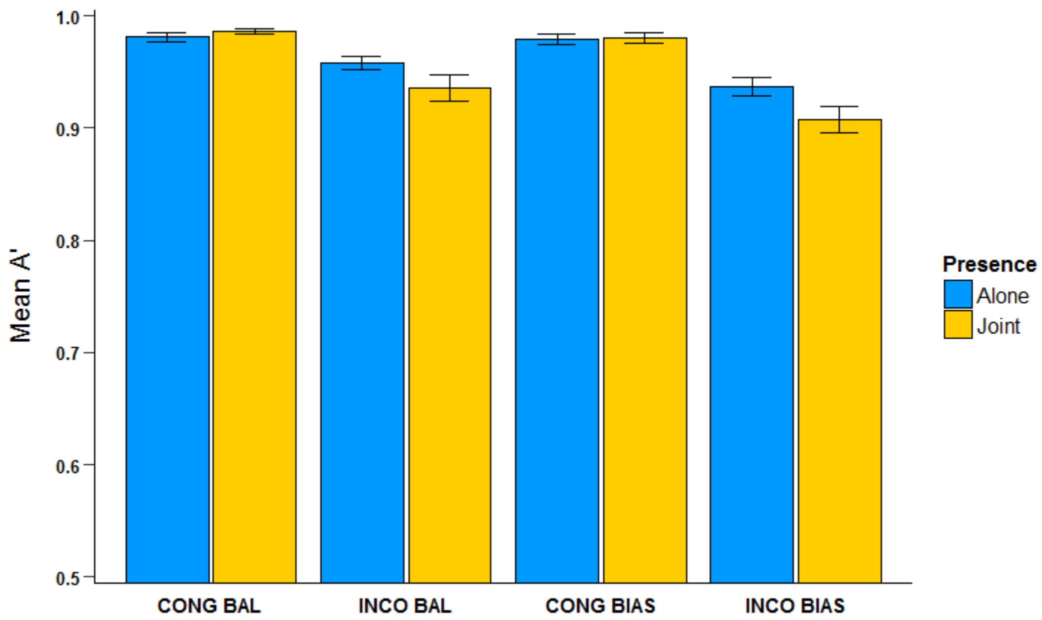

Figure 5.2. Mean A' (±SEM). CONG - Congruent condition, INCO - Incongruent condition, UNREL - Unrelated condition; BAL - Balanced homonyms, BIAS - Biased homonyms. Alone Presence condition is depicted in blue and Joint Presence condition is depicted in yellow. Note that the y-axis is depicted from 0.5 up for clarity.

Furthermore, mean reaction times were entered in a 3x2 mixed ANOVA, with a within-subject factor Condition (CONG, INCO, UNREL) and a between-subject factor Presence (Alone, Joint). The data, including the factor Bias, are depicted in Figure 3.

The analysis revealed a significant main effect of Condition, $F(2, 68) = 14.31$, $p < .001$, $\eta_p^2 = .30$. To disentangle this, three paired samples t-tests were run comparing the mean reaction times between all three levels of Condition. The t-tests showed that overall the reaction times were faster in CONG, compared to UNREL, ($M = 85.21$, $SEM = 16.31$), $t(35) = 5.22$, $p < .001$, $d = .87$, as well as compared to INCO ($M = 60.32$, $SEM = 15.07$), $t(35) = 4.00$, $p < .001$, $d = .66$. The difference between CONG and INCO conditions was not significant ($M = 24.88$, $SEM = 17.13$), $t(35) = 1.45$, $p > .1$, $d = .24$. The main effect of Presence was not significant, $F(1, 34) = 2.85$, $p = .1$, $\eta_p^2 = .08$, and the interaction of the two factors did not reach significance either, $F(2, 68) = .12$, $p = .88$, $\eta_p^2 = .004$.

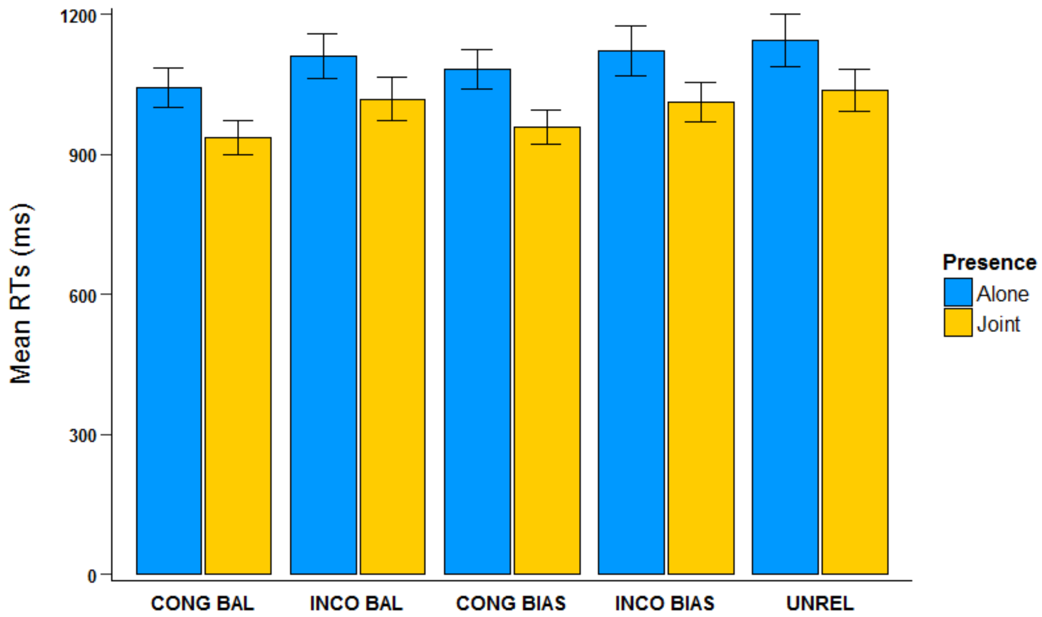

Figure 5.3. Mean reaction times (±SEM). CONG - Congruent condition, INCO - Incongruent condition, UNREL - Unrelated condition, BAL - Balanced homonyms, BIAS - Biased homonyms. Alone Presence condition is depicted in blue and Joint Presence condition is depicted in yellow. Note that in the four conditions of interest (CONG BAL, INCO BAL, CONG BIAS, INCO BIAS) the statistic reflects mean reaction time from trials where participants gave 'related' response, while in UNREL condition it reflects mean reaction time from trials where they gave 'unrelated' responses.

Analysis of reaction times (Figure 5.3) using 2x2x2 ANOVA revealed only a significant main effect of Congruence, $F(1, 34) = 15.69$, $p < .001$, $\eta_p^2 = .32$, with the reaction times being faster in CONG ($M = 1011.23$, $SEM = 29.58$) compared to INCO condition ($M = 1070.89$, $SEM = 33.54$). In addition, there was a marginally significant effect of Presence, $F(1, 34) = 3.24$, $p = .081$, $\eta_p^2 = .08$, indicating faster reaction times in Joint ($M = 981.11$, *SEM* = 38.60) compared to Alone condition (*M* = 1089.02, *SEM* = 43.76). There were no other significant main effects or interactions (*ps* > .1).

Discussion

The purpose of the present study was to investigate the question of whether and how the presence of another attendee influences resolution of semantic ambiguities, or more specifically, whether presence of an active co-attendee with restricted access to contextual information influences the way in which people handle such contextual information. It was hypothesized, in line with the previous studies on language comprehension in joint settings (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3), that in the presence of such co-attendee, the contextual information in the participant's privileged ground (i.e., information not shared with another individual) would exert less of an influence on the interpretation of an ambiguous word presented in common ground. In the case of the present study, this would mean that private sentence primes such as "The canoe entered shallow waters and struck the bank" would reduce one's propensity to judge shared prime-target word pairs, such as "bank"-"finance", as unrelated in the presence of a co-listener who does not have access to the private sentence primes. While the results demonstrate an effect of the presence of another individual, the direction of this effect is opposite to what was expected, that is, the presence of such incongruent private primes increased the participants' propensity to judge such prime-target word pairs as unrelated. The results therefore show that, in presence of a co-attendee, the information in privileged ground has a stronger effect on the interpretation of ambiguous words than in the absence of co-attendee. In addition, there was no interaction between homonym bias and presence of a co-attendee, indicating that the social effects operate independently of the properties of the homonyms.

The results demonstrate, in line with the previous literature on pragmatic language processing in dyadic (e.g., Keysar et al., 2000; Hanna et al., 2003; Hanna & Tanenhaus, 2004; Brennan & Hanna, 2009; Brown-Schmidt & Hanna, 2011) and triadic contexts (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2; Chapter 3), that people are sensitive to different perspectives due to observed change in the sensitivity to private information in the presence of a co-listener unable to access this information. The study further extends this by showing that this sensitivity is present even in the cases where two alternative interpretations of the same lexical item are held by the respective co-listeners. The direction of this effect is, however, in opposite to that of the previous studies on triadic interactions. This is possibly because, in these experiments, consideration of another's perspective manifested itself in terms of an increased focus on the common ground, while in the present case it resulted in an increased focus on the privileged ground. While perhaps surprising, this pattern can be explained in the light of Constraint-Based account of perspective taking during communication (e.g., Brown-Schmidt & Hanna, 2011), as well as through consideration of the basic purpose of communication in general.

The Constraint-Based account (e.g., Brown-Schmidt & Hanna, 2011) proposes that the cues that influence language comprehension, including information about another's perspective, are deployed according to their relative salience. In the context of most paradigms used in the studies on perspective taking during communicative acts, it is predictable that the common ground information would be relatively more salient than the information in the privileged ground. In the studies on use of perspective information during referential communication (e.g., Keysar et al., 2000; Hanna et al., 2003; Hanna & Tanenhaus, 2004), the participant has to choose a referent based on the speaker's description. This description is, in the critical trials, ambiguous from the participant's perspective (due to the presence of private competitors). The participant therefore has to use the information about the speaker's perspective, that is, to realize that some of the possible referents are not in the common ground with the speaker and therefore cannot be referring to them, in order to resolve the ambiguity. The timing of the effects of perspective information depends on the relative salience of the competitors, with studies using low salience competitors showing perspective effect nearly immediately (e.g., Hanna et al., 2003; Hanna & Tanenhaus, 2004), while high salience competitors delay deployment of the effect of perspective (e.g., Keysar et al., 2000; Keysar et al., 2003). Critically, while the mentioned studies focus on reference to objects in the common ground, there are studies showing that use of perspective information is not restricted to the referents present in the common ground only (Brown-Schmidt, 2009b; Brown-Schmidt et al., 2008; Nadig & Sedivy, 2002). For instance, in the study of Brown-Schmidt (2009b), participants conducted a referential task with an experimenter where certain objects were hidden from the experimenter due to a different visual perspective. The experimenter would then inquire to the participants about these objects located in the hidden locations based on the location of the objects in the common ground, for example, "what is above the cow that's wearing lipstick". Crucially, in the critical trials there was a competitor, for instance, the cow that is wearing shoes. If the object above the cow that is wearing shoes was referred to previously, and was thus in the common ground, the participant would preferentially look to the location above the cow that's wearing lipstick already upon hearing the word "cow". Since at that point the reference was not specific enough to distinguish between the two cows, the preference for the privileged ground location can be interpreted as a result of integration of the experimenter's perspective information into reference resolution. These studies show that use of information about another's perspective is not restricted to the common ground, but it is rather used as a cue to the information that is salient with respect to the nature of the communicative task. In the present study, however, the participants were not explicitly incentivized to focus to either common ground or privileged ground, which leaves the question of why the latter exerted larger influence in the presence of a co-listener open. A possible reason for this may have to do with interlocutors' propensity to be effective communicators.

While it is generally agreed that consideration of shared information constitutes the backbone of successful communication, it is also assumed that what makes it effective is informativity or relevance of its contents (Grice, 1975; Wilson & Sperber, 2004). In other words, a lot of what makes communication a worthwhile endeavour is constituted by the information that is not known to our interlocutors, or as Brown-Schmidt & Heller (2007) aptly note "...conversation would be rather dull if we only spoke about things that were already mutually known". It is therefore possible that, if unrestricted by specific task demands, people have a tendency to use perspective information as a means of identifying the information that could be relevant to be communicated to others. Based on such assumption, the increased effect of privileged ground can be thought of as reflecting people's natural aptness to be relevant communication partners (Rączaszek-Leonardi et al., 2014).

In relation to the psycholinguistic models of perspective taking, it is important to note that the present result is inconsistent with the Perspective-Adjustment account of perspective taking (Keysar et al., 2000). This account proposes that during reference resolution people are initially egocentric and only opt out to use perspective information if the egocentric strategy fails. As pointed out previously by Brown-Schmidt & Heller (2007), this account assumes that as perspective information is used the listener shifts their attention away from the egocentric perspective (which includes both common and privileged ground) toward common ground. This is inconsistent with the previous (Brown-Schmidt, 2009b; Brown-Schmidt et al., 2008; Nadig & Sedivy, 2002) and present observations showing that integration of another's perspective can actually shift attention toward privileged ground.

The present experiment cannot fully elucidate whether the direction of the observed effect is a result of mental simulation (Rueschemeyer et al., 2015; Westley et al., 2017; Chapter

2; Chapter 3) or a different cognitive operation. However, it is possible to argue that the opposite to the observed pattern of the results would be more in line with the simulation account. This is because, as seen in the previous experiments, simulation of language comprehension process was connected to the processing of information in the common ground from the viewpoint of the confederate, virtually disregarding the privileged ground. Nevertheless, the present result is not necessarily at odds with the mental simulation account. It is still possible to speculate that simulation of the co-listener's processing was the crucial mechanism highlighting the difference between what the co-listener does and does not know, providing ground for assignment of more weight to the privileged ground information.

In addition, one could be tempted to interpret the observed effect as an effect of mere social presence rather than of a more communication-specific cognitive mechanism. This is because the experiment lacked a control condition in which a co-listener with access to the contextual sentence information was present. While addition of such control condition could help to clarify this question, the current literature does not seem to support the mere presence explanation. This is because recent studies showed that mere presence leads to an improved task performance, for instance in the classic Stroop task (Augustinova & Ferrand, 2012) or in distorted face processing task (Garcia-Marques et al., 2015). While it is true, that older literature (Schmitt et al., 1986; Markus, 1978) found this pattern only for easy/familiar tasks, with social presence hindering performance in difficult/unfamiliar tasks, the difficult tasks used in these studies were very different from the present paradigm (e.g., putting on unfamiliar lab clothes in Markus, 1978). The present paradigm rather shares the essential properties with the Stroop task, such as the need to inhibit the distractor in order to successfully accomplish the task. Since, based on this literature, mere presence of another person would rather predict improved performance in the presence of a co-listener; the mere presence explanation of the results seems unlikely.

In conclusion, the present experiment shows two things. First, in line with the previous literature in experimental pragmatics, the study demonstrates that people are sensitive to their co-listener's different perspectives, more specifically to the lack of access to context information. More importantly, and somewhat at odds with the previous literature, the study shows that this sensitivity does not necessarily manifest in a more common ground oriented processing. In the present experiment, the opposite was observed; with the participants showing increased sensitivity to the information present in the privileged ground. Unlike most previous studies, the present experiment did not explicitly require the participants to focus on what information their communication partner can access. Due to this, it is possible that the observed increase in sensitivity to the privileged ground is a result of human tendency to communicate in relevant and informative manner.

Chapter 6
General Discussion

Overview of the presented work

The goal of the present work was to investigate how the information about a co-listener's perspective is used in communicative contexts. The main source of motivation for this was the observation that several topics were neglected in the current literature on mentalizing during verbal communicative acts. The first of these gaps is that the current literature focuses primarily on dyadic interactions, specifically on conversation between two interlocutors, while it was not yet extensively tested whether findings from these paradigms are applicable to how a co-listener's perspective is processed. To address this, four studies were conducted focusing on the effect of the presence of a co-listener; more specifically, on how their different perspective influences one's language processing. The second gap that the present work aimed to address is that, while there is no scarcity of literature on the topic of mentalizing during language comprehension, relatively few studies have addressed the issue of the cognitive mechanisms underlying taking or using another's perspective. The first of the presented four studies focused on this issue, and specifically on testing the account proposing that mentalizing about another's language processing is achieved by means of mental simulation. The second and the third of the presented studies focused on investigating the properties of such mental simulation. The results of the individual studies will first be summarized before turning to the discussion.

The aim of Chapter 2 was to investigate the neural correlates of sentence processing in presence of a co-listener who has a restricted access to the contextual information, that is, in the presence of a co-listener with a different perspective. This fMRI study was a direct follow up on a previous ERP study (Rueschemeyer et al., 2015), which demonstrated the existence of the Social N400-effect, a putative electrophysiological correlate of simulation of another's language processing. For this reason, the experimental design followed the design of the Join Comprehension task used in the original ERP study as closely as possible (Rueschemeyer et al., 2015). In the modified task, participants were presented with short narratives consisting of two sentences. Depending on the condition, the co-listener had the same perspective as the participant (i.e., they could hear and/or see both sentences) or a different perspective (i.e., they could only see the second sentence). In the critical context-dependent condition, the second sentence was interpretable only within the context of the first sentence. The results showed that when the perspectives were the same, there was an increase in activity in the regions of Extended Language

Network (ELN) reflecting effortful narrative processing and context integration (Ferstl et al., 2008; 2018; Mar, 2011). However, when the perspectives were different, this activity disappeared, suggesting that the participants processed the target sentence as if they were not presented with the context sentence, that is, from the perspective of the co-listener. This further suggests that the participants simulated language comprehension from the perspective of the co-listener's, which is in line with the previous ERP study. In addition, when the perspectives were different, processing of context dependent sentences was accompanied by an increase in functional connectivity between the language system (left IFG) and two regions of the mentalizing network (ventral mPFC, Precuneus). This suggests that when pragmatic demands are high, the two systems work in concert in order to integrate social and linguistic information. Overall, the study supports the simulation account of others' language processing, and provides evidence of involvement of mentalizing network when considering another's mental states during language comprehension.

Chapter 3 focused on whether the simulation of a co-listener's language processing, indexed by the Social N400-effect, depends on the presence of a shared task, that is, on both the participant and the co-listener engaging in a joint action. Rationale for this investigation is based on a) the assumption that human communication is a form of joint action (Clark, 1996), and b) on the literature on joint action in a non-linguistic domain showing that people represent another's actions if they are involved in a joint action with them (i.e., in a shared task), but not vice versa (Sebanz et al., 2003; Tsai et al., 2006). To test whether language comprehension shows the same shared task dependence, a version of Joint Comprehension task from a previous experiment showing evidence of Social N400-effect (Westley et al., 2017) was adapted. The only important difference between the version of Westley and colleagues and the adapted version is that while in the former both the participant and the co-listener performed a shared task (i.e., answered questions about their own and one another's comprehension), in the latter the co-listener was a passive reader, with only the participant performing a task. The results showed no evidence of Social N400-effect. This suggests that, similarly to joint action, representation of another's mental states in communicative contexts is sensitive to joint engagement of the concerned parties.

Chapter 4 aimed to test whether simulation in terms of the Social N400-effect occurs at lower levels of language processing (in this case lexical access), as opposed to higher level of lexical integration, at which it was observed in the previous experiments (e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Chapter 2). The previous literature on mentalizing and joint action shows that representation of another's mental states can occur for various low level phenomena (e.g., Frischen et al., 2009; Böckler et al., 2011; Surtees et al. 2016). While simulation of language comprehension was shown to be related to both mentalizing and joint action (Chapter 2 and Chapter 3, respectively), the question of whether it operates – similarly to the observations made in non-language domains – at lower processing levels was not yet empirically examined. Across two ERP experiments, participants were presented with single high and low frequency words, first alone, and then nearly immediately in the presence of a co-listener. Upon the alone presentation of the words, the canonical word frequency N400-effect where low frequency words elicit more negative signal deflection than high frequency word was observed. It was hypothesized that if people simulate co-listener's language processing at the level of lexical access, the same effect should be observed again when the same word was presented in the presence of a co-listener. This prediction was not confirmed, suggesting that simulation of language processing may not occur at lower levels of language processing.

Finally, the goal of Chapter 5 was to explore, in a behavioural experiment, how perspective taking influences the way private contextual information is used. Participants were presented with prime-target word pairs consisting of an ambiguous prime word and an unambiguous target word (e.g., "bank" – "river"). These were, in the critical condition, preceded by a context sentence priming incongruous interpretation of the ambiguous word (e.g., "He deposited his monthly wage at the local bank.", priming the interpretation of the word "bank" as a financial institution). The stimuli were presented either to the participant alone, or in the presence of a co-listener. If the co-listener was present, they only had access to the prime-target pair, but not to the context sentence. The task for both parties was to judge whether the prime and the target words were semantically related or not (regardless of the sentence prime). The analysis of task responses indicated that in the presence of a co-listener the incongruous context sentences had greater effect on the relatedness judgements than when the co-listener was not present, that is, the participants judged related word pairs as unrelated more often in the presence of a co-listener. The result suggests that if people are not constrained by a task to focus solely on the other's mental states, restricting the attention to the common ground (as is usually the case in the research in pragmatics), they may show increased focus toward the private information. It was speculated that this may be because private information may potentially be relevant to the other party; therefore, the effect could reflect people's aptness to be effective communicators.

Overall, the findings reported in the presented empirical studies provide evidence suggesting that a) people simulate co-listener's language comprehension process, and this simulation is accompanied by increased coupling between mentalizing and language systems (Chapter 2); b) verbal communication is a form of joint action (Chapter 3); c) simulation of another's comprehension process does not occur at lower levels of language processing hierarchy (Chapter 4); and d) differences in perspectives do not always lead to an increased focus toward the common ground, but may at least in some cases lead to an increased focus toward privileged ground (Chapter 5). While the individual studies were discussed in their respective chapters, the rest of the text will mainly focus on providing a more integrative account of how the present findings as a whole contribute to the understanding of communication, focusing on the topics of joint action, mental simulation, and similarities and dissimilarities between interactions with interlocutors and co-listeners. More specifically the following sections aim to explain how the results of the presented studies relate to the research on joint action, in support of the communication as joint action proposal (Clark, 1996); how the observed evidence of simulation (Chapter 2) and the lack of it (Chapter 3; Chapter 4) can be reconciled in order to provide an insight into the role of simulation in communication; and how research on the use of co-listener's mental states converges and diverges with the research on more direct, dyadic types of communicative contexts. Finally, ideas and suggestions for future research will be briefly presented as well.

Communication as joint action

One of the main assumptions about the pragmatic aspects of communication is that communication is a form of action, and more specifically a form of joint action. The view of language as a type of action can be traced back to the 20th century analytic philosophy, to authors such as Austin, Searle, or Wittgenstein. This view of language communication as not a mere signal exchange but a way of achieving specific goals through speech acts can be now seen as the foundation of research into pragmatic aspects of communication across the fields of science. Much of this work goes beyond just simply equating language with action: it also highlights its cooperative nature. This can perhaps most notably be seen in Grice's Cooperative principle (1975), Wilson and Sperber's Relevance theory (2004), Clark's description of language as a type of joint action (1996), or the recent work of Scott-Phillips (2018) where the authors highlight that successful communication requires cooperation and coordination between the interlocutors. Since the present work builds on these foundations, as well as it takes inspiration from the empirical research on joint action, this section aims to explore the relationship between joint action and the current findings.

The strongest evidence for the communication as joint action proposal comes from the experiment presented in Chapter 3. This experiment was explicitly designed to test this proposal, and as mentioned before it shows that the presence of the Social N400-effect depends on the involvement of the two co-listeners in a shared task. This is in agreement with the shared task dependence of co-representation effects observed in joint action literature (Sebanz et al., 2003; Tsai et al., 2006). On the other hand, and in line with the previous ERP literature on the Social N400-effect (e.g., Rueschemeyer et al., 2015; Westley et al., 2017), the fMRI study presented in Chapter 2, where both co-listeners were engaged in a shared task, shows evidence of mental simulation. These results straightforwardly demonstrate the shared task dependence of the Social N400-effect, or, more generally, the simulation of another's language comprehension in line with the proposal of communication as joint action. Considering communication in such a cooperative and coordinative manner may also be helpful when aiming to explain the results of the study presented in Chapter 5.

The behavioural study on the influence of perspective taking on lexical ambiguity resolution presented in Chapter 5 provides an effective example of the instrumental and collaborative nature of communication. As mentioned before, the results of this study suggest that when people are not explicitly constrained to focus on the information they share the access to with the co-listener (due to, for instance, specific task demands) this may result in an increased focus on the information in the privileged ground. This is in line with the cooperative approaches to communication, as it suggests that although the participants appreciated the shared knowledge, the possibility that the private information has potential to be more relevant for the co-listener than the shared information might have resulted in increased allocation of the attentional resources to the privileged ground. This finding is partially at odds with the empirical literature on joint action. This is because in this literature, the effect of representation of another's action is measured through the observed interference of the knowledge about another's action with the participant's own action (e.g., Sebanz et al., 2003; Sebanz et al., 2005; Sebanz et al., 2006a; Atmaca et al., 2008). If applied straightforwardly this would, in the framework of the current experiment, predict the effect of the co-listener to go in the opposite direction, that is, a stronger effect of common ground in the presence of the co-listener compared to when conducting the task alone. This is because it would be expected that the knowledge about the co-listener's action would show an increased interference with the egocentric processing, as is the case in the studies on joint action. On the other hand, in the current experiment the information presented in the common ground was not in a direct conflict with the participant’s own task. Consequently, as is the case in the experiments on joint action, such prediction might not be warranted.

While the above seems largely to point toward the communication as joint action proposal, the results of Chapter 4 seem somewhat difficult to map onto this. This EEG study tested whether simulation of another’s comprehension process occurs at lower levels of language processing, specifically at the level of lexical access. While, in the studies on joint action, evidence of low level simulation was observed (e.g., Sebanz et al., 2006b), in the present work, no such evidence was observed at the level of lexical access. Conversely, rather than pointing toward the absence of simulation at lower levels of language processing, the lack of such effect may also point to another possibly absenting property of joint action: temporal coordination. Temporal coordination refers to the fact that during joint action, such as in the case of two people moving a piece of furniture from one room to another, there is a need for both actors to coordinate each other in a moment-to-moment fashion in order to accomplish their joint goal (e.g., Newman-Norlund et al., 2007). In the current experiment, the participants were presented with the stimuli first alone, and only afterwards in the presence of a co-listener. At the time when the stimulus was novel to the co-listener, it was not novel to the participant anymore. It is therefore possible that since the initial processing of the stimuli was temporally dislocated, the cognitive mechanisms connected to joint action processing were simply not triggered.

Overall, the results of the present work seem to be consistent with the description of communication as a type of joint action. The results of chapters 2 and 3 demonstrate shared task dependence of mental simulation, suggesting simulation of language comprehension follows the same pattern as simulation effects observed in joint action. Further, assuming that such relationship between the two domains is psychologically real seems to be helpful when explaining the results observed in Chapter 5, as it seems consistent with the suggested cooperative nature of communication. With respect to Chapter 4, further experimentation would be needed to fully establish its relationship to joint action due to the reason presented above (an alternative experiment which would correct for this issue by more closely following with the Joint Comprehension task was presented in the discussion section of Chapter 4).

Mental simulation

The previous EEG studies on perspective taking in triadic contexts (e.g., Rueschemeyer et al., 2015; Westley et al., 2017) highlight that this may be achieved through the process of simulation of another’s mental states. This is indicated by the presence of the Social N400-effect which was suggested to reflect vicarious experience of the co-listener’s comprehension process. Since the present work can partly be viewed as a further development of the ideas introduced in these studies, the topic of simulation was of central importance as well.

The strongest evidence for mental simulation in the present work can be found in the fMRI study presented in Chapter 2. As mentioned previously, in this study it was observed that the ELN, connected to larger context integration (Ferstl et al., 2008; 2018; Mar, 2011), showed an increase in activity only when the co-listener had, similarly to the participant, a full access to the entire two-sentence narrative (i.e., both the context, and the target sentence whose interpretation depended on the context sentence). This was not the case when the co-listener did not have access to the context sentence, and thus there was no context to integrate in order to construct a meaningful narrative. This was interpreted as evidence of simulation because it seems to reflect an adjustment of the participant’s comprehension process based on the knowledge of what information the co-listener has access to.

Although Chapter 2 provides evidence of mental simulation supporting the previous EEG studies (e.g., Rueschemeyer et al., 2015; Westley et al., 2017), its necessity is challenged by the results of the experiment presented in Chapter 3. This experiment shows, in line with the literature on joint action, no evidence of the Social N400-effect in the absence of a shared task. However, despite the absence of evidence of simulation, the participants showed ceiling performance in the task prompting them about the co-listener’s sentence understanding (i.e., “Do you think the last sentence was plausible for your partner?”). This suggests that although the supposed neural markers of simulation can be observed when participant is engaged in a task with a co-listener with different perspective, they may not reflect processes necessary for successful performance in such a task.

In order to reconcile the results from the studies showing an apparent presence of simulation (i.e., Chapter 2; Rueschemeyer et al., 2015; Westley et al., 2017; Jouravlev et al., 2018; Forgács et al., 2018), with the evidence of absence of simulation in an absence of joint action (i.e., Chapter 3), a hybrid account needs to be adopted; considering both simulation as well as theory-theory approaches to mentalizing. First, since regardless of the involvement in a shared task the participants were able to make correct judgements about another’s understanding, it seems that it is possible to mentalize without simulation. This suggests that, although simulation is not present in all cases, judgements about another's understanding can be inferred based on the properties of the sentences and information about another's perceptual access. Consequently, mentalizing does not necessarily need to operate in an online manner, in line with theory-theory accounts of perspective taking (e.g., Gopnik & Wellman, 1992). On the other hand, if the listeners are jointly involved in a shared task, information about the co-listener's perspective is used online and resembles egocentric processing, in line with the simulation approach (e.g., Shanton & Gallese, 2010). The question then emerges of what the utility of such simulation is. There are at least two possible answers.

The first, more pessimistic approach to the utility of simulation can be drawn based on the research on mirror neurons introduced in the discussion section of Chapter 3. In this section, an explanation of the lack of the Social N400-effect was considered in analogy with the Hickok's (2009) critique of the causal role of motor mirror neurons in actions understanding. The conclusion of his treaty was that mirror neurons (i.e., motor simulation) are not necessary for successful action comprehension, and therefore they perhaps serve a more auxiliary function, or that the apparent simulation is merely a conditioned coupling between certain neural activity and certain observed actions. Considering this, it is possible to speculate that the neural substrate responsible for the Social N400-effect simply provides the listener an enriched appreciation of the co-listener's comprehension (or lack thereof), or it is a purely reflexive response to it. This explanation, however, does not seem entirely plausible within the context of the present work. This is because mirror neuron activity does not require joint action to be triggered, it can be observed by an agent merely watching another agent performing a movement without any joint commitment (e.g., Rizzolatti & Craighero, 2004). Since the same is not the case with the Social N400-effect, this analogy may not be an appropriate framework for explanation of the observed pattern of occurrence of simulation under certain conditions.

A more plausible and optimistic explanation emerges when simulation is considered in the light of the cognitive requirements for successful cooperation. Here, again, consideration of communication as a type of joint action, accenting the issue of temporal coordination introduced in the previous subsection, will be helpful. As mentioned above, joint action as conceived in the current research requires the actors to coordinate their actions in a moment-to-moment fashion in order to accomplish their joint goal (e.g., Newman-Norlund et al., 2007). Such coordinated action then requires an online integration of the co-actor's actions. It is then possible that while another's action can be successfully reasoned about using a more theory-theory-like approach, simulation plays a crucial role in fast online action coordination. Extending this to the domain of language comprehension and the Social N400-effect, which mimics the canonical (i.e., egocentric) N400-effect and is thus an instance of online language processing from another's perspective, it seems reasonable to assume that, in communication, simulation may play a similar role. This seems plausible since utterances in natural conversation are often integrated very quickly, to the point that in some cases listeners provide a reply well before the speaker has finished their utterance (e.g., Jefferson, 1973; 1984; Schegloff, 2000). Therefore, what is described as co-representation in joint action research and simulation in joint comprehension research may reflect fast online processing of the information about the co-actor/co-listener; as opposed to more reasoning dependent theory-theory processing. This interpretation is then in line with the observation that the Social N400-effect and the co-representation effects disappear in the absence of a shared task. This is because, if the co-listener is not engaged in a shared task, the online cooperative aspect of communication is absent, and there may be no incentive for one to coordinate their comprehension process with them.

The provided interpretation is also broadly in line with the results of the experiment presented in Chapter 5. As mentioned above, in this experiment an increased effect of privileged ground was observed when the experimental task was conducted together with a co-listener (and thus it was a joint task) compared to when the participants performed the task alone. Since there was no explicit incentive for the participant to focus on the co-listener's mental states, that is, to judge their understanding with respect to the common ground, the results were speculated to possibly reflect a more natural course of integration of the co-listener's perspective. This may be because, as mentioned in Chapter 5, the information in the privileged ground has more potential to be relevant for further communication than the common ground. Consequently, this effect may reflect the process of integration of another's perspective with the goal of preparation of a reply based on the potentially relevant private ground information. This is in line with the current interpretation because, similarly to natural communication, this would require a fast, more online integration of the co-listener's perspective, as suggested above.

The interpretation can also be treated with respect to the previously mentioned psycholinguistic models of timing of alternative perspective information use. The first, Perspective-Adjustment account, suggests that people are egocentric by default, and only use such information after the egocentric strategy fails (e.g., Keysar et al., 1998; Keysar et al., 2000; Keysar et al., 2003; Wu & Keysar, 2007). The other, Constraint-Based account, suggests that information about another's perspective is but one of many types of cues aiding language comprehension and can influence it from the very beginning, depending on its relative salience compared to other types of cues (e.g., Hanna et al., 2003; Hanna & Tanenhaus, 2004). The previous work on the Social N400-effect is more in line with the latter account. This is because this effect occurs at the same time as the canonical N400-effect (Westley et al., 2017), which suggests that simulation of another's comprehension process does not occur only after the egocentric strategy has failed. If this were so, the effect would be expected to occur with a delay. Within the context of the present work, the results of the EEG study presented in Chapter 3 can be viewed as broadly in line with the Constraint-Based account as well. As mentioned before, in this study, no evidence of the Social N400-effect was observed in the absence of a shared task. This suggests that in cases where people are not engaged in a shared task, the relative salience of the information about another's mental states is greatly diminished compared to other cues (perhaps due to the absence of need to coordinate with the co-listener in a moment-to-moment fashion). Such information then may not have any immediate meaningful effect on language processing, or at least not an effect observable by the means utilized in the study.

At this point it is helpful to note that what is essentially proposed here is a two system model, not entirely unlike the prominent two system model of mentalizing introduced by Apperly & Butterfill (2009). In their model attempting to explain the developmental course of mentalizing, with particular accent on the false-belief reasoning, the authors propose that there is a) an efficient but inflexible system that operates with belief-like state (i.e., thinking in terms of another, for instance, 'registering' an object's location rather than 'believing' it is at a certain location), and b) a demanding but flexible system. While the current proposal does not have the ambition to map onto this model, the common feature is that in the present case, simulation can be presumed to be more efficient than reasoning-based mentalizing. This is due to its proposed function in online mentalizing, which presumably requires the speedy integration of another's mental states. There are however multiple divergences, for example, there is no good reason to think that simulated mental states are belief-like states since due to their nature they seem to resemble genuine first-person processing. Further, the current conjecture as it stands now is more functionally specific with simulation being tied to joint action, but such specificity is not established in the model of Apperly & Butterfill (2009). Therefore, at the moment, the relationship between the two models is not entirely clear.

Altogether, the present work suggests that while simulation of another's mental states might be an important mechanism for perspective taking, this may be restricted to cases when online, moment-to-moment integration of information about another's perspective may be required. At the moment, however, this should be considered either a hypothesis, or a speculation, rather than a fully-fledged theory, and further empirical investigations will be required in order to evaluate its veracity.

Interacting with interlocutors and co-listeners: convergences and divergences

Although the present work focuses on how the information about a co-listener's perspective is processed, the current investigation can be seen as a part of a larger research program, spanning linguistic, psychological, and neuroscientific approaches, with the common goal of explaining the cognitive and neural mechanisms of human communication. Since, as mentioned before, perspective taking with respect to a speaker received more attention in the literature, it is important that the current results are evaluated in the light of the findings and theories based on such investigations. Such evaluation reveals that while there are commonalities between how an interlocutor's and co-listener's perspectives are integrated in dyadic and triadic interactions, there are also differences between the integration of speaker's and co-listener's perspectives.

Perhaps the most general point the present work supports is that, similarly to the interlocutor in dyadic interactions, in triadic contexts people also use information about another's perspective. While this may seem trivial, it is not straightforward to assume that people consider the mental states of co-listener's if these are not involved in a direct information exchange with them. However, unlike in rigidly controlled experimental settings, in natural contexts co-listeners are usually potential speakers and listeners, which could be the reason why it may be vital for one to consider their perspective. In other words, it can be speculated that consideration of a co-listener's perspective may serve to set the common ground for future direct interactions.

Regarding the underlying mechanisms, the main parallel between mentalizing about interlocutors and co-listeners can be observed at the neural level, as suggested in Chapter 2. Here it was shown that integration of information about a co-listener with a different perspective is connected to an increase in coupling between language and mentalizing systems. This is in line with the neuroimaging research on dyadic interactions, as this clearly shows involvement of mentalizing system (e.g., van Ackeren et al., 2012; Bašnáková et al., 2013; Spotorno et al., 2012; Willems, 2010), with some studies also showing its interaction with the language system (e.g., Enrici et al., 2011; van Ackeren et al., 2016; Tettamanti et al., 2017). Since both strands of research show convergence in suggesting the mentalizing system as the core mechanism responsible for social aspects of language processing, it is possible to conclude that this core mechanism is common to both types of interactional contexts.

A divergence between mentalizing about interlocutors and co-listeners occurs when they are considered with respect to joint actions. As could be seen in Chapter 3, simulation of co-listener's comprehension does not occur if the co-listener is not participating in a shared task with the participant. This, however, should presumably never be the case in a dyadic exchange between two interlocutors. This is because while a co-listener may or may not be engaged in joint action with the listener, conversation partners are always involved in joint action, as they have to coordinate their actions (i.e., their speech acts) in order to achieve their communicative goals. While it is unknown whether people simulate language comprehension from the speaker's perspective, this shows that there are aspects of perspective taking that vary depending on joint action and may not always be present in triadic interactions, but which are presumably always present in dyadic interactions.

Another difference stemming from the distinct engagement with an interlocutor as compared to a co-listener can be observed when considering low level linguistic representations. As the results presented in Chapter 4 suggest, people do not simulate low level processes, such as lexical access (as indexed by the absence of word frequency N400-effect), in contrast to high level processes, such as sentence level lexical integration (as indexed by the presence of Social N400-effect in previous studies; e.g., Rueschemeyer et al., 2015; Westley et al., 2017; Jouravlev et al., 2018). On the other hand, the previously introduced interactive alignment model (Pickering & Garrod, 2004) suggests that, in dyadic exchanges, mental representations at all levels of language processing of the interacting parties align through simple priming mechanisms. In the light of this model, the results of Chapter 4 further imply that, when people do not have means to align their mental representation through priming mechanisms, they do not employ simulation to compensate for the lack of availability of such priming; at least not at the lower levels of language processing. It also needs to be mentioned that a recent EEG study on the Social N400-effect in infants (Forgács et al., 2018) seems to suggest the presence of simulation at low processing levels. In this experiment, participants and confederates were presented with simple objects with single word names (e.g., "bunny", "cup", etc.). In the critical condition, the label given to an object was correct from the infant's perspective, but incorrect from the confederate's perspective. Infants in this condition showed a significant Social N400-effect, suggesting they were experiencing the object-label incongruence from the perspective of the confederate. While this effect was elicited by single words, the target phenomenon does not appear to be different from the rest of the previous studies on Social N400-effect (Rueschemeyer et al., 2015; Westley et al., 2017; Jouravlev et al., 2018). This is because similarly to these, the effect seems to stem from the confederate having their semantic expectations violated; therefore, this study does not seem to tap into the low-level comprehension mechanisms in the same way as the study presented in Chapter 4.

The divergences presented in the previous two paragraphs have one significant aspect in common – they seem to be merely accidental, based on the restricted direct exchange between the co-listeners. Together with the observed convergences, this suggests that perspective taking with respect to either co-listener or interlocutor is largely a result of the same cognitive mechanism – mentalizing –, while the divergences do not reflect an essentially different approach to the two types of communication partners. This is in line with the previously presented point that in natural contexts co-listener is often a potential interlocutor, implying the cognitive mechanism underlying perspective taking of the two types of communication partners should be largely similar.

Future directions

While the present work provides several answers and hints about how people use information about a co-listener's perspective and about the nature of simulation during language comprehension, there still remain open questions, and several new emerge. Some suggestions for future research were presented throughout the previous empirical chapters, but these were mainly proposed to correct for the possible shortcomings and uncertainties stemming from the nature of the specific experimental paradigms or their administration. The text below focuses on future directions in a wider sense, based on the ideas and speculations put forward in the present chapter.

In the discussion above, it was suggested that the use of different perspectives in communication, regardless of whether this is with respect to a speaker or a co-listener, relies on the same cognitive faculty: mentalizing. This suggestion was based on the observation that the regions of mentalizing network were shown to be connected to processing in both domains. In addition, the same is the case in joint action that has also been shown to be accompanied by an increase of activity in mentalizing network (e.g., Eskenazi et al., 2015; Chauvigné et al., 2018). There is, however, substantial variation between the regions of the mentalizing network involved in all three domains; for instance, in the case of joint action, studies show an increase in activity (over a control condition) in right TPJ (Newman-Norlund et al., 2008), mPFC (Sebanz et al., 2007), right TPJ and mPFC (Chauvigné et al., 2018), and Precuneus (Eskenazi et al., 2015). This is perhaps not surprising due to the substantial task variation between the studies; nevertheless, it also warrants cautiousness when making conclusions about a common cognitive and neural substrate. To resolve this issue, an empirical investigation directly comparing joint action, and communication in dyadic and triadic settings should be conducted in order to establish whether the suggested functional overlap is true.

Further, the hypothesis put forward in this chapter that simulation may serve as means for a more immediate coordination of two communicators/co-actors (e.g., during fast verbal exchanges such as ordinary conversation or in case of joint action during tasks that require temporal coordination) as opposed to more reasoning based mentalizing, could be empirically tested. Although it is not straightforwardly obvious to the author at the time of writing this what the specific experimental design would look like, there seem to be at least two general approaches that could be employed to test this. First, such study should, regarding the nature of behavioural responses, focus on reaction times rather than on correct responses. This is because, as it was shown in Chapter 3, people can perform such tasks at near ceiling levels independent of the evidence of simulation. The simplest approach would present the participant with a task such as the Joint Comprehension task presented in Chapter 3, both with the shared task and without the shared task. The task (regardless of whether shared or not) would be to answer the task questions as quickly as possible. If the participants would show faster reaction time in the shared task condition, this could be considered evidence of simulation serving more immediate purposes. The second approach would be based on the identification of a (hypothetical) brain region or a network responsible for simulation. A method such as Transcranial Magnetic Stimulation (TMS) used to temporarily disrupt the activity in the region/network could be then used to test whether the speed of responses in a joint comprehension task (with a shared task) is markedly altered by this disruption, compared to a control non-disruption condition. The second approach has the advantage of not allowing the participants to (consciously or unconsciously) compensate for the absence of the shared task, since the shared task would be present in both conditions and the experimental manipulation would only be introduced through TMS.

Limitations

While some limitations regarding the specific approaches and experimental designs used in the present work were mentioned previously, there are some additional, more general, limitations or concerns that one could have regarding the work's ability to identify the hypothesized effects or their absence.

Within the context of the present studies one may have concerns regarding the statistical power of some of the presented studies to reliably identify statistically significant effects. Particularly, this may be the case for the EEG studies presented in chapters 3 and 4, where, in the conditions of interest, null effects were observed when considering event-related potentials. One may wonder whether this is the case because the effects do not exist, or instead due to the experiments being underpowered. There are two reasons this does not necessarily constitute an issue. The first is that the sample size was sufficiently large in order to detect the N400-effect in which both these studies were interested since this effect can be observed with as few as 16 participants (Rugg, 1990). The sample size was always larger than that in the present work (N = 42 in Chapter 3; N = 25 and N = 18 in the two experiments in Chapter 4, respectively). However, one could still have worries that while the sample sizes were large enough to detect the canonical N400-effect they may not be large enough to detect the potentially smaller or less reliable socially elicited N400-effects. This again should not be of concern since, for instance, the previously mentioned study on the Social N400-effect in adolescents (Westley et al., 2017) reports similar N400-effect sizes for the canonical and social effects (M = 3.63 and M = 3.53, respectively). Because this evidence suggests that the Social N400-effect is not of different amplitude than the canonical N400-effect, the issue of statistical power seems to be of less concern with respect to the electrophysiological effects themselves.

Moreover, the issue of statistical power could be of concern with respect to the analyses of individual differences presented in Chapter 3. In this chapter correlation analyses were conducted between behavioural measures such as EQ or Stroop effect and the Social N400-effect size. While there were no significant correlations between the variables of interest, there may be some uncertainty about whether this is due to the absence of correlation or insufficient statistical power. In the future explorations into this issue, statistical power should be considered more carefully when determining the sample size.

There is an additional concern regarding the interpretation of the null effects observed in chapters 3 and 4. The analyses were conducted using the standard frequentist approach to statistics, which is known to be suboptimal for such purposes, as opposed to the alternative Bayesian approach (e.g., Quintana & Williams, 2018). Although this seems to be partially amended in Chapter 3 by means of quantitative comparison of the results with the data from a previous study, this does not fully address the issue since the observation that the effect was significantly smaller in the present compared to the previous study is not an evidence of an absence of the effect in the present study. Bayesian approach would therefore constitute a viable alternative to the frequentist approach taken in the present analyses.

Conclusion

The present work aimed to investigate whether and how people use information about a co-listener's perspective during communicative tasks. Particular focus was put on whether the simulation of another's mental states is the crucial mechanism responsible for such perspective taking. Overall, the results of the presented studies show that people take co-listener's mental states into account in communicative contexts, although there seem to be certain restrictions to this. This is shown, for example, by the lack of evidence of simulation in absence of a shared task; as well as by the absence of simulation at the level of lexical access. The presented work also provides positive evidence that people do simulate other people's mental states, as shown by the fMRI experiment suggesting that at least in some cases simulation is the cognitive mechanism by virtue of which understanding of others' mental states is achieved. Further, the work provides empirical evidence for the similarity of joint action and communication, as shown by the fact that no evidence of simulation is observed during communication in an absence of a shared task, which is the case of non-linguistic joint action as well. And finally, the work provides evidence that consideration of another's mental states does not necessarily lead to an increased focus toward the shared information, providing evidence that in some cases it may lead to an increased focus toward the private information instead. Overall, based on the present results, a picture is emerging where simulation is not a necessary mechanism for successful consideration of another's mental states, but may be necessary for fast paced integration of another's mental states, as is the case during natural communication. However, whether this truly is the case is a question that requires further empirical research in order to be satisfactorily answered.

Appendix

Appendix 1 - Chapter 3: Cluster analysis

Rationale

Upon visual inspection of individual signals at S5, it seemed plausible that subset of the participants could be showing the Social N400-effect. To elucidate whether this was the case, a quantitative approach was sought allowing for classification of the individual ERP effects into two groups. Since to the author's knowledge there is no standard way to approach such issue, the full sample of 42 participants was split into two groups using clustering analysis. The hypothesis was that one of these groups would show an evidence of the Social N400-effect, while in the other group there would be no evidence of this effect.

Method

Clustering

Difference wave was calculated for each participant as the difference between average signal in COR and INC conditions at S5. From this difference wave only the time series from the 365-515 ms interval were considered, i.e., from the interval within which a significant canonical N400-effect was shown to be significant at S1. The difference wave from this interval was then compared (i.e., distance was calculated) between each pair of participants using Dynamic Time Warping (DTW). DTW is a nonlinear method for nonstationary time series comparison that allows for the reduction of the effects of time shifts between the time series under comparison. For example, if one compares two nearly identical difference waves, both showing evidence of the N400-effect, but in one case this effect appears 25 ms later than in the other, DTW algorithms can account for this time shift. If these time series would be compared using the Euclidean distance method, the difference between the two would be inflated due to the time shift. DTW was chosen because, even though a relatively short interval was analysed and the N400-effect is expected to be relatively fixed in timing, slight time shifts do occur at an individual level due to noise in the signal. To calculate DTW distance, a publicly available implementation of the method for Matlab was used (Wang, 2014).

The comparison of the difference waves therefore resulted in a 42x42 distance matrix (since there were 42 subjects). To cluster the individual participants into two groups k-medoids clustering method was used (as implemented in Sapp, 2010). K-medoids is a robust clustering method similar to the popular k-means clustering. The advantage of k-medoids over k-means method is that it does not rely on clustering around means, which makes it a suitable method for clustering of arbitrary measures such as DTW distance. The algorithm was set to cluster the participants into two clusters.

Cluster analysis

After the sample was split in two in the clustering analysis, the signal from S5 was analysed individually in each cluster. The differences between PLAUS and IMPLAUS conditions were then analysed using two-tailed cluster mass permutation t-test, similarly to the full sample analysis of S1. The only difference between the current case and the analysis of S1 was that, when forming clusters, all t-scores with uncorrected *p*-values of .05 or less were considered, while in the S1 analysis a more restrictive .01 threshold was used. This was done because a) the original sample was split into two, resulting in decreased statistical power, and b) the analysis was exploratory, warranting more lenient statistical criteria.

Additional S1 and S4 analysis

In order to determine whether the observed differences between the clusters were not an effect of earlier differences at S1 or S4, an additional analysis was conducted to find out whether the cluster has an influence on the amplitude at these two instances. To do this, the average amplitudes from 365-515 ms window were entered into a mixed 2x2x2 ANOVA, with within subject factors Sentence (S1, S4) and Plausibility (PLAUS, IMPLAUS), and a between subject factor Cluster (C1, C2).

Results

The clustering analysis split the sample into two clusters (see Figure A1), one with 28 participants and the other with 14 participants (there will be further referred to as C1 and C2, respectively). In C1, cluster based permutation t-test revealed a significantly more negative deflection in INC compared to CON condition in 285-475 ms window ($p < .01$); in C2, two significant clusters both with more negative signal in CON compared to INC condition. The first cluster was in 270-440 ms window ($p < .01$), followed nearly immediately by the second cluster in 450-555 ms window ($p < .05$).

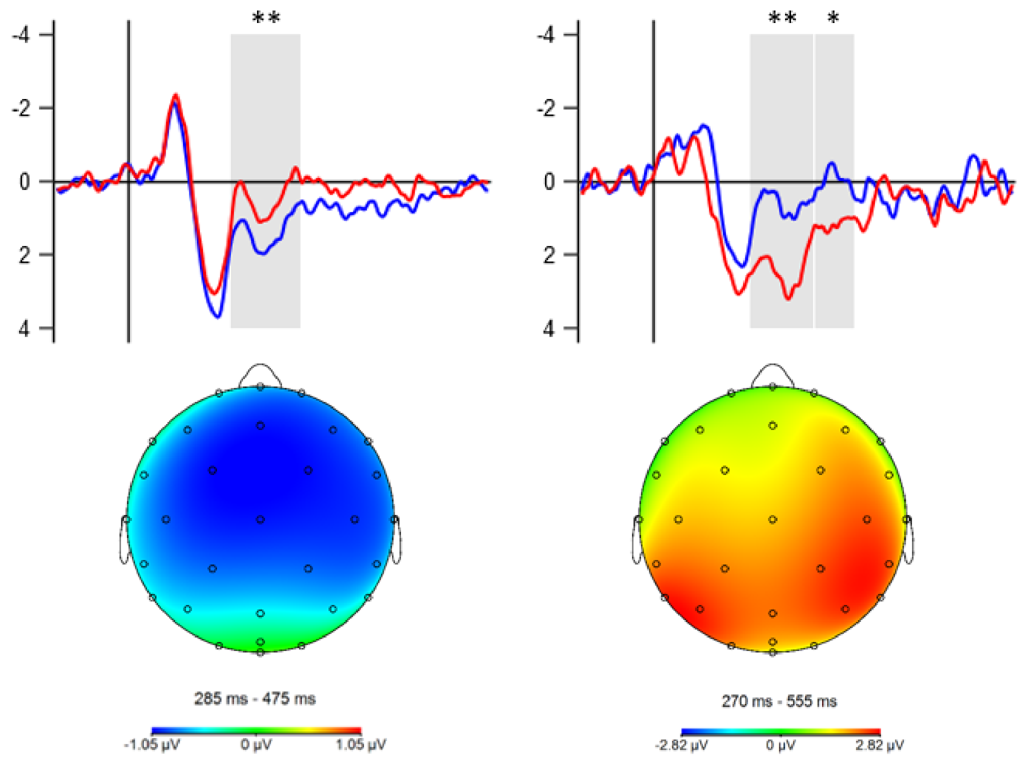

Figure A1. Event related potentials and averaged scalp topographies from the analyzed windows (grey regions) at S5 for both clusters. Time courses depict average from three central channels (C3, Cz, C4) for PLAUS (blue) and IMPLAUS (red) conditions across three analysed sentences (S1, S4, S5). Y-axis represents amplitude in microvolts. Note that the scales for the topographies are different due to different effect sizes.

Further, the signal from 365-515 ms window was analysed using a 2x2x2 ANOVA, with within subject factors Sentence (S1, S4) and Plausibility (PLAUS, IMPLAUS), and a between subject factor Cluster (C1, C2). This analysis revealed a significant main effect of Sentence $F(1, 40) = 69.55$, $p < .001$, $\eta_p^2 = .64$, with more negative signal amplitude at S1 ($M = -2.61$, $SEM = .31$) than at S4 ($M = -.04$, $SEM = .20$), and a significant main effect of Plausibility, $F(1, 40) = 5.90$, $p = .020$, $\eta_p^2 = .13$, with more negative signal for IMPLAUS ($M = -1.54$, $SEM = .24$) then for PLAUS sentences ($M = -1.11$, $SEM = .22$). There was also a significant interaction of Sentence and Plausibility, $F(1, 40) = 12.52$, $p = .001$, $\eta_p^2 = .24$. To resolve this interaction, two paired samples t-tests were run comparing between the two levels of Plausibility at S1 and S4 separately (Bonferroni corrected for 2 comparisons). This analysis showed that while there was no difference between PLAUS and IMPLAUS sentences at S4, $t(41) = -1.07$, $p = .58$, $d = .17$, there was a significant difference between the two at S1, $t(41) = 4.76$, $p < .001$, $d = .73$, with more negative signal deflection in IMPLAUS ($M = -3.18$, $SEM = .35$) than in PLAUS condition ($M = -2.05$, $SEM = .30$). There were no other significant main effects or interactions ($ps > .1$).

Evaluation

In this analysis, the data from the experiment presented in Chapter 3 were further analysed using a clustering approach in order to disentangle whether the observed lack of differences between PLAUS and IMPLAUS sentences in the full sample analysis was not a result of a presence of two clusters. Two clusters were identified, a cluster with a positive going difference between the two conditions and a cluster with a negative going difference between the two conditions. While this is in line with the way clustering algorithms operate, that is, by maximizing the difference between the clusters, it is also a part of the reason why the present analysis is not entirely trustworthy. This is because, as can be expected, clustering the difference waves into two clusters is likely to produce opposite going clusters, regardless of whether these reflect genuine effects present in the data. However, such procedure could be partially validated if the morphology of the resulting clusters would reflect well-known electrophysiological components. Nonetheless, this does not seem to be the case. In the case of the negative going cluster, its morphology does not seem to reflect the Social N400-effect observed in the previous studies, or N400-effect more generally. The positive going cluster does not seem to be readily interpretable within the context of the present experiment.

Appendix 2 – Chapter 5: Analysis of correct response rates

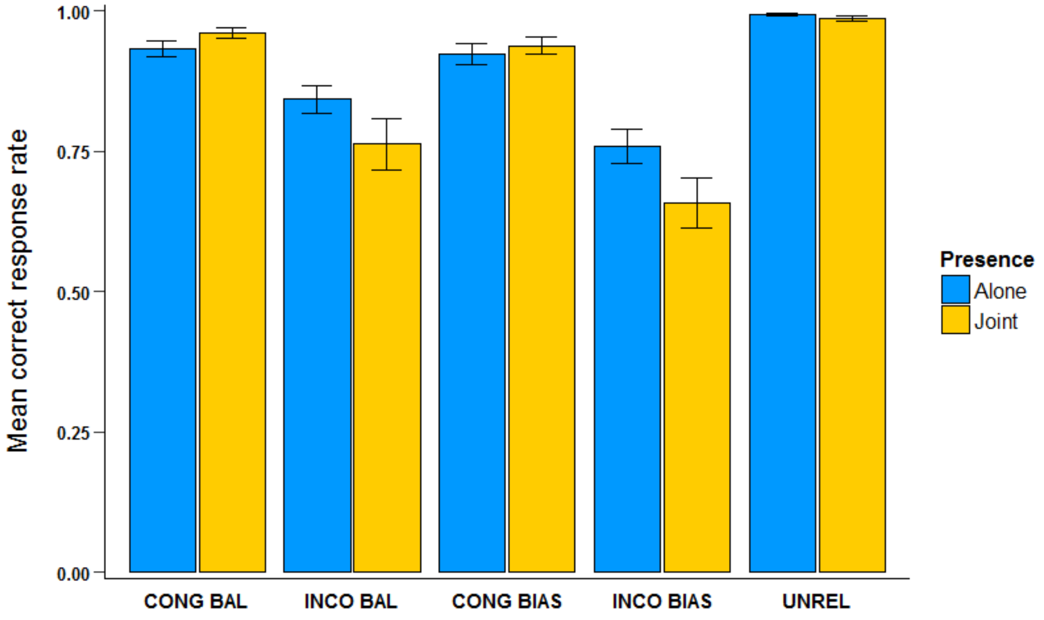

Figure A2. Mean proportion of correct response rates (±SEM). CONG - Congruent condition, INCO - Incongruent condition, UNREL - Unrelated condition; BAL - Balanced homonyms, BIAS - Biased homonyms. Alone Presence condition is depicted in blue and Joint Presence condition is depicted in yellow. Note that in the four conditions of interest (CONG BAL, INCO BAL, CONG BIAS, INCO BIAS) the statistic reflects the proportion of 'related' responses, while in UNREL condition it reflects the proportion of 'unrelated' responses.

The correct response rates from CONG and INCO conditions were analysed with an inclusion of factor BIAS in a 2x2x2 mixed ANOVA with within subject factors Congruence (CONG, INCO) and Bias (Balanced, Biased), and a between subject factor Presence (Alone, Joint). This analysis revealed a significant main effect of Congruence, $F(1, 34) = 69.63$, $p < .001$, $\eta_p^2 = .67$, showing worse performance in INCO compared to CONG trials. The main effect of Bias, was also significant, $F(1, 34) = 17.26$, $p < .001$, $\eta_p^2 = .34$, showing worse performance for Biased ($M = .82$, $SEM = .02$) compared to Balanced homonyms ($M = .88$, $SEM = .01$). The main effect of Presence was not significant, $F(1, 34) = 1.60$, $p = .22$, $\eta_p^2 = .05$. Importantly, there was a significant interaction of Congruence and Presence, $F(1, 34) = 6.50$, $p = .015$, $\eta_p^2 = .16$, with the difference between CONG and INCO trials being larger in Joint ($M = .24$, $SEM = .16$) than in Alone condition ($M = .13$, $SEM = .02$). To resolve this interaction, two independent samples t-tests comparing the response rates between Alone and Joint condition were compared for each Congruence group. The t-tests showed that correct response rate was not significantly different between the two Presence groups in CONG trials (t(34) = -1.27, p = .21, d = .44), but there was a marginally significant difference for INCONG trials (t(34) = 1.95, p = .059, d = .67), with the correct response rate being lower in Joint (M = .71, SEM = .042) compared to Alone condition (M = .80, SEM = .02). The interaction of Congruence and Bias was also significant, F(1, 34) = 10.98, p = .002, η_p^2 = .24, with the difference between CONG and INCONG trials being larger for Biased (M = .22, SEM = .03) compared to Balanced homonyms (M = .14, SEM = .03). To resolve this interaction two paired samples t-tests were run comparing between Biased and Balanced words for each Congruence condition separately. This analysis revealed that while there was no significant difference between Biased and Balanced words in CONG condition, t(35) = 1.16, p = .26, d = .19, in INCO condition the performance was significantly better for Balanced (M = .81, SEM = .02) compared to Biased ambiguous words (M = .71, SEM = .03), t(35) = 4.49, p < .001, d = .75.

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