

Effects of stimulus processing on the event-related brain potentials of close others

Amanda Louise Tardif, B.S.

Integrated Program in Neuroscience, Faculty of Medicine

McGill University, Montreal

Submitted: December 2019

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree
of Master of Science

© Amanda Louise Tardif, 2019

Table of Contents

Abstract	4
Résumé	5
Acknowledgements	6
Introduction	
<i>Neuroscience and the Study of Consciousness</i>	<i>7</i>
<i>Similarity of Percepts</i>	<i>10</i>
<i>Review of Haffar et al. (2018)</i>	<i>13</i>
<i>The Present Study: Addressing the Problems of Haffar et al. (2018)</i>	<i>23</i>
Materials and Methods	
<i>Participants</i>	<i>27</i>
<i>Consent</i>	<i>28</i>
<i>Stimuli</i>	<i>28</i>
<i>Procedure.....</i>	<i>31</i>
Partners	31
Alone Group	35
Debriefing	35
<i>Data acquisition</i>	<i>36</i>
<i>Offline data processing and measures</i>	<i>37</i>
<i>Analyses</i>	<i>39</i>
Results	
<i>Electrophysiology</i>	<i>43</i>

<i>Permutation test.....</i>	52
Discussion	54
Conclusion	60
Contributors	61
References	62
Appendices	69
<i>Appendix A: IAPS Image Numbers</i>	70
<i>Appendix B: ERPs of participants who had at least one electrode with a significant p-value after performing the Monte Carlo permutation test.....</i>	76

Abstract

This work focuses on the similarity of percepts, that is, how individuals could have similar internal, subjective, and conscious experiences of the perception of sensory stimuli. It has been suggested that consciousness emerges from specific patterns of firing in particular subsets of neurons. However, that specificity contrasts with the large differences that can exist between individual brains. It also appears inconsistent with the fact that the nature of a percept does not seem to ultimately be constrained by either the physical stimulus itself or the brain areas that contribute to its processing. Using this logic, there would be no way for all brains to produce similar percepts in response to the same stimulus. Nevertheless, they must be similar in order for individuals to communicate effectively about their environment. In nearly every social interaction, we assume that others perceive stimuli the same way we do; we assume that words designate the same percepts for us as they do for others. These inconsistencies spurred the hypothesis that there are influences between individual brains that help them build percepts that are similar, especially between individuals who share a social bond. To test this, Haffar, Pantecouteau, Bouten, & Debrulle (2018) used EEG hyperscanning and found that participants' event-related potentials (ERPs) were modulated by the visual stimulus that a partner was viewing, even though this stimulus was not in the visual field of the participant. This work aimed to replicate their results, as well as determine whether social factors such as a feeling of presence and theory of mind abilities can impact those potential ERP modulations.

Résumé

Ce travail porte sur la similarité des percepts, c'est-à-dire sur comment les individus pourraient vivre des expériences de perceptions internes, subjectives et conscientes similaires d'un même stimulus sensoriel. Il a été suggéré que la conscience émergerait de l'activation d'ensembles neuronaux spécifiques. Cependant, cette spécificité contraste avec les grandes différences existantes entre cerveaux. Cela semble également incompatible avec le fait qu'un percept ne semble pas être restreint par le stimulus physique lui-même ni par les zones du cerveau qui contribuent à son traitement. En utilisant cette logique, il n'y aurait aucun moyen pour tous les cerveaux de produire des percepts similaires en réponse au même stimulus. Néanmoins, ils se doivent d'être similaires afin que les individus puissent communiquer efficacement à propos de leur environnement. Dans presque toutes les interactions sociales, nous supposons que les autres perçoivent les stimuli de la même manière; nous supposons que les mots désignent pour nous les mêmes percepts que pour les autres. Ces incohérences ont conduit à l'hypothèse qu'il existe des influences entre les cerveaux des individus, en particulier entre des individus partageant un lien social proche, les aidant ainsi à construire des perceptions similaires. Pour tester cela, Haffar, Pantecouteau, Bouten et Debruille (2018) ont utilisé l'hyper-balayage EEG découvrant que les potentiels évoqués des participants pourraient être modulés par un aspect d'un stimulus visuel visualisé par un partenaire, même si le stimulus n'était pas visible dans le champ visuel du participant. Ce travail visait à reproduire leurs résultats et à déterminer si des facteurs sociaux tels que le sentiment de proximité et la théorie de l'esprit pouvaient avoir une incidence sur ces modulations potentielles de l'ERP.

Acknowledgements

I would firstly like to thank my supervisor Dr. J. Bruno Debruille for his expertise and guidance throughout this entire work. None of it would be possible without his willingness to pursue the important ideas we have tackled here. I would also like to thank the students who pioneered this research along with Dr. Debruille in its early stages: Sheila Bouten, Maud Haffar, Hugo Pantecouteau, and Shahin Tavakol. A sincere thank you is extended to my committee members, Naguib Mechawar and Boutheina Jemel, whose input and feedback were integral to my progress. I would especially like to thank Boutheina Jemel for taking the time and effort to guide me through the MATLAB toolbox Fieldtrip and for writing the codes required to perform the essential Monte Carlo permutation analysis. I would additionally like to thank my program mentor, Joseph Rochford, for his very useful suggestions regarding our statistical analyses. I must also thank my fellow master's students in the lab, Ilya Demchenko, Matthieu Lenne, and Ashley-Chau Morris for their willingness to provide help at any step of the way. Thank you to Matthieu Lenne especially for translating the French version of the abstract and for being a sounding-board for all things regarding this project. Finally, I would like to thank my family for their unwavering support and encouragement throughout my academic career.

Introduction

Neuroscience and the study of consciousness

Consciousness has been a main focus in neuroscience since the very beginning of scientific investigation into the functions of the human brain. In fact, one of the main reasons why neuroscience was developed was to tackle the mind-body problem, that is, to understand how the brain, which is material, could produce the mind, which was thought by many to be immaterial. Scientists investigating this problem have encountered many challenges, partially due to the difficulty of defining consciousness with concrete and measurable terms while also taking seriously its fundamental first-person subjectivity (Roepstorff, 2001). One way of approaching this difficulty is by splitting it into two types of problems: the “easy problem” and the “hard problem” as defined by Chalmers (1995). Much of research has focused on the “easy problem,” which can involve identifying neural correlates of consciousness (NCCs). NCCs are defined by Crick and Koch (1990) as the minimum set of neuronal events that are sufficient for the formation of a specific aspect of a reportable conscious perception. Identifying NCCs involves comparing what the brain is doing during “unconscious” behaviors (e.g., sleeping, performing automatic behaviors or reflexes, etc.) with what it is doing during “conscious” behaviors (e.g. being awake, performing voluntary behaviors, perceiving stimuli, reporting mental states or percepts, planning, etc.). Methods such as functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), or event-related potentials (ERPs) are often used to reach this goal (see Dehaene & Changeux, 2011 for a review).

On the neural level, the ability of functional clusters of neuronal groups to rapidly differentiate into any conscious state seems to be what underlies the difference between “conscious” and “unconscious processing” (Tononi & Edelman, 1998). From this perspective, a conscious state can be reduced to neural activity, but only in the sense that it is reliant on the functional effects of lower level activity on higher-level organization, and not on intrinsic properties of specific neurons (Dehaene & Naccache, 2001). This is supportive of the idea that patterns of activation are related to a functional output, specifically in perception. However, it is not clear how or why these patterns “elevate” certain processes to a conscious level while others remain unconscious, or how it is related to the specific subjective contents of a percept. Instead, researchers have worked on categorizing fundamental properties of consciousness and determining how certain neural states embody them (Oizumi, Albantakis, & Tononi, 2013).

One of these properties is that conscious processing unfolds in a serial manner. This is supported by attentional blink studies showing that when a stimulus is being attended, it temporarily inhibits the perceiver’s ability to process another stimulus that shortly follows the first one (Asplund, Fougner, Zughni, Martin, & Marois, 2014; Sergent & Dehaene, 2004). Essentially, one can only be conscious of one thing at a time. This can also be observed in the phenomenon of binocular rivalry, where a different image is presented to each eye but only one of them can be perceived at a time (Panagiotaropoulos, Deco, Kapoor, & Logothetis, 2012; Tsuchiya & Koch, 2005). In contrast, most things our brains are processing that do not enter consciousness are occurring in parallel (Rumelhart, Hinton, & McClelland, 1986; Baars, 1993). Attention is another important factor in consciousness: anything one does not attend will not become conscious (Broadbent, 1958; Lachter, Forster, & Ruthruff, 1997). More recent findings

have further teased apart the fronto-parietal networks allowing for allocation of attention, task monitoring, and working memory from those in more posterior areas which seem to be responsible for the processes involved in the experience of specific contents of consciousness (Koch, Massimini, Boly, & Tononi, 2016). All of this research helps to solve many of the “easy problems” of consciousness.

The “hard problem,” however, remains out of reach: how or why a neural pattern results in a specific accompanying experiential nature is still a mystery. In the domain of sensory perception specifically, this explanatory gap (Levine, 1983) begs the question of how a set of depolarizations triggered by the behavior of particles (e.g., sound waves moving with a certain frequency) can *be* a percept (e.g., a sound with a certain pitch that is perceived by an individual). These phenomenal qualities of percepts have been referred to by philosophers and neuroscientists as “qualia” in order to talk about the subjective nature of a percept that is separate from the stimulus or the brain area responsible for its processing (Block, 2004). This concept is intrinsically tied to the “perceiver” and his/her brain that created it: it cannot exist without him/her, and therefore he/she cannot be separated from the process of perception itself. I will thus be using the term “percept” to refer to the experiences that are created by the brain in response to a stimulus and embody a particular subjective nature. Percepts are not replications of the physical world but are instead representations of it. These representations are what make up the “3D movie” (Chalmers, 2014) that the brain constantly builds as a response to what is in the environment. Importantly, the “3D movie” also includes the perceiver and his or her mental states, thoughts, and bodily sensations, which are also integrated into the patchwork of consciousness through self-representation. There is then a sensitivity to this first-person

perspective 3D movie, which can result in the creation of new percepts (e.g., being surprised by the content of our own “3D movie”). This constant dynamic differentiates the perspective developed here from the problematic idea of a conscious homunculus that is “watching” what has been constructed, resulting in the problem of endless regress.

Similarity of percepts

This work is not concerned with the question of how a percept comes to have a particular nature (i.e., answering the hard problem), but rather with the related but equally difficult question of how this nature could be similar across individuals. Given the fact that percepts are inherently private, we must always make the assumption that others perceive objects in the world similarly to how we do in order to communicate effectively. This assumption is most famously questioned in the “inverted spectrum” thought experiment, in which a world is imagined where one person’s experience of “red” is another person’s experience of “green.” Because everyone in this world has the same color terminology, these two individuals never come to know that their percepts of the same wavelength of the visible spectrum are in fact inverted. The philosophical debate surrounding this concept, how it relates to consciousness, and its plausibility is extensive (see Byrne, 2018 for a review).

However, there are a few examples that point to gross differences in percepts across individuals, as is posited in this “inverted spectrum” world, being impossible. Firstly, it does not seem plausible that uniform systems of spoken language would have emerged if percepts were not similar across individuals. Accurately producing and receiving signals within a shared environment requires all members of a group to similarly perceive the objects to which those

signals refer. This would have been extremely important for early humans: mating, in-group bonding, predator avoidance, and passing on knowledge about things within the environment all would have relied on a basic similarity of perception across group members (Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012). Individuals who could better accurately both produce and receive these signals in relation to the environment would have had a survival advantage. It thus would have been evolutionarily advantageous for individuals to have the ability to build similar percepts, and it is clear today that the way we communicate about the world is deeply rooted in them.

There are multiple instances of how, when percepts largely differ, it is discovered. A recent and note-worthy example is the photo “The Dress” that went viral online in 2015 due to widespread disagreement over its color (Figure 1). “The Dress” had social media users divided over whether it was blue and black or gold and white. The source of the disagreement over this particular image has been attributed to individual differences in discrimination along the blue-white color axis, as well as in tendencies to assume either a cool or warm illumination (Lafer-Sousa, Hermann, & Conway, 2015; Winkler, Spillmann, Werner, & Webster, 2015). The ambiguous lighting in the original photo combined with these individual biases resulted in two opposing percepts. This suggests that when in similar illumination or physical environment, individuals’ perceptions of color are generally similar, and no disagreement arises. This likely extends to other sense modalities (see Pressnitzer, Graves, Chambers, De Gardelle, & Egger, 2018 for a similar example in the auditory domain).



Figure 1. Original image of “The Dress” that went viral on social media.

Synesthesia is another notable example of discoverable differences in percepts. Synesthesia is a perceptual phenomenon involving a “merging” of the senses where an ordinary sensory activity (e.g. reading words) is accompanied by another sensory percept (e.g., seeing colors) (Simner, 2007). Many synesthetes report having assumed that others experience similar cross-modal perceptions and are surprised when they later learn this is not the case (Hubbard, 2007). However, it is known that in visual synesthesia there can be activations of the visual cortex without external visual stimulation (Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001; Nunn et al., 2002). It could thus be argued that in the absence of abnormal cortical connections or activations such as in synesthesia, percepts are similar across individuals due to the similarity in brain structure and organization of the areas that respond to specific types of

stimuli. But this argument comes into question given the known plasticity of the brain, or its ability to “rewire” itself in the cases of stroke or early loss of a particular sensory system as in acquired blindness or deafness (Finney, Fine, & Dobkins, 2001; Sadato, Okada, Honda, & Yonekura, 2002). It must be concluded then that the nature of a percept cannot be fully explained by examining only the activity of the brain areas with which it correlates. Even the suggestion that it is not neuronal groups but rather patterns of activations within them that are responsible for this nature cannot explain how individuals could experience similar percepts: it is unclear how different neural networks could learn to produce functionally similar patterns if the nature of the stimulus itself is not constraining such patterns.

Review of Haffar et al. (2018)

Given these perspectives, the source of the assumed similarity of percepts across individuals becomes unclear. To account for this, Haffar et al. (2018) hypothesized that individuals might not only be sensitive to the production of their own percepts but to that of others as well, which could help brains produce similar representations. To test this, they designed an experiment where changes in a participant’s brain activity resulting from the manipulation of a stimulus shown to a partner could be detected. They used electroencephalography (EEG) to compute event-related potentials (ERPs) as a measure of brain activity.

ERPs are calculated by averaging the EEG epochs of the trials of a given experimental condition. An epoch contains raw EEG corresponding to the time period over which a stimulus was presented. This averaging process results in a reduction of the noise present in raw EEG,

leaving only the signal of the synchronous activation of neural populations that were related to the sensory, motor, or cognitive event to which the epochs were time-locked (Luck, 2005). This signal is the event-related potential (ERP), which contains components that can be studied based on their positive or negative deflection, latency, or scalp distribution. By measuring ERP voltages within certain time-windows, the experimental manipulation of specific ERP components can be assessed and the role of that component in certain cognitive processes can be determined. ERPs provide a millisecond-by-millisecond look at changes in these processes.

ERP studies have been especially important in the field of cognitive neuroscience, providing insight into the timing of, and the relationship between, various cognitive activities. In early ERP work, it was discovered that visual stimuli that are attended result in larger amplitudes of early ERP components (P1 and N1) compared to stimuli that were ignored or not noticed (Hillyard, Hink, Schwent, & Picton, 1973; Herrmann & Knight, 2001). Another early component, the N170, is evoked by the presentation of human faces but not by animate or inanimate non-face stimuli (Bentin, Truett, Puce, Perez, & McCarthy, 1996), revealing that ERP components can be directly related to the nature of the stimulus being perceived. Late occurring components (e.g. N400, LPP) have been linked to the processing of a stimulus' meaning, its involvement in working memory operations, or its integration into mental representations (Kutas & Federmeier, 2001; Hahne & Friederici; Brouwer, Fitz, & Hoeks, 2012). From the abundant literature on ERP components, it is apparent that these studies can provide a framework for understanding stimulus processing. Given these qualities, this method was appropriate for Haffar et al. to use in order to test their hypothesis that an individual's processing could be impacted by that of another person to whom the individual is socially close. Their methods provide the basis

for the present work. In their study, they used an EEG hyperscanning protocol in which they recorded EEG from two partners while an image was presented to each of them simultaneously. Because of the unique nature of their hypothesis, they did not have an *a priori* hypothesis regarding which ERP components they expected to be modulated by the predicted influence.

To my knowledge, there have not been any studies that directly tested for an effect of one person's stimulus processing on that of another person in order to explain how similar percepts could be produced (other than the work that is reviewed in this thesis). Instead, most EEG hyperscanning studies have focused on functional similarities or phase synchronization of oscillations of two people's brains while they are interacting. The common denominator across these studies is that participants are directly involved in a social interaction, for example a game or task that requires cooperation or coordination (Dumas, Lachat, Martinerie, Nadel, & George, 2011). It is therefore assumed that such brain-to-brain coupling must be a result of behavioral feedback. A more difficult to understand but logically possible assumption would be that there are emergent inter-brain dynamics and couplings that can occur as a result of complex interactions between an individual and his/her interacting partner, as well as the environment (Konvalinka & Roepstorff, 2012). It is therefore necessary to fully introduce the scope of this thesis by summarizing the methods and results of Haffar et al. (2018), as it depicts a unique use of hyperscanning that could potentially detect any passive and/or systematic effects of one individual's stimulus processing on that of another that does not occur during direct social interaction.

Haffar et al. recruited pairs of participants who were friends, siblings, romantic partners, etc. They theorized that their proposed effect could be stronger in those with an existing social

bond vs. complete strangers. Indeed, it appears logical that an individual could be more sensitive to the stimulus processing of someone with whom they have things in common (e.g., cultural background, upbringing, etc.) and engage socially, as (s)he could be more “tuned” to his/her close others. In the experiment, two images were presented on one computer screen while the two participants sat directly next to each other, both looking at the screen. One image was located on each half of the screen, and a cardboard divider was placed in such a way that either participant could only see the image on the side closest to him/her (i.e., the person sitting on the left could only see the left half of the screen and vice versa). A curtain was also hung between them so that even if they moved their eyes or head, they would be unable to see the image on their partner’s side of the screen. The curtain also prevented them from seeing their partner in their peripheral vision. Each trial in the experiment consisted of the simultaneous presentation of the two images (Figure 2).

Computer screen in Haffar et al. (2018)

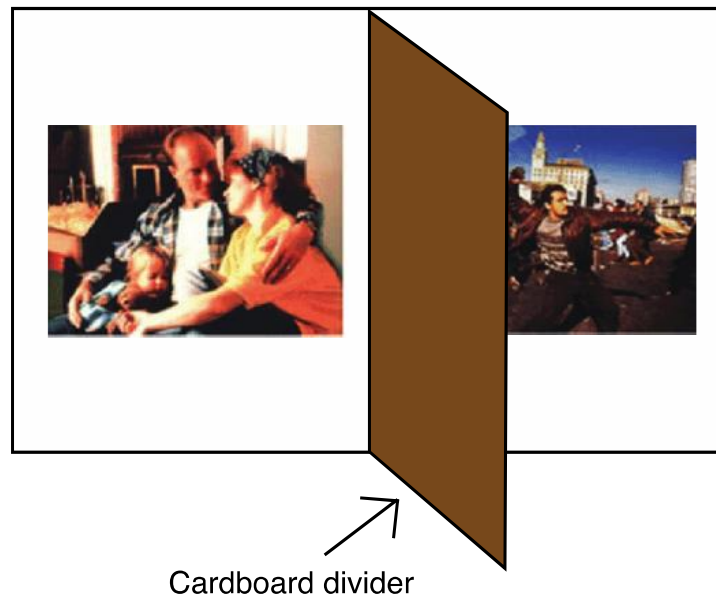


Figure 2. Schematic of the appearance of the computer screen during one trial in Haffar et al. (2018). In each trial, the two images were presented at the exact same time.

Four blocks of trials were presented. Within each block, the sameness of the two images in each trial was manipulated, as well as the participants' knowledge about that sameness. For two of the blocks, an announcement was presented on both sides of the screen which read, "You will see different images than your friend." The other two blocks began with the announcement, "You will see the same images as your friend." This information functioned as a prime for the brain of the participants to modulate its use of the hypothesized sensitivity to the stimulus processing of their partner. Haffar et al. reasoned such a sensitivity should depend on the knowledge of whether or not the other individual is viewing the same visual scene. For two out of the four blocks, the statement before the block was untrue (i.e., they were told they would see different images but instead were presented identical images, and vice versa). The blocks where

the announcement was true were considered “concordant” and the blocks where the announcement was false were considered “non-concordant” (see Table 1). Figure 3 shows a schematic of the stimulus presentation in a non-concordant block. Due to the cardboard divider and the curtain, partners had no way of discerning whether or not the trials in a given block were in concordance with the preceding announcement. Additionally, the curtain prevented a participant from detecting any physical reactions his/her partner may have had to particularly graphic images, which, if they did not match with the reaction of the participant, could have hinted that it was currently a non-concordant block.

Table 1. Blocks of trials that were presented in Haffar et al. (2018).

Block #	Actual sameness of the two images simultaneously presented in each trial	Announcement preceding the block	Type of block (condition)
1	Identical	“You will see the same images as your friend.”	Concordant
2	Different	“You will see the same images as your friend.	Non-concordant
3	Different	“You will see different images than your friend.”	Concordant
4	Identical	“You will see different images than your friend.”	Non-concordant

Note. The order of presentation of these blocks was randomized across pairs but are labeled #1-4 here for ease of representation.

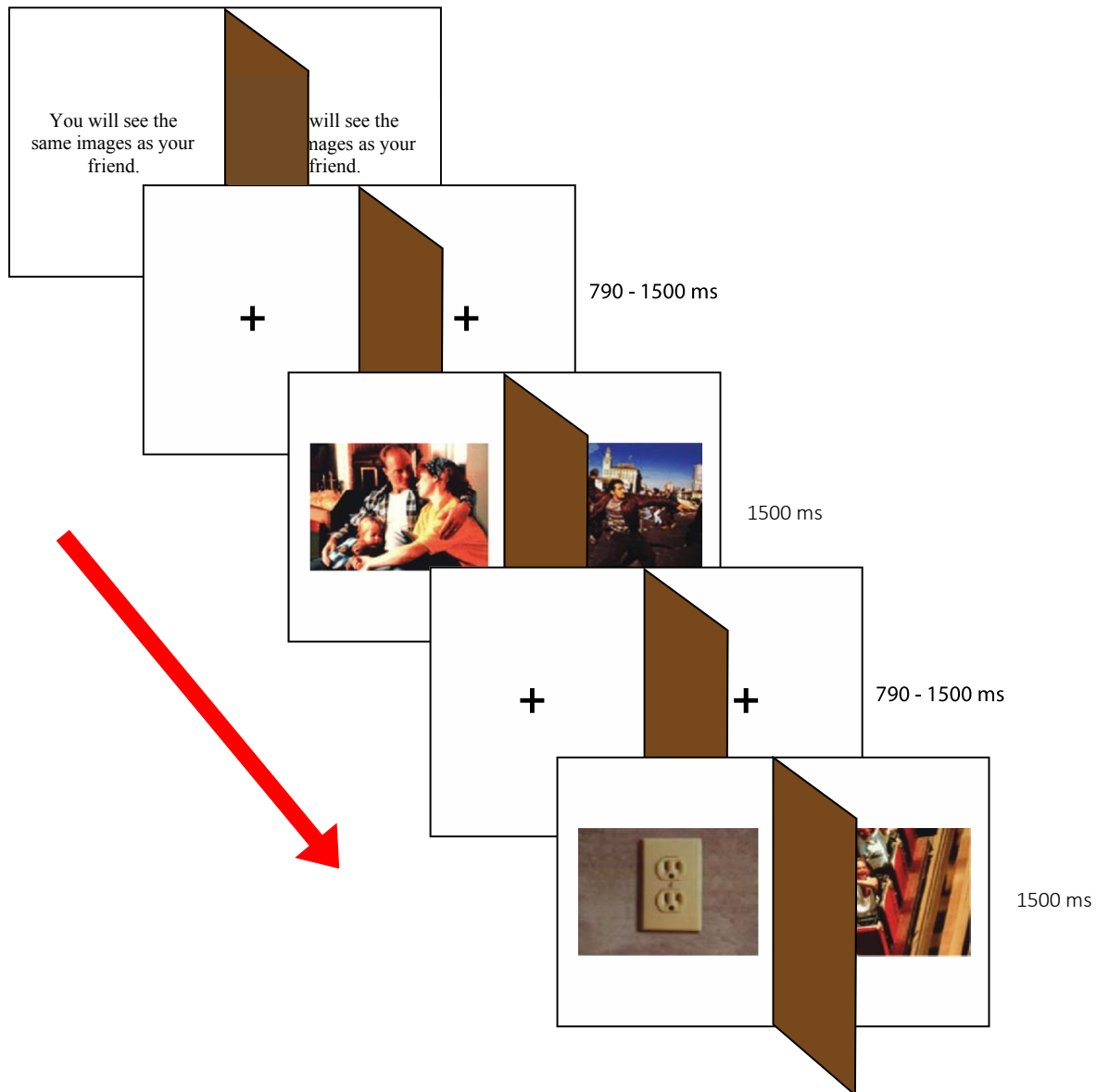


Figure 3. Example of a stimulus presentation in a non-concordant block in Haffar et al. (2018).

Each image appeared for 1500 ms and was followed by a black fixation cross, the duration of which varied between 790 and 1500 ms.

Haffar et al. computed ERPs by creating one for the average of the two concordant blocks and one for average of the two non-concordant blocks, resulting in two ERPs for each participant. Figure 4 shows the grand average ERPs of these two conditions for the 16 pairs they tested (n=32). They found a main effect of concordance on ERP mean voltages in two time-windows (350-550 ms and 650-950 ms). In other words, the ERPs of the blocks where the images did not match the announcement were different from the ERPs of the blocks where they did match, even though it was impossible for participants to know when either condition was occurring. These results were taken as support the hypothesis that the partner's processing of the visual stimulus impacted that of the participant. However, a few problems could have contributed to the results that they found. The work of this thesis aimed to replicate the results of Haffar et al. while addressing those problems.

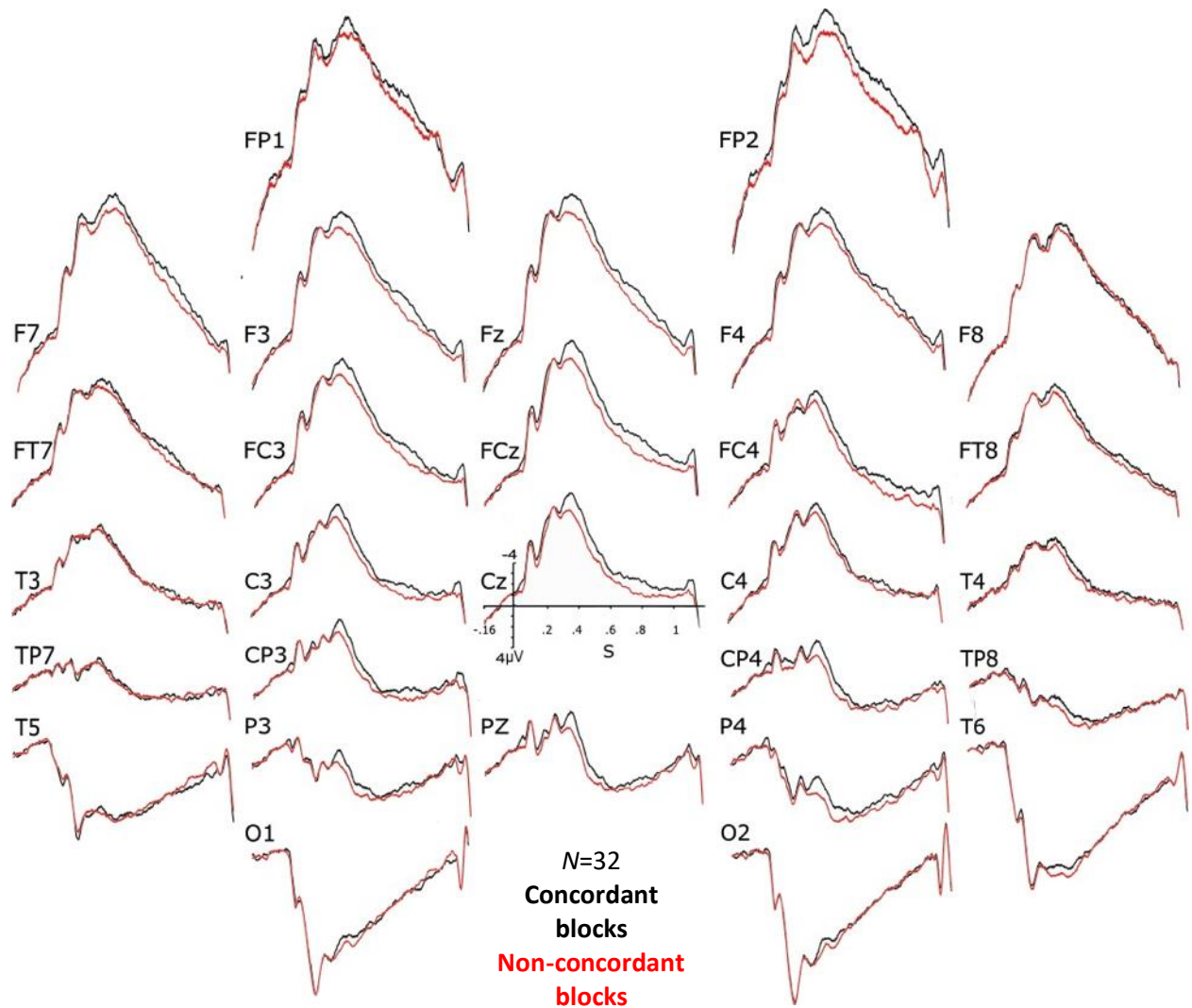


Figure 4. Grand average ERPs of Haffar et al. (2018) ($n=32$). The red lines are the ERPs of the two gathered blocks where the stimulus sameness was non-concordant with the announcement preceding the blocks. The black lines are the ERPs of the two gathered blocks where the stimulus sameness was concordant with the announcement preceding the blocks.

The present study: addressing the problems of Haffar et al. (2018)

Haffar et al. used a curtain between partners as a method for ensuring they could not discover whether they received a true or a false announcement before each block of stimuli. During the debriefing session, participants mentioned that they did not feel deceived at any point.

Nevertheless, it could be argued that the discovery still occurred and remained covert. Some of the stimuli they used depicted war, sex, and other scenes which could have elicited small gasps or changes in breathing as a reaction. While the curtain should have successfully stopped participants from noticing their partner's physical movements in response to those shocking images (e.g., a reflexive moving of the head backward, wincing, head tilting, etc.), it was not sufficient to prevent participants from hearing any of their partner's possible reactions (e.g., nervous laughter, change of breathing pattern, etc.). If this occurred during a non-concordant block where participants believed they would be seeing identical images and the partner's audible reaction did not align with the image on the participant's side of the screen, the falseness of the announcement could have been preconsciously detected. Although extremely unlikely, such a covert and/or preconscious detection could have had an impact on a participant's processing of the entire block. To address this, we used a similar stimulus presentation but tested partners who were in separate rooms, eliminating all possibility of noticing each other's reactions to the stimuli. These partners had a prior existing social bond to match what was done in Haffar et al.

Another problem in their design was that trials were presented in blocks of each condition. It is a well-studied phenomenon that ERPs can be affected by fatigue or repetition (Humphrey, Kramer, & Stanny, 1994; Polich & Kok, 1994). Therefore, having all the trials from

one condition in the same block could have resulted in these effects being present in the ERPs of the later blocks that a participant was presented. Although Haffar et al. randomized the order of the presentation of the blocks across pairs, this could still be a concern. On the other hand, preconsciously detecting that they were in a concordant or in non-concordant block (either through the previous examples or through the hypothesized influence of the partner's stimulus processing) could have resulted in the development of a strategy of processing that impacted the entire block. To avoid these two possibilities, we randomized the order of types of trials (concordant vs. non-concordant) within the experiment rather than presenting them in blocks of each type. For simplicity and ease of understanding, we also reduced the number of conditions from four to two: in the present work, the only announcement that was given before the stimulus presentation was that participants would see different images than their partner. Randomly, each trial was either concordant with this announcement or non-concordant. Thus, we maintained the critical distinction of comparing ERPs for which the two conditions differed in concordance. We hypothesized that there would be a difference in ERP mean voltage between the concordant and non-concordant condition. Our objective was to search for any effect of the nature of the partner's stimulus on the ERPs of the participant. We did not have any *a priori* hypothesis about the direction of these effects or about which particular ERP components they would involve.

Although necessary to produce completely reliable results, these changes in the experimental design could modify the ERP effects found in Haffar et al (2018). They could diminish them or even prevent them. One factor in these potential modifications could be the now increased physical distance between the partners. Partners were sitting extremely close to each other in Haffar et al., and they probably could not help but strongly feel in each other's

presence. The testing of partners in separate rooms could have greatly decreased this feeling of togetherness. Before the stimulus presentation, we thus asked partners to try and feel in the presence of each other despite being physically separated and, after the experiment, we asked them how successful they thought they were at doing so. Using these responses, we grouped participants into a felt-together group and a felt-alone group; maintenance of such a feeling for at least half of the experiment was defined as the criteria for being in the felt-together group. Using these two groups, it could be assessed whether this feeling could have influenced the results of Haffar et al. Both within-subjects and between-subjects analyses were thus performed. To further investigate the role of feeling the presence of the partner during the experiment, we also recruited a control group of individuals who were presented the same stimuli alone instead of with a partner. This served as a baseline for what ERP differences can be found between two randomly chosen sets of trials simply by chance when an individual is presented with a sequence of IAPS images.

Another social factor that seemed relevant to control for was the severity of the autism-like traits of each participant. Since this work focuses on the idea that interactions between brains and similarity of percepts across individuals, it may be related to the concept of theory of mind. Theory of mind is the ability to attribute full mental states to other individuals and understand that they may have perspectives different than one's own (Baron-Cohen, 2000). This is often considered in research on autism-spectrum disorders (ASD), since individuals with ASD are known to have difficulties with theory of mind, resulting in a decreased ability to imagine what others are thinking and abnormal social development (Baron-Cohen, Leslie, & Frith, 1985). These issues are most present during childhood development but can continue into adulthood in

varying degrees (Brewer, Young, & Barnett, 2017). To investigate whether a stronger tendency toward ASD-like traits in the normal population is related to the degree to which a person's stimulus processing can be impacted by that of another individual, partners were asked to complete the Autism-spectrum Quotient (AQ) before the experiment. The AQ measures the degree to which an adult who does not have ASD possesses the social and cognitive traits associated with it (Baron-Cohen, Leslie, & Frith, 1985). Based on their scores, participants were grouped into high- and low-AQ scorers (using a median split) in order to assess whether ERP differences between the concordant and non-concordant conditions could be greater in one group or the other. Only fifteen participants were administered the AQ in the present study. Ultimately, more data with AQ scores needs to be collected to make any claims about this relationship, and therefore the current preliminary results will not be presented in this thesis. The importance of the continued study of this relationship will be discussed, however.

In the present study, we also chose to do a more in-depth analysis of the ERPs themselves than was done in Haffar et al. We measured the mean voltages of the ERPs of all the partners in the 350-550 ms and 650-950 ms time-windows to cover the N400 and LPP components, as this is where Haffar et al. found differences. However, given the changes in the experimental design and the fact that any ERP effect of concordance would support the hypothesis, we further explored the data by measuring those mean voltages in an early (75-150 ms) time-window to check whether any very early precursor effects were present. Mixed model repeated measures ANOVAs were performed on these mean voltages to assess the effect of concordance on ERPs and whether it interacted with the feeling of togetherness. We also visually inspected the grand average ERPs for any noticeable differences that were not within those predetermined time-

windows and were not discovered in Haffar et al. in order to build new *a priori* hypotheses for future studies.

Due to the lack of precise expectations of ERP differences after making the aforementioned changes to the experimental protocol, we felt taking these extra steps were important for testing the hypothesis. To this end, and not to miss significant but idiosyncratic differences that would not appear on ERP grand averages, single subject permutation tests using single trial EEG epochs were also performed to assess whether differences found in each subject were due to chance or were actually due to the manipulation of the concordance of stimuli with the announcement.

Materials and methods

Participants

Forty-three pairs of closely related individuals were recruited ($N=86$; 22 M, 64 F). For each pair, the two participants had known each other for at least 3 years. All of them were between 18 and 30 years of age (mean age=23.1 years, $SD=3$) with normal or corrected-to-normal vision. All of them had completed or were in the process of completing a university degree. Individuals were not eligible to participate if they consumed more than twelve alcoholic beverages per week, used recreational drugs, had a history of a psychiatric disorder, took medication related to such a disorder, or if one of their first-degree relatives had a history of schizophrenia or bipolar disorder. Criteria were checked using a self-report eligibility questionnaire. Both members of a pair had to meet these criteria to be included in the study.

A control group of 27 individuals who came to the lab without a partner was also recruited (Alone Group; 12 M, 15 F). They were recruited in the same manner and the same inclusion/exclusion criteria were used (mean age=22.2 years, SD=3.05).

Consent

All participants read and signed the informed consent form prior to the experiment. Both the consent form and the study itself were accepted by the Douglas Ethics Review Board at the Douglas Mental Health University Institute where the study was conducted. The board follows the principles expressed in the Declaration of Helsinki. Data were anonymized, which did not distort scientific meaning.

Stimuli

For pairs, the stimuli were 600 images from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 1997). A trial consisted of two IAPS images: one image was presented to one partner, and the other was presented to the other partner at the exact same time. These two images could be identical, or they could be different. It was always announced before the stimulus presentation that they would see different images than their partner. Therefore, trials with two different images were part of the “concordant condition” and trials with two identical images were part of the “non-concordant” condition (see Table 2).

Table 2. The two conditions used in the present study.

Announcement preceding the stimulus presentation	Sameness of the two images presented in a trial	Condition
“Your partner will be seeing different images.”	Identical	Non-concordant
	Different	Concordant

Six different stimulus sequences were created. Sequences #1-3 contained 300 of the 600 IAPS images, while sequences #4-6 contained the other 300. The sequences were made using six folders of images, each of which contained 100 different IAPS images (folders A-F). For one sequence, three folders were utilized during the stimulus presentation. One was used for the non-concordant condition (identical images) in order to display the same image to both participants. The two other folders were used for the concordant condition (different images) in order to display one image from each folder to either participant. Therefore, by the end of the experiment, each participant had seen a total of 200 images. Table 3 shows how the folders of IAPS images were allocated to different stimulus sequences, and how many pairs were presented each sequence.

Within one sequence, the order of concordant and non-concordant trials was randomized with respect to the other sets. In other words, within a given stimulus sequence the order of trials was always the same and the same pairings of images were always used. For example, every pair

that was presented stimulus sequence 1 saw the same exact order and the same pairings of images, but this differed from sequence 2.

Each IAPS image has a rating on a scale of 1-9 for three dimensions: valence, arousal, and dominance (Lang, Bradley, & Cuthbert, 2008). The average rating of the images within each folder is given in Table 4, as well as the number of pairs who were presented each sequence. The IAPS image numbers that were contained in each folder can be found in Appendix A.

Table 3. Allocation of IAPS image folders to each stimulus sequence.

Stimulus sequence	Folder of images used for non-concordant condition (two identical images presented)	Folders of images used for concordant condition (two different images presented)	Number of pairs presented the sequence
1	A	B, C	6
2	C	A, B	7
3	B	A, C	8
4	D	E, F	8
5	F	D, E	7
6	E	D, F	7

Table 4. Mean(SD) rating of images within each folder used to create stimulus sequences.

	A	B	C	D	E	F
Valence	4.8(3.8)	5(3.8)	4.9(3.6)	5(5.9)	5(5.9)	5(6)
Arousal	5(3.7)	5(3.7)	5.1(3.6)	4.7(6)	5(6)	5(6)
Dominance	4.9(3.6)	4.9(3.7)	5.2(3.6)	4.9(6)	4.9(6)	5(5.7)

Note. Ratings can be found in the IAPS Technical Manual (Lang et al., 2008).

For the Alone Group, the stimuli were 140 IAPS images. There were no sets of identical or different images since participants were alone and not with a partner. Only a single image was presented at a time.

For every participant from both groups, each image appeared for 1500 ms, followed by a black fixation cross centered on a white background with a duration varying from 790 ms to 1500 ms. The fixation cross was replaced by the image of the next trial. Continuous EEG was recorded from every participant.

Procedure

Partners

After reading and signing the consent form (or after doing so and then completing the AQ for those who were administered it), participants were escorted to the hyperscanning laboratory. For pairs, one partner was seated in front of a computer screen in a room that was adjacent to the room in which the other partner was seated (1 person in each room). The wall shared by the adjacent rooms had a double glass window (86 x 178 cm) that was covered by a removable curtain on both sides. The curtain was open during the EEG setup but was closed at the start of the experiment and for its entire duration. Figure 5 shows the experimental setup for the partners.

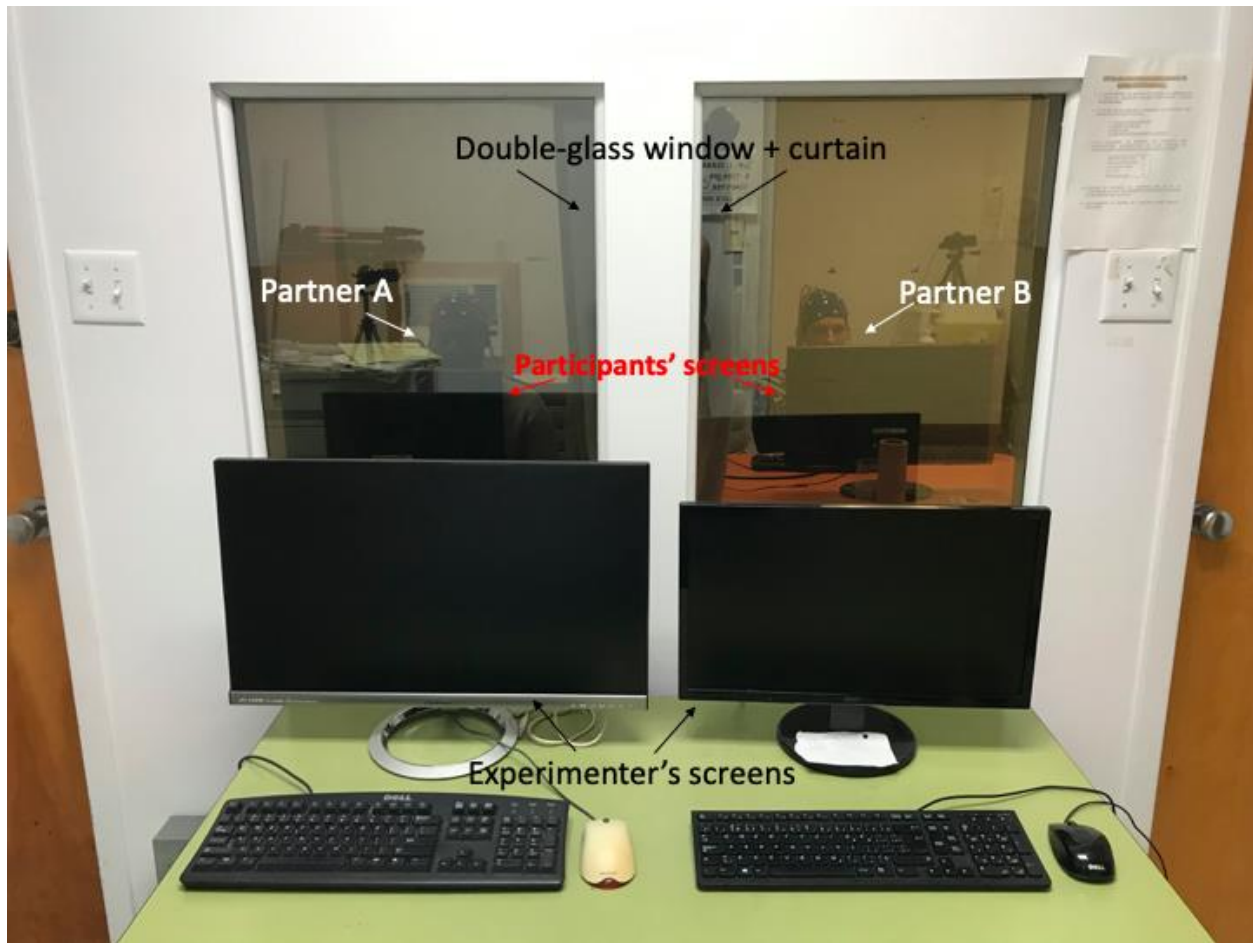
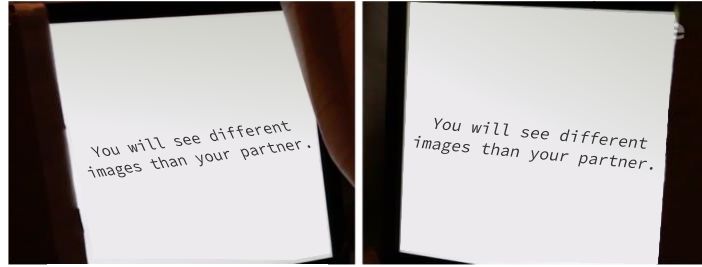


Figure 5. Experimental setup. *Note:* during the entire experiment, an opaque black curtain covered the entirety of the windows in front of each participant, so they could not see the experimenter sitting in front of the experimenter screens. The lights inside the participants' rooms were also dimmed.

Just before the stimulus presentation, participants were instructed that their task was to try and memorize all of the images they would be presented and that while doing this they should try to feel the presence of their partner despite not being able to see them. A simple memorization task was chosen in order to ensure the maintenance of attention throughout the entire experiment without biasing processing strategy. After the task instruction, an announcement appeared on both screens saying that they would be seeing different images than their partner. Then the stimulus presentation began. Figure 6 shows examples of what the presentation on the two screens looked like for a trial in each condition.

Before the Stimulus Presentation



Partner A's Screen

Partner B's Screen

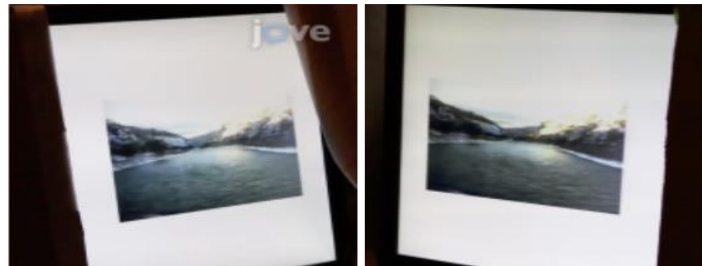
Concordant Condition



Partner A's Screen

Partner B's Screen

Non-concordant Condition



Partner A's Screen

Partner B's Screen

Figure 6. Examples of IAPS stimuli on each partner's screen during a concordant condition trial and a non-concordant condition trial. Screenshots were taken with permission from Tardif, et al. (2018).

Alone Group

Each participant in the control group was seated in a room in front of a single computer screen and was completely alone during the experiment. These participants were also instructed to try and memorize each image. There was no announcement about stimulus sameness; the stimulus presentation began after the task instruction.

Debriefing

All participants completed a debriefing questionnaire upon finishing the experiment. Partners completed this individually without talking to their partner and had to report the degree to which they felt in the presence of their partner during the experiment despite being in separate rooms. The question read: “We asked you to try to feel in the presence of your partner during the experiment even when the curtains were closed. Please select the option that best represents when you felt in the presence of your partner during the experiment. Be sure to read the choices carefully and select the one that best applies.” The choices were: “I felt in the presence of my partner during the entire image presentation,” “I felt in the presence of my partner for MORE than 50% of the image presentation,” “I felt in the presence of my partner for about 50% of the image presentation,” “I felt in the presence of my partner for LESS than 50% of the image presentation,” or “I didn’t feel in the presence of my partner at all during the image presentation.” Participants who responded “100% of the time,” “more than 50% of the time,” or “about 50% of the time” were categorized as the felt-together group. Participants who responded “less than 50%

of the time” or “I didn’t feel in the presence of my partner at all” were categorized as the felt-alone Group. Thus, partners in a pair could be in the same group or in different groups. They were also asked whether or not they felt deceived at any point during the experiment and, if yes, to give their reason.

Data acquisition

The electroencephalogram (EEG) was recorded from each participant using 28 tin electrodes in an elastic cap from Electro-Cap International. These electrodes were placed according to the modified expanded 10-20 system (Electrode nomenclature committee, 1991). Electrodes were grouped into three subsets: sagittal (Fz, Fcz, Cz, and Pz), parasagittal (Fp1/2, F3/4, Fc3/4, C3/4, Cp3/4, P3/4, and O1/2), and lateral (F7/8, Ft7/8, T3/4, Tp7/8, and T5/6). Figure 7 shows their locations on the scalp. There was a separate set of amplifiers for each cap during the simultaneous recording of partners. The right earlobe was used as the reference and the ground was taken from an electrode two centimeters ahead of Fz. For all amplifiers, high- and low-pass filter half-amplitude cut-offs were set at 0.01 and 100 Hz, respectively. An additional 60 Hz notch filter was also used. EEG signals were amplified at a gain of 20,000 and digitized online at a 256 Hz sampling rate. For pairs, data was stored in a single file with 56 channels that was later divided into one for each participant.

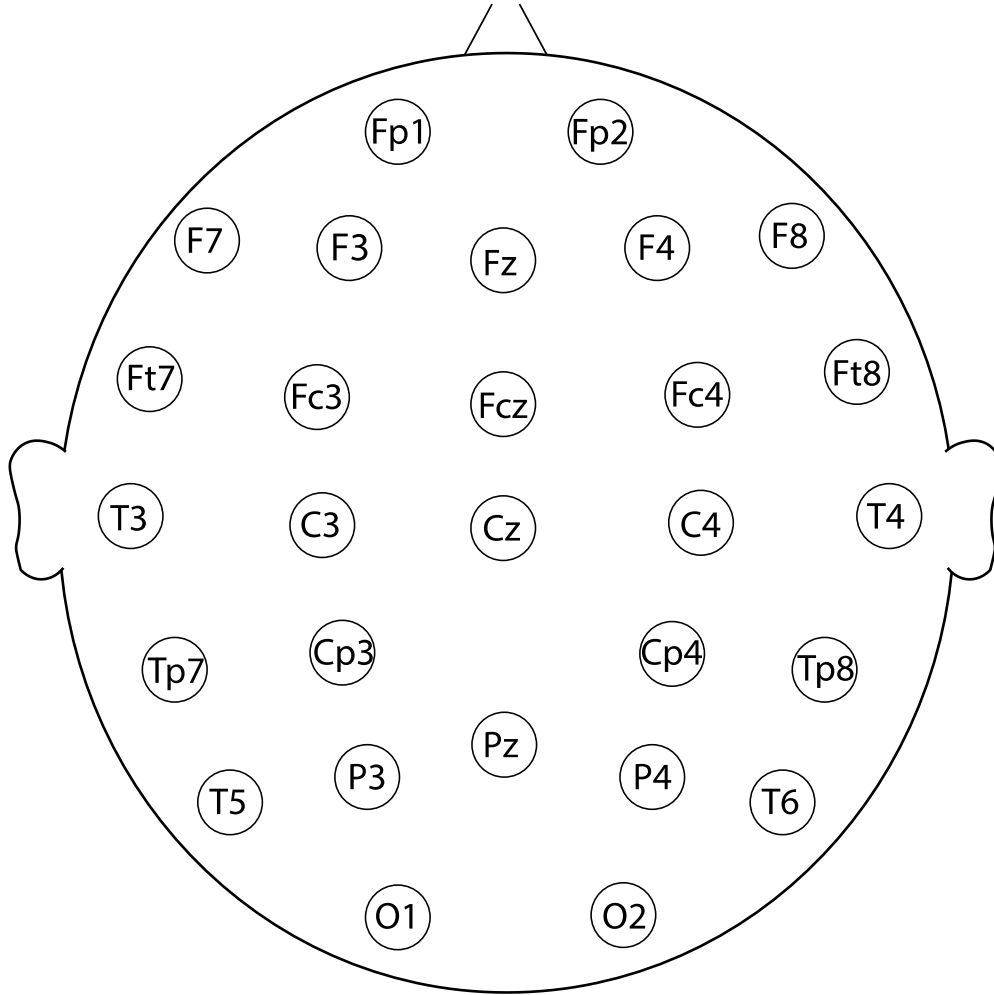


Figure 7. Scalp locations of the 28 electrodes from which EEG was recorded.

Offline data processing and measures

EEG epochs starting 200 ms before the stimulus onset and ending 1000 ms after were extracted from the continuous EEG. The baseline of each of these epochs was set by computing the mean voltage value from -200 ms to the onset of the stimulus and by subtracting this value from each point of the whole EEG epoch. Then, EEG epochs that were contaminated by eye movements, excessive myogram, amplifier saturations, or analog to digital clipping were removed using the

Matlab toolbox EEGLab (version 14.1.1b) (Delorme & Makeig, 2004). This was done by removing EEG epochs having flat lines persisting for more than 100ms or with amplitudes exceeding $\pm 75 \mu\text{V}$. For electrode sites nearest to the eyes (Fp1/2, F7/8), this amplitude threshold was increased to $\pm 100 \mu\text{V}$ to account for the possibility of more prevalent eye movement myograms. If there was a channel having so many artifactual epochs that too few (i.e., less than 30) remained to compute ERPs, this channel was recomputed by interpolating nearby channels. Trial epochs were averaged for each condition and for each participant in a 1200 ms time window, beginning 200 ms before the onset of the stimulus until 1000 ms after its onset. For pairs, these steps were performed separately for channels 1-28 (EEG of one partner) and channels 29-56 (EEG of the other partner). Each file was then divided into two, each containing the two ERPs (one for each condition) of a single subject and were analyzed independently of the pair to which participants initially belonged. Grand average ERPs were computed by averaging together the ERPs for all participants.

Since participants in the Alone Group did not have a partner, there could be no concordant or non-concordant conditions by which to label and sort the epochs. Two ERPs for participants in the Alone Group were therefore computed using two randomly sorted sets of trial epochs. This was repeated 4 times, so that we had four sets of two randomly computed ERPs for each participant, yielding four grand average ERPs to use as a baseline comparison. For analysis, however, only the first set was used.

Mean voltages were measured from the ERPs of every participant in three initial time-windows of interest (75-150 ms, 350-550 ms, and 650-950 ms) at every electrode. Upon visual inspection, unexpected but clear differences on the N3 component (200-350 ms) on Fp1 and Fp2

as well as in the 350-650 ms time-window at posterior electrodes were discovered. Therefore, ERP mean voltages were measured and analyzed for those time-windows, as well.

Analyses

For the 86 participants who were tested in a pair, mixed model repeated-measures ANOVAs were run using IBM-SPSS (version 23) to analyze ERP mean voltages in all time-windows using a multivariate approach. Within-subjects factors for the sagittal subset of electrodes were concordance (concordant vs. non-concordant) and electrodes. For the parasagittal and lateral subsets, the same within-subject factors were used with an additional factor: hemiscalp (left vs. right). Group (felt-together vs. felt-alone) was used as a between-subjects factor. Additional repeated measures ANOVAs were performed on mean voltages for the felt-together and felt-alone groups separately, using the same within-subjects factors as listed above. The Greenhouse & Geisser correction (1959) was used in all ANOVAs, and corrected F - and p -values are given. When there were significant interactions between concordance and electrodes in the 200-350 ms or 350-650 ms time-windows, post-hoc paired samples t -tests were performed on electrodes within those subsets that appeared to be the source of the interaction based on the grand average ERPs.

A single subject permutation test procedure was also performed on mean voltage measures made on each single trial EEG epoch using the Fieldtrip MATLAB toolbox (version 2019.04.10; Oostenveld, Fries, Maris & Schoffelen, 2011). For each subject, the artifact-free trial epochs from both conditions were taken (in the case of the Alone Group, two of the randomly sorted sets of trial epochs used to compute ERPs were used). A paired samples t -test was

performed to compare the average EEG voltage of those epochs from the two conditions within the three time-windows of interest and for each electrode, yielding a “critical t -value” for each. It was possible that the two conditions could have had a different number of artifact-free epochs, so in order to use such dependent tests it was sometimes necessary to randomly select however many epochs necessary to be removed from the condition having more so that the two conditions could have an equal number of epochs. The average number of epochs having to be removed in order to obtain an equal number was four, and the average number of remaining epochs was 69 (SD=17).

In order to evaluate a critical t -value, we compared it to a distribution of 1,000 t -values obtained from 1,000 permutations of epochs (Monte Carlo method). First, the artifact-free epochs of both conditions were pooled together. Then, two “null samples” were formed from the pool using a random partition. A null sample thus contained epochs from both conditions at random. The paired samples t -test was performed again but now comparing the two null samples, and the t -value was recorded. This resampling procedure was repeated 999 more times, yielding a total of 1,000 new t -values which approximated the distribution under the null hypothesis. It was used to evaluate the probability of finding the critical t -value (Di Nocera & Ferlazzo, 2000; Maris & Oostenveld, 2007). This procedure was performed on each channel and in each time-window of interest for each participant.

Instead of taking all critical p -values that were located within either of the 2.5% tails of their corresponding null distribution as significant, we used the Benjamini-Hochberg false discovery rate (B-H FDR) procedure (1995) to correct for multiple comparisons. This procedure controls the number of false positives within the total number of significant p -values. To do so

for each participant, the 28 p -values from each electrode within a given time-window were ranked from smallest to largest. Significance of each p -value was then evaluated by comparing it to its corresponding B-H FDR threshold, which was calculated using the formula:

$$0.10 \times (\text{rank} \div 28)$$

The rank of each p -value is its position in the ranking of smallest to largest. The rank of is divided by the number of tests. In this case it was 28 since that was the number of electrodes measured for each participant and a critical dependent samples t -test was performed for each. This result is multiplied by the chosen FDR (0.1, or 10%). P -values that were smaller than their B-H FDR calculated threshold based on their rank were considered significant.

Results

Debriefing responses

After the experiment, all participants completed a debriefing questionnaire. For the partners, they were asked to report the degree of which they felt in the presence of their partner during the entire experiment. Table 5 indicates the number of participants in each group and their demographic information.

Five of the 86 participants tested with a partner reported feeling deceived at any point during the experiment. However, only three of them indicated that their feeling actually stemmed from the announcement given before the stimulus presentation. Of the remaining two, one did not understand the question and the other referred to an unrelated aspect of the experiment being the source of her perceived deception (she felt that when pressing the spacebar to advance

through the screens containing the task instructions she was not actually controlling the advancement and the experimenter was the one doing so).

Table 5. Number and demographics of participants tested with a partner who felt together and who felt alone

Group	Number of participants (out of $N=86$)	Number of males	Number of females	Mean age (SD)
Felt-alone	47	14	33	22.9 (2.8)
Felt-together	39	8	31	23.3 (3.3)

Electrophysiology

Figure 8 shows the grand average ERPs of the 86 participants who were tested with a partner. The statistically significant results of the repeated measures ANOVAs of those participants' ERP mean voltages for all time-windows are included in Table 6. Interactions between concordance and electrodes were found in each time-window for at least one electrode subset, but no main effect of concordance on ERP mean voltages was found. Visual inspection of grand averages showed that posterior electrodes had the largest difference between concordant and non-concordant ERPs and were likely the source of the interactions in the 350-650 ms time-window. Post-hoc paired samples *t*-tests (two-tailed) performed there revealed significant differences at T6 [$t(83)=-2.6, p=0.01$], O2 [$t(81)=-2.7, p=0.007$], and O1 [$t(83)=-2.2, p=0.03$]. For the 200-350 ms time-window, post-hoc paired samples *t*-tests (two-tailed) were performed on Fp1 ($t(84)=-2.3, p=0.01$), Fp2 [$t(84)=-2.6, p=0.009$], F3 [$t(85)=-2.3, p=0.02$], and F4 [$t(-2.2)=-2.2, p=0.03$] which appeared to be the source of the interaction. The mixed model repeated measures ANOVA performed on mean voltages did not show any interaction between group and concordance in any time-window.

Subtraction waveforms of the felt-together and felt-alone groups are shown in Figure 11. For the 200-350 ms and 350-650 ms time-windows, mean voltage subtractions for both groups are shown in the spline interpolated maps of Figures 12a & b. Figure 13 shows the grand average ERPs for electrode O2 from the four sets of ERPs of the Alone group. Only O2 is depicted since this electrode had the most reliable difference in the two groups of partners in the 350-650 ms time-window.

ERP results from the high- and low-AQ scorers will not be reported; there is currently not enough participants who completed the AQ to reliably make any claims regarding whether there is a larger difference between concordant and non-concordant ERPs in either of those two groups of participants.

Felt Together

Figure 9 shows the grand average ERPs of the felt-together group ($n=39$). Additional repeated measures ANOVAs in the 350-650 ms time-window revealed an interaction between concordance and electrodes at the sagittal subset [$F(3, 120) = 5.6, p = 0.009, \eta_p^2 = 0.1$]. Paired samples t -tests (one-tailed) performed on posterior electrodes where the difference appeared the largest indicated a difference between the concordant and non-concordant ERPs at O2 [$t(36) = -1.8, p = 0.039$]. For the 200-350 ms time-window, the same analyses revealed a tendency toward an interaction between concordance and electrode at the parasagittal subset [$F(6, 210) = 3.02, p = 0.06, \eta_p^2 = 0.08$].

Felt Alone

The same analysis performed on the felt-alone group in the 350-650 ms time-window revealed an interaction between concordance and electrodes at the parasagittal subset [$F(6, 264) = 3.6, p = 0.04, \eta_p^2 = 0.08$] and lateral subset [$F(4, 176) = 3.4, p = 0.03, \eta_p^2 = 0.07$]. The paired samples t -tests (one-tailed) on posterior electrodes revealed differences at T6 [$t(45) = -2.08, p = 0.043$] and O2 [$t(44) = -2.07, p = 0.044$]. For the 200-350 ms time-window, the repeated measures ANOVA revealed a tendency toward an interaction between concordance and electrode at the parasagittal subset [$F(6, 264) = 3.4, p = 0.05, \eta_p^2 = 0.07$].

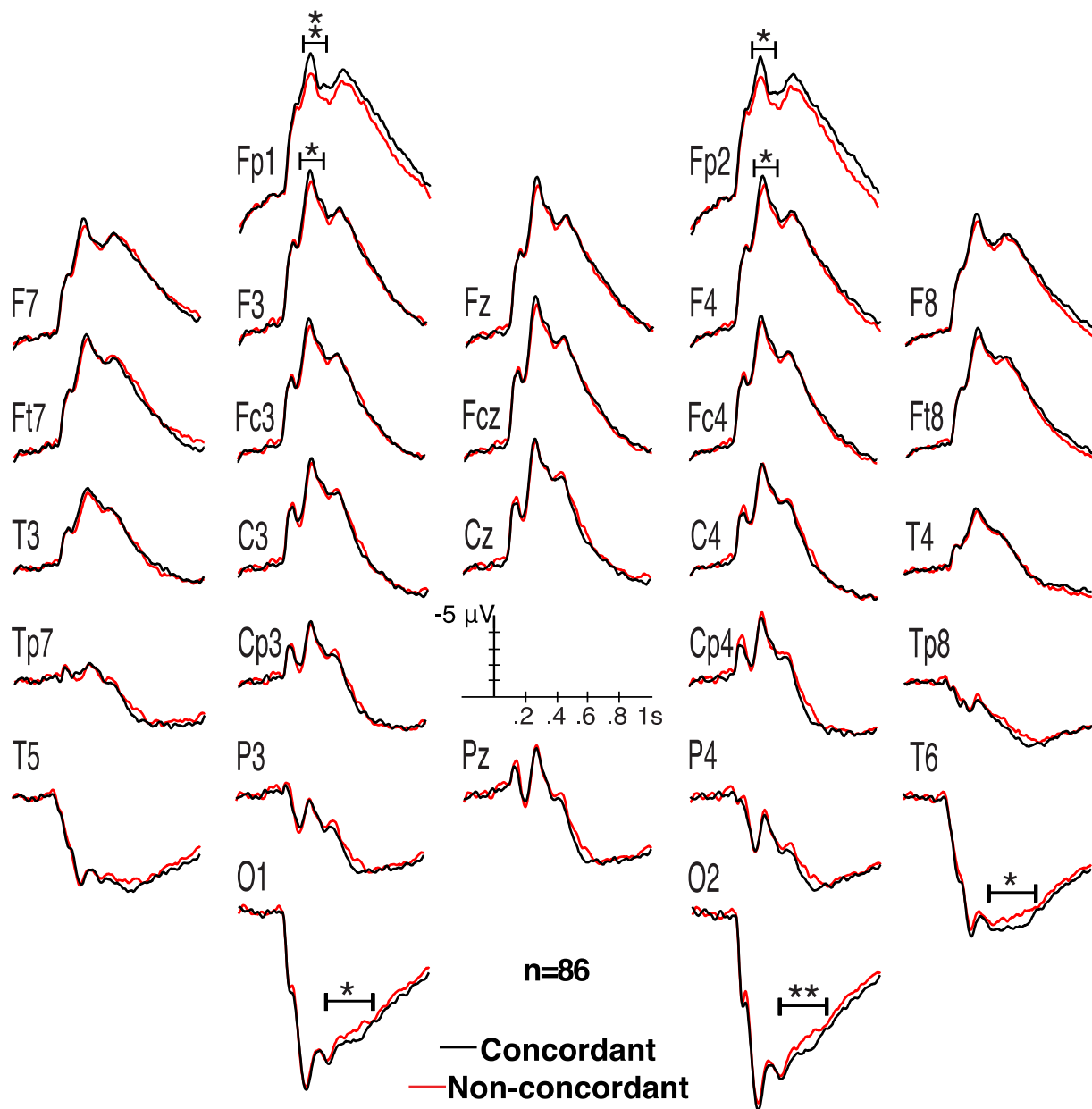


Figure 8. Grand average ERPs of the 86 participants who were tested with a partner. Negative values (microvolts) are going up on the y-axis, and the x-axis represents time. Stars indicate a statistically significant difference in mean voltages in the indicated time-windows found when testing that electrode separately using a paired samples *t*-test (two-tailed; * $p < 0.05$; ** $p < 0.01$).

Table 6. Statistically significant results ($p < 0.05$) of repeated measures ANOVAs on ERP mean voltages for all the participants who were tested with a partner ($n=86$).

Time Window: Electrode Subset		Within-subjects factor	F	df	p	η_p^2
75-150 ms:	Lateral	Concordance x electrode	3.1	4, 320	0.04	0.04
200-350 ms:	Parasagittal	Concordance x electrode	5.6	6, 474	0.007	0.06
350-550 ms:	Sagittal	Concordance x electrode	8.5	3, 252	0.001	0.09
	Parasagittal	Concordance x electrode	7.6	6, 474	0.001	0.08
	Lateral	Concordance x electrode	4.7	4, 320	0.007	0.05
350-650 ms:	Sagittal	Concordance x electrode	5.7	3, 252	0.006	0.06
	Parasagittal	Concordance x electrode	7.9	6, 474	0.001	0.09
	Lateral	Concordance x electrode	4.5	4, 320	0.007	0.05
650-950 ms:	Parasagittal	Concordance x electrode	4.7	6, 474	0.01	0.05

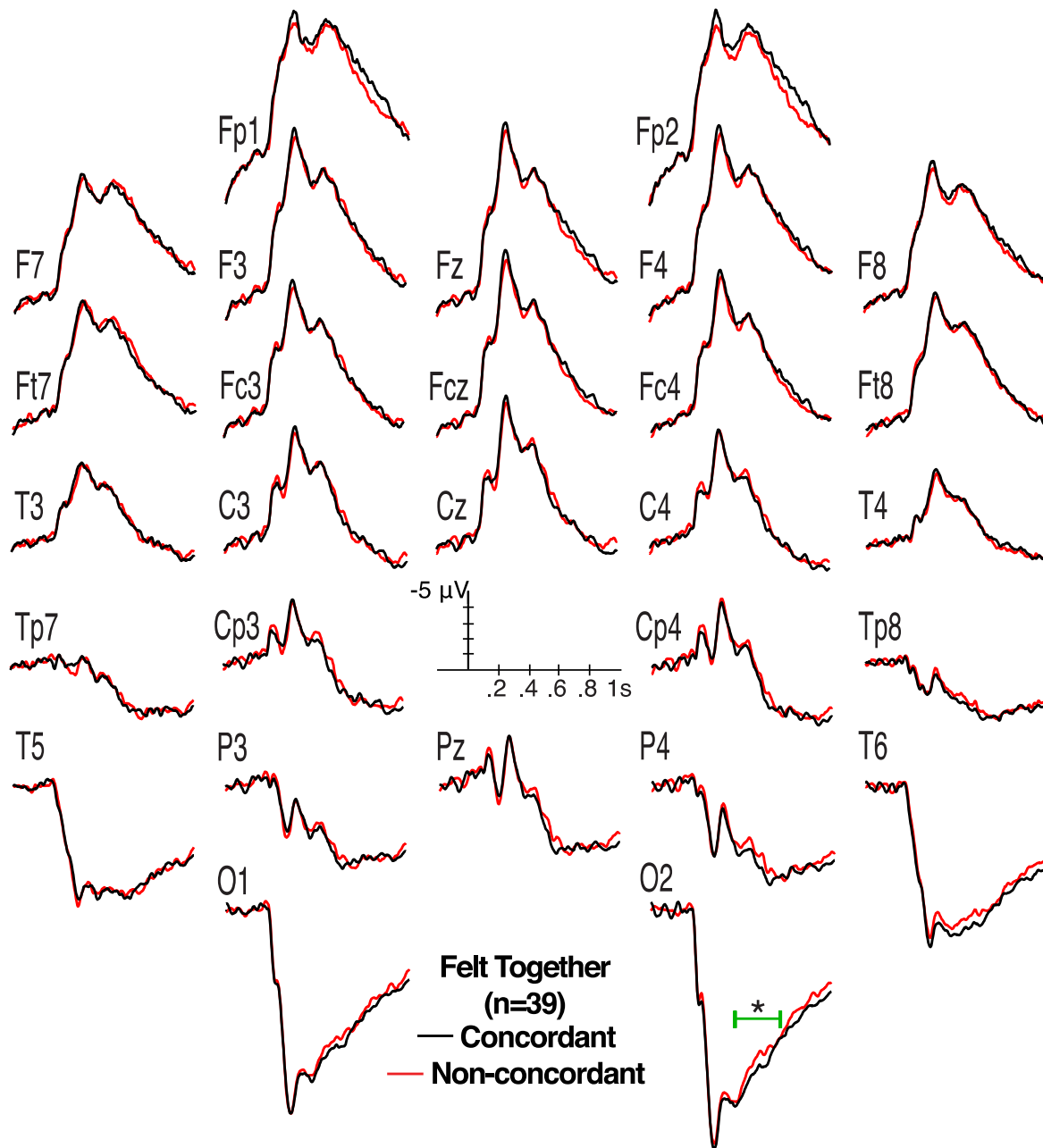


Figure 9. Grand average ERPs of the 39 participants who were tested with a partner and reported feeling in the presence of their partner during at least half of the experiment (felt-together).

Negative values (microvolts) are going up on the y-axis, and the x-axis represents time. A star indicates a statistically significant difference in mean voltages in the indicated time-window found when testing that electrode separately using a paired samples *t*-test (* $p < 0.05$).

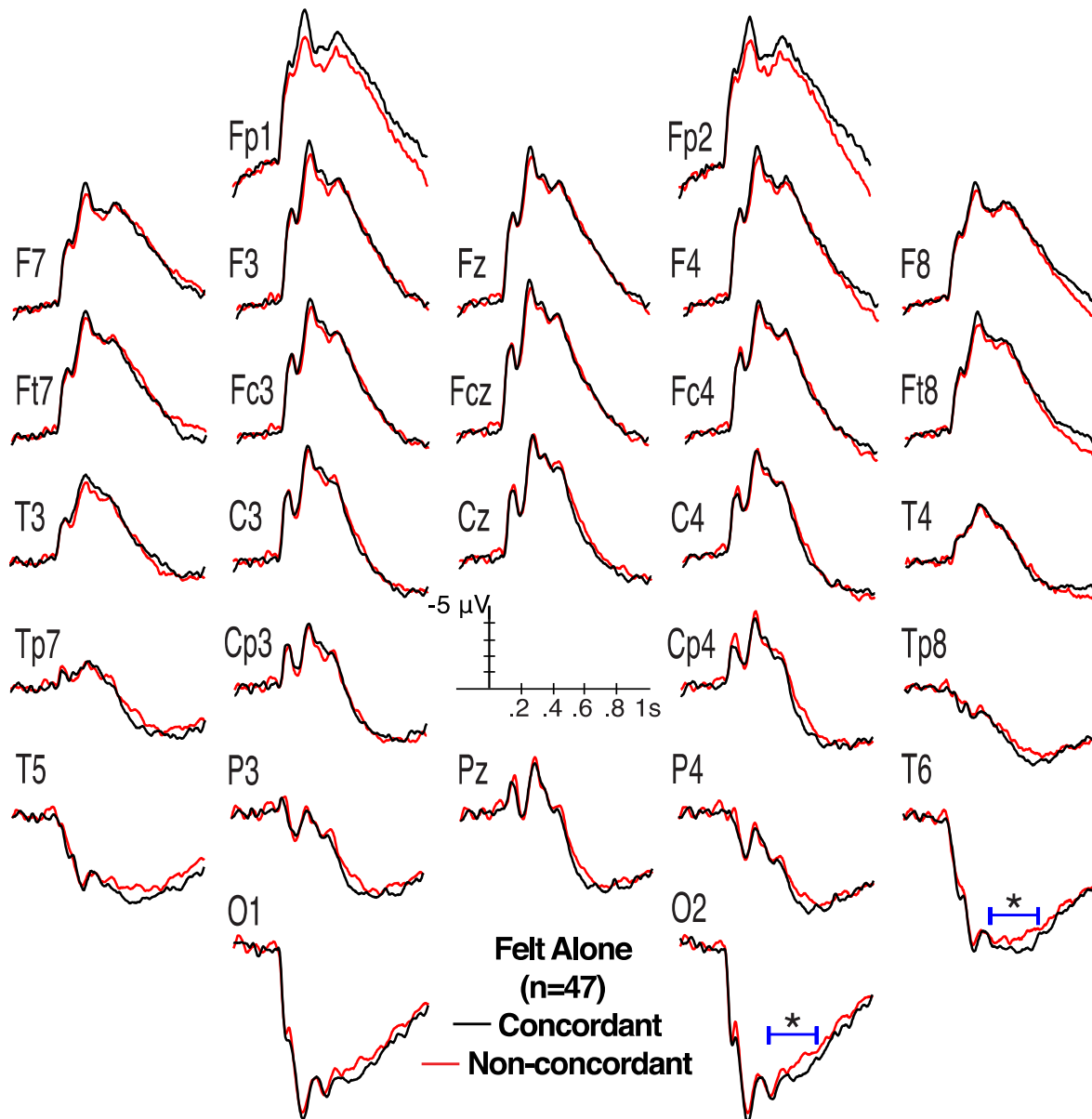


Figure 10. Grand average ERPs of the 47 participants who were tested with a partner and reported feeling in the presence of their partner for less than half of the experiment or not at all (felt-alone). Negative values (microvolts) are going up on the y-axis, and the x-axis represents time. A star indicates a statistically significant difference in mean voltages in the indicated time-window found when testing that electrode separately using a paired samples t -test (* $p < 0.05$).

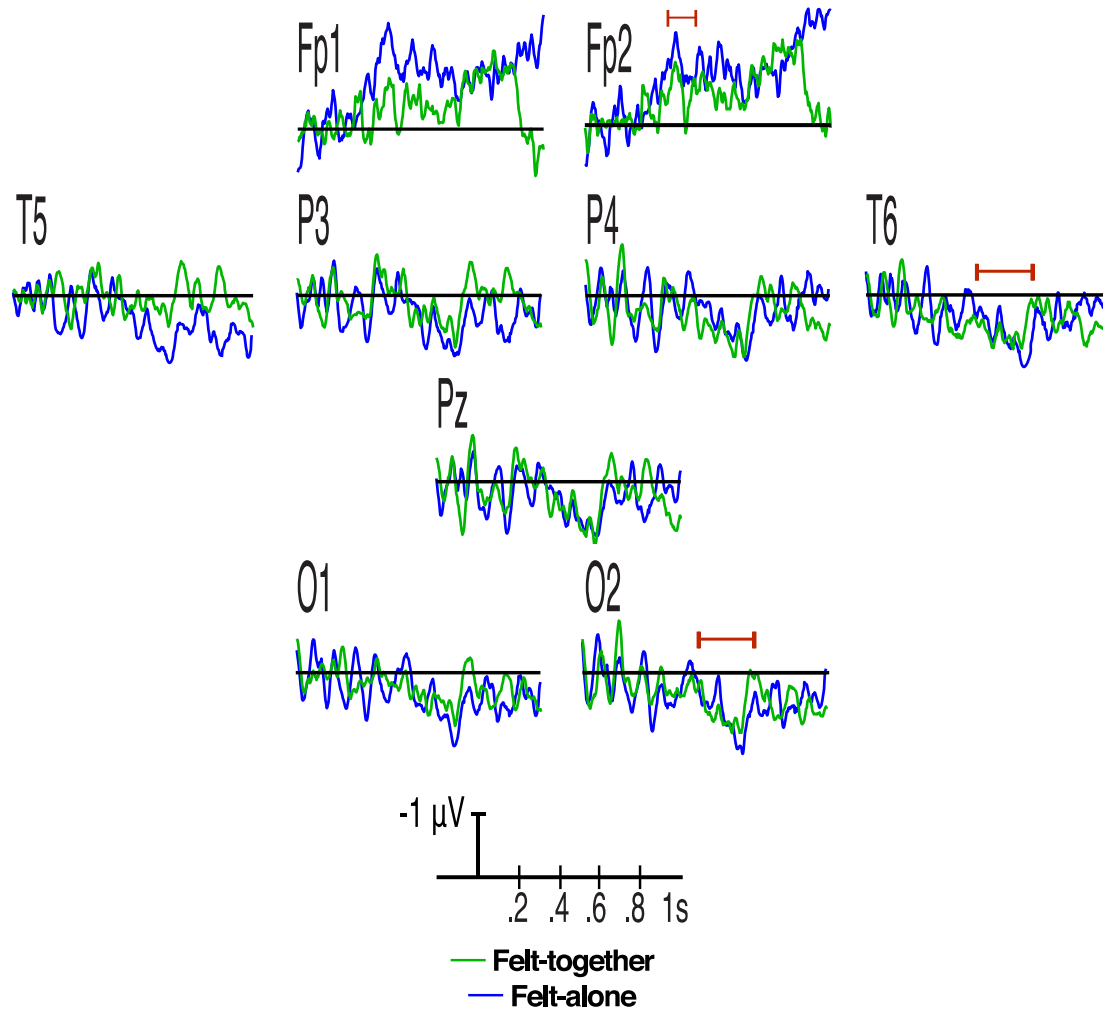


Figure 11. Subtraction waveforms (concordant minus non-concordant) for the felt-together and felt-alone Groups. Negative values (microvolts) are going up on the y-axis, and the x-axis represents time. For O2 and T6, tick marks for the 350-650 ms time-window are included. For Fp2, tick marks for the 200-350 ms time-window are included.

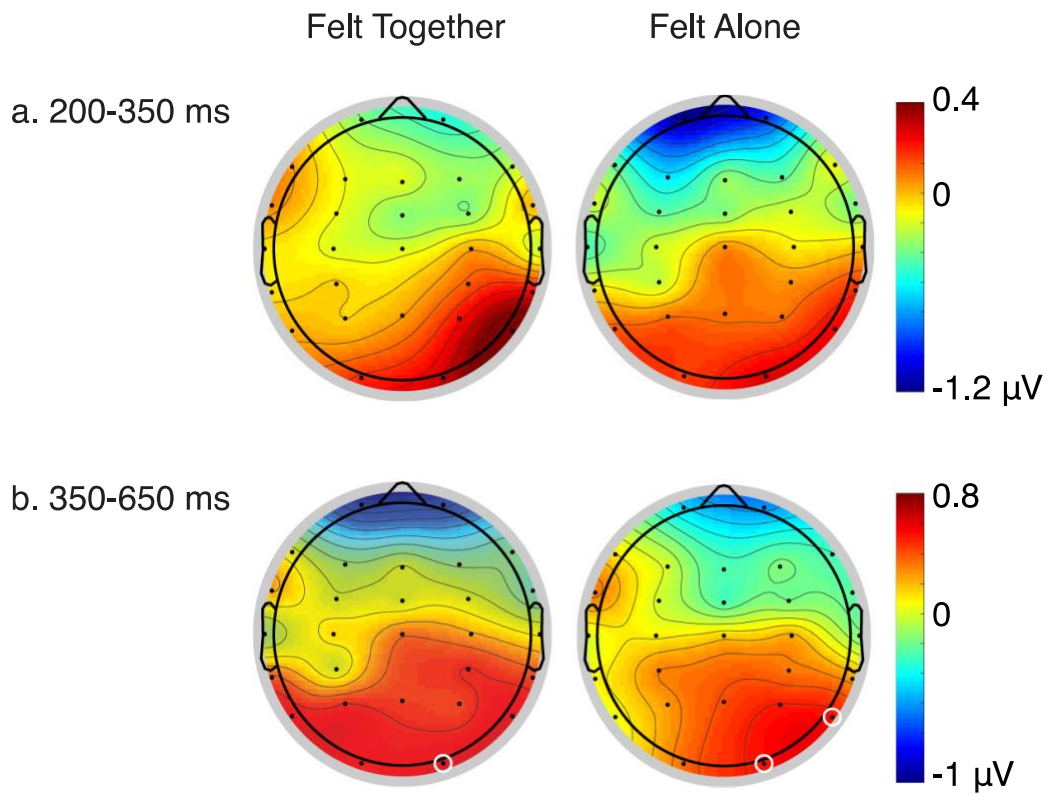


Figure 12. Mean voltage subtractions (concordant minus non-concordant) in the (a) 200-350 ms and (b) 350-650 ms time-windows. A ring indicates a statistically significant difference in mean voltages in those time-windows discovered when testing that electrode separately using a paired samples t -test in that group (* $p < 0.05$).

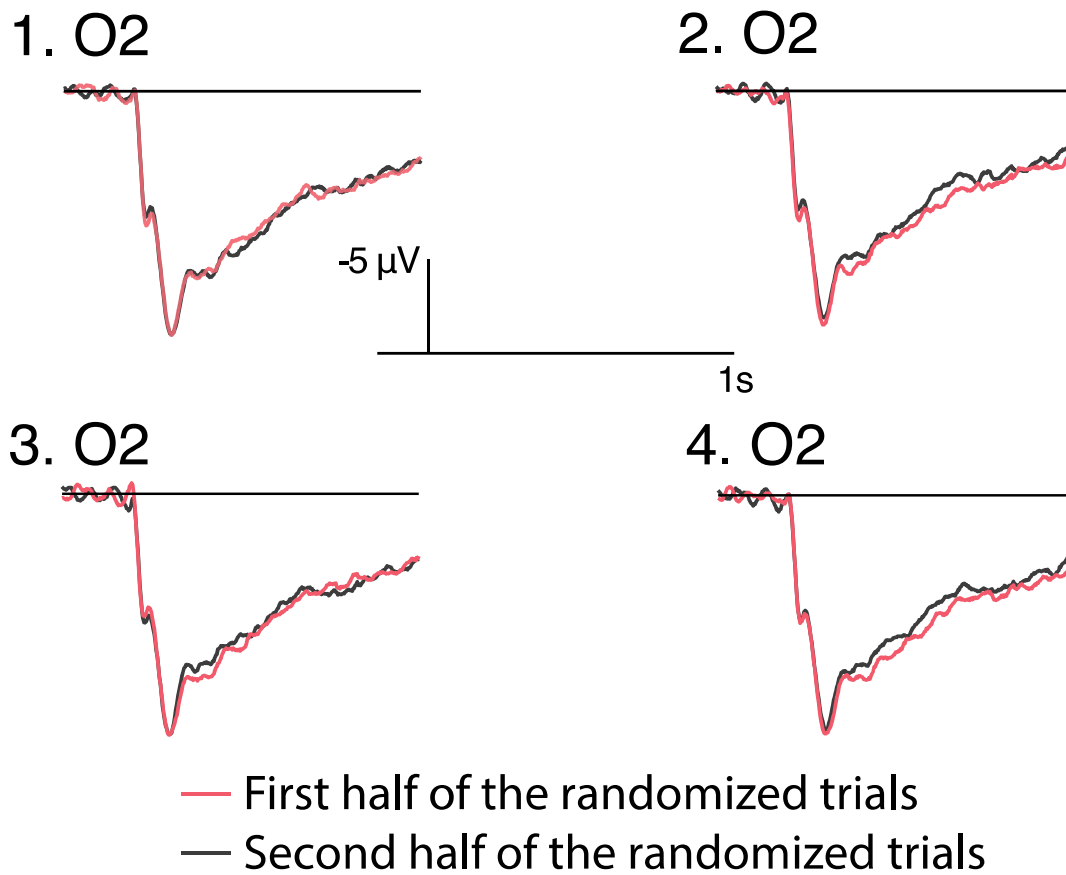


Figure 13. Grand average ERPs at electrode O2 for the four different randomizations of trials for analysis of the Alone Group (numbered 1-4) (see Methods). *Note:* Only the first of these sets of ERPs was used for analyses, but all four are depicted here to show the possible variance of ERP differences when randomly sorting trials.

Permutation Test

From the permutation tests, the number of subjects with a significant p -value after correcting for multiple comparisons with an FDR of 10% was totaled for each electrode in every time-window. Figure 14 shows spline interpolated maps depicting these totals for those tested with a partner and those tested alone. Because the mixed model ANOVAs did not reveal any interaction of group with concordance, these data were not analyzed separately for the felt-alone and felt-together groups. The ERPs of all subjects who had a significant p -value after the FDR can be found in Appendix B.

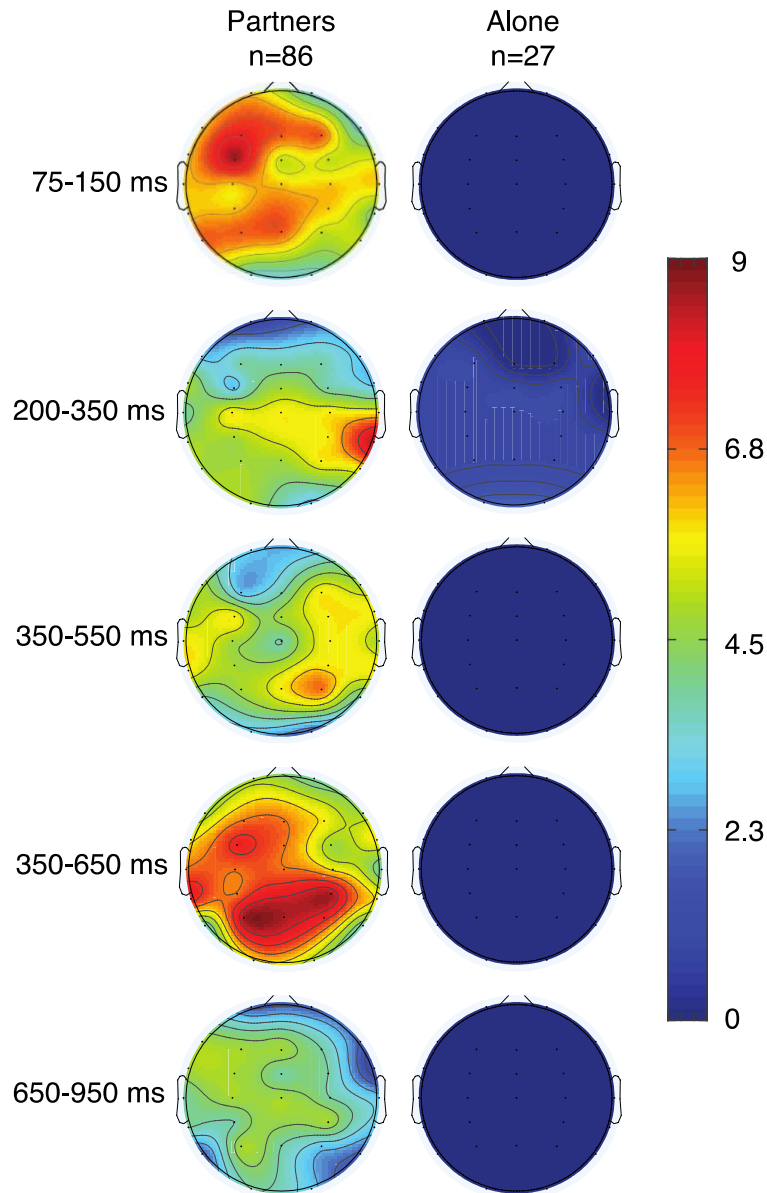


Figure 14. Spline interpolated maps depicting the total number of participants tested with a partner and tested alone having a significant p -value obtained from the permutation test procedure at each electrode and within each time-window.

Discussion

The current study focused on the concordance effects found on the ERPs in Haffar et al. (2018). These effects were discovered when the two partners of each pair of participants had to memorize images of the International Affective Pictures System. Just before this task, announcements were made as to whether the two images (one for each partner) that were simultaneously presented were going to be the same or not. The ERPs elicited by these images were found to depend on their real concordance with the announcement even though their presentations were made privately for each partner.

To test whether the ERP results were in fact due to the manipulation of concordance or to other variables, the current study investigated whether the effects could be replicated when the two partners of each pair were tested in separate rooms and when concordant and non-concordant trials were mixed at random rather than grouped in blocks of trials of the same condition. In effect, the new study design aimed to remove all possibilities for partners to discover when non-concordant trials were occurring. If ERP differences remained between the concordant and non-concordant conditions, it would be support for the original hypothesis espoused by Haffar et al. regarding a potential mechanism for a similarity of percepts across individuals.

In contrast with the prior studies, I report no main effect of concordance on the mean voltages of ERPs. However, repeated measures ANOVAs revealed interactions of concordance with electrodes. These significant effects were found even though each image was presented privately to each partner and it was impossible for participants to check the accuracy of the announcement. Upon visual inspection, it appeared that the source of the interactions was located

mainly at posterior electrode sites in the 350-650 ms time-window. There, ERPs were slightly more positive for the concordant than for the non-concordant condition. Interestingly, these small differences appeared to be replicable. In both the felt-together group and the felt-alone group the effect appears to be of a similar size, direction, scalp location and timing (see Figs. 11 & 12).

On the other hand, a permutation test with 1,000 repetitions (Monte Carlo method) performed on raw EEG epochs was used to detect idiosyncratic effects in individual participants. It was combined with the use of the false discovery rate procedure to correct for the multiple comparisons. The efficacy of this procedure at avoiding false positives was confirmed by only two participants in the alone control group with a significant critical t -value at any of the electrode sites in any of the time-windows of measure. In contrast, as illustrated by Figure 14, up to 10% of the participants (9 out of 86) tested with a partner were found by this procedure to have significant effects at a given electrode. Interestingly, this was the case in the 350-650 ms time-window in the posterior region of the scalp.

To say that the results support the existence of the effects hypothesized by Bouten et al. (2014), that is, an effect of stimulus processing of the partner on that of the participant, is a conclusion that must be rigorously assessed. There are three main explanations that at first seem to account for the somewhat mysterious results. However, upon further inspection they do not hold up within the context of the experimental design:

1. The observed ERP effect is very small and merely due to chance level differences between trials. To investigate this explanation, the use of a permutation test procedure performed on each participant was necessary. The results of those analyses indicated that for some electrodes and time-windows, up to 10% of participants tested with a partner had differences in

EEG epochs of the two conditions that were due to the manipulation of concordance and not noise. These results were significant even after assessing p -values against their B-H FDR threshold (FDR of 10%). This alone is surprising and must be taken seriously, but it is even more intriguing when coupled with the result of the control group (those tested without a partner). Analyzing the data of the control group by randomly labeling epochs into two groups and computing two ERPs modeled the differences that could occur at chance level when participants memorize IAPS images. We would expect the alone group to have had a similar proportion of significant p -values at multiple electrodes and time-windows if the effects were due to another variable not specific to being with a partner. It may then be concluded that the ERP mean voltage differences found in partners at posterior electrodes in the 350-650 ms time-window (see Figs. 8 & 14) are in fact due to concordance.

2. The ERP differences observed, while reliable, were due to another variable. I considered that the ERP differences were perhaps the result of an effect of simply doing the experiment with a partner vs. doing it alone, or the effect of belief that was instilled by the announcement. However, because of the randomized presentation of trials, any such effects would have been present systematically across *all* trials of the experiment, not one condition more than the other. Thus, it would have disappeared after the powerful averaging procedure of computing ERPs. Fatigue or practice effects can also be ruled out due to the randomized presentation of trials. Indeed, from trial to trial, the only variable that was changing was whether the partner's IAPS stimulus was identical or different to that of the participant. This change was impossible to detect by either partner. This does not support the idea that a variable other than concordance was the source of observed ERP differences in those tested with a partner.

3. The ERPs of the non-concordant condition (where stimuli were identical) elicited the activation of similar feature detectors in the brains of the two partners, which resulted in similar ERPs which differed from those of the concordant condition (where stimuli were different). Although this could be true for one set of partners, this could only be reflected in ERP grand averages if the images in the non-concordant condition (identical stimuli) were the same for a majority of partners, and this was not the case. The use of six different stimulus sequences ensured that there was proper balancing of IAPS images and helps to rule out the explanation that non-concordant ERPs differed from concordant ones across partners because of the stimulus similarity itself. Further, within one pair there could be images that were similar in content or composition across the two conditions. What sets those trials apart is whether the partner is seeing the identical image or not.

Upon considering all factors, the ERP differences discovered in the present study seem unable to be accounted for other than by an effect of the partner's stimulus processing on that of the participant. However, there are some limitations that could be addressed in future efforts to replicate the results. First, a better control group should be used. A more appropriate control could be participants who come to the experiment with a partner and go through the entire set up together, but then just before the start of the experiment (once the curtain is closed) the partner is secretly removed from the experiment. Then, the participant would still have the announcement as well as the belief that they are doing the experiment with a partner. Images that were either identical or different than those of the participant would still appear on the screen of the partner who had been removed, but there would be no one there to perceive them. If ERP differences between the concordant and non-concordant conditions were still present in a control group of

these participants, it would indicate that the effects were not due to inter-individual influences but rather to another variable that is inherent to the processing of the individual participant. If no ERP differences were found, it would suggest that the presence of the partner (and his/her conscious perception of the images alongside of the participant) is necessary to observe them in the participant.

Second, it would be beneficial to use simpler stimuli rather than IAPS images. IAPS stimuli are often images of complex scenes and can contain graphic content, which could elicit strong emotional reactions from some participants. To reduce variance in ERPs it would be useful to repeat the study but with more simple and neutral stimuli, such as color patches, shapes, or differently oriented arrows.

Third, we are unable to pinpoint the reason why the nature of the ERP effect seems to have changed from that detected in Bouten et al. (2014) and Haffar et al. (2018). There, the non-concordant ERPs were more positive than those of the concordant conditions. The ERPs we recorded revealed the opposite difference. Additionally, they found a main effect of concordance for both the LPP (650-950 ms) and N400 (350-550 ms) time-windows and we did not. The changes are intriguing and can only be related to the two factors that were particular to the current experiment, namely, the fact that trials were mixed at random and the greater physical distance between partners. Future work needs to more precisely control for these variables in order to make hypotheses about how ERPs of partners testing in this manner can be altered in different protocols.

It is also important that this work continues to obtain an adequate amount of data regarding ERP differences and AQ scores. If it is found that either high- or low-AQ scorers have

a larger difference between ERPs of the concordant and non-concordant conditions, it could provide insight into the mechanisms behind some of the social deficits that are prevalent in autism-spectrum disorders (ASD). For example, it could be that individuals with ASD are hypersensitive to the effects on their brain from the stimulus processing of people around them, which could cause them to isolate themselves or withdraw in order to lessen the potential sensory overload.

On the other hand, individuals with ASD could also be hyposensitive to these effects or unable to integrate the additional information into their own stimulus processing. If the latter were the case, it could account for their troubles with applying theory of mind and engaging in joint attention, especially in childhood. In the framework of the hypothesis tested in the present study, the information about what other people are perceiving (i.e., what they are fixating upon) would be important for the brain of an individual to utilize when integrating potential effects of another person's stimulus processing into that of the individual. Accordingly, it has been shown in multiple studies that children with ASD have a lesser ability to spontaneously follow another person's gaze direction or engage in joint attention (see Elsabbagh & Johnson, 2007 for a review). Further, even when they are able to successfully follow the direction of someone's gaze, children with ASD have difficulty using that information to infer intent or desire (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995). If the results presented in this thesis are indeed related to the building of percepts within a social environment, it could explain the perceptual and social difficulties seen in ASD. We should continue to investigate any potential interactions between AQ scores and how much an individual's brain activity can be impacted by that of another person during stimulus processing (i.e., ERP differences between concordant and

non-concordant conditions, in this case). More insight into how this unfolds in participants scoring higher on the AQ could help guide approaches to working with individuals with ASD, particularly children.

Conclusion

Haffar et al.'s (2018) original hypothesis was based upon their idea that inter-individual influences of brain activity during stimulus processing could provide an account for similarity of percepts across individuals. Such a mechanism would be of great importance for human development since the sensory stimuli within the physical environment do not have a perceptual nature in and of themselves, and human brains can be vastly different from person to person. Given that ERPs are an index of stimulus processing and the ERPs recorded here were time-locked to the appearance of a visual stimulus, we do infer that the results are related to processes which underlie visual perception. This suggests that there is a measurable effect of an individual's processing of a visual stimulus on that of another individual which depends on the sameness of those two stimuli, even when that sameness is contrary to their held knowledge. However, these effects were of a different nature than those found in Haffar et al. Future studies should attempt to replicate the results in order to investigate potential mechanisms of the reported ERP differences and confirm their support of the hypothesis. The involvement of these influences and/or the extent to which they relate directly to consciousness is also yet to be determined. This would entail more replications of these results with better controls, which would allow for the more in-depth discussion of the theoretical implications on the study of consciousness.

Contributors

The research project was written by J. B. Debruille, who also supervised the work presented here and reviewed this thesis. Data collection from 28 of the 56 pairs tested was done by Shahin Tavokol. Myriam Lecousy, Matthew Sparks, and Ashley Chau-Morris collected the data for 13 pairs. Amanda Louise Tardif did so for the last 15 pairs, assisted by Diane Nguyen-Thi. The data for the Alone Group was collected by Tarlan Daryoush and Natalie Frye. Jean Debruille set up the experimental stimulus sequences and presentation. Amanda Louise Tardif processed and analyzed the data of all participants (pairs and alone) and wrote the manuscript. Boutheina Jemel created the codes necessary to perform the permutation test analysis.

References

- Aleman, A., Rutten, G. J. M., Sitskoorn, M. M., Dautzenberg, G., & Ramsey, N. F. (2001). Activation of striate cortex in the absence of visual stimulation: an fMRI study of synesthesia. *Neuroreport*, 12(13), 2827-2830.
- Asplund, C. L., Fougner, D., Zughni, S., Martin, J. W., & Marois, R. (2014). The attentional blink reveals the probabilistic nature of discrete conscious perception. *Psychological science*, 25(3), 824-831.
- Baars, B. J. (1993). How does a serial, integrated and very limited stream of consciousness emerge from a nervous system that is mostly unconscious, distributed, parallel and of enormous capacity. *Experimental and theoretical studies of consciousness*, 98, 282-303.
- Baron-Cohen, S., Campbell, R., Karmiloff-Smith, A., Grant, J., & Walker, J. (1995). Are children with autism blind to the mentalistic significance of the eyes?. *British Journal of Developmental Psychology*, 13(4), 379-398.
- Baron-Cohen, S. (2000). Theory of mind and autism: A fifteen year review. *Understanding other minds: Perspectives from developmental cognitive neuroscience*, 2, 3-20.
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal statistical society: series B (Methodological)*, 57(1), 289-300.
- Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of cognitive neuroscience*, 8(6), 551-565.

- Block, Ned (2004). Qualia. In Richard L. Gregory (ed.), *Oxford Companion to the Mind*. Oxford University Press.
- Brewer, N., Young, R. L., & Barnett, E. (2017). Measuring theory of mind in adults with autism spectrum disorder. *Journal of autism and developmental disorders*, 47(7), 1927-1941.
- Broadbent, D.E. (1958). *Perception and Communication* (London: Pergamon).
- Byrne, Alex, "Inverted Qualia", *The Stanford Encyclopedia of Philosophy* (Winter 2018 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/win2018/entries/qualia-inverted/>
- Chalmers, D. J. (1995). Facing up to the problem of consciousness. *Journal of consciousness studies*, 2(3), 200-219.
- Chalmers, D. (2014, March). *David Chalmers: How do you explain consciousness?* [Video file]. Retrieved from https://www.ted.com/talks/david_chalmers_how_do_you_explain_consciousness?language=en
- Crick, F., & Koch, C. (1990). Towards a neurobiological theory of consciousness. In *Seminars in the Neurosciences* (Vol. 2, pp. 263-275). Saunders Scientific Publications.
- Dehaene, S., & Changeux, J. P. (2011). Experimental and theoretical approaches to conscious processing. *Neuron*, 70(2), 200-227.
- Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. *Cognition*, 79(1-2), 1-37.

- Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, 134(1), 9-21.
- Dumas, G., Lachat, F., Martinerie, J., Nadel, J., & George, N. (2011). From social behaviour to brain synchronization: review and perspectives in hyperscanning. *Irbm*, 32(1), 48-53.
- Electrode Nomenclature Committee. (1991). Modified expanded 10–20 system. American EEG society. *Journal of Clinical Neurophysiology*, 35, 200-202.
- Elsabbagh, M., & Johnson, M.H. (2007). Infancy and autism: progress, prospects, and challenges. *Progress in brain research*, 164, 355-83.
- Finney, E. M., Fine, I., & Dobkins, K. R. (2001). Visual stimuli activate auditory cortex in the deaf. *Nature neuroscience*, 4(12), 1171.
- Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, 24(2), 95-112.
- Haffar, M., Pantecouteau, H., Bouten, S., & Debruille, J. B. (2018). Effects of Stimulus Processing on Event-Related Brain Potentials of Close Others. *Preprints.org*, 2018060084 (doi: 10.20944/preprints201806.0084.v1)
- Hasson, U., Ghazanfar, A. A., Galantucci, B., Garrod, S., & Keysers, C. (2012). Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends in cognitive sciences*, 16(2), 114-121.

- Herrmann, C. S., & Knight, R. T. (2001). Mechanisms of human attention: event-related potentials and oscillations. *Neuroscience & Biobehavioral Reviews*, 25(6), 465-476.
- Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, 182(4108), 177-180.
- Hubbard, E. M. (2007). Neurophysiology of synesthesia. *Current psychiatry reports*, 9(3), 193-199.
- Humphrey, D. G., Kramer, A. F., & Stanny, R. R. (1994). Influence of extended wakefulness on automatic and nonautomatic processing. *Human factors*, 36(4), 652-669.
- Koch, C., Massimini, M., Boly, M., & Tononi, G. (2016). Neural correlates of consciousness: progress and problems. *Nature Reviews Neuroscience*, 17(5), 307.
- Konvalinka, I., & Roepstorff, A. (2012). The two-brain approach: how can mutually interacting brains teach us something about social interaction?. *Frontiers in human neuroscience*, 6, 215.
- Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after Broadbent (1958): still no identification without attention. *Psychological review*, 111(4), 880.
- Lafer-Sousa, R., Hermann, K. L., & Conway, B. R. (2015). Striking individual differences in color perception uncovered by 'the dress' photograph. *Current Biology*, 25(13), R545-R546.

- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). International affective picture system (IAPS): Technical manual and affective ratings. *NIMH Center for the Study of Emotion and Attention*, 39-58.
- Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8. University of Florida, Gainesville, FL.
- Levine, J. (1983). Materialism and qualia: The explanatory gap. *Pacific philosophical quarterly*, 64(4), 354-361.
- Luck, S. J. (2005). An introduction to the event-related potential technique. *The MIT Press*, 7-21.
- Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S. C., Parslow, D. M., Morgan, M. J., ... & Gray, J. A. (2002). Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. *Nature neuroscience*, 5(4), 371.
- Oizumi, M., Albantakis, L., & Tononi, G. (2014). From the phenomenology to the mechanisms of consciousness: integrated information theory 3.0. *PLoS computational biology*, 10(5), e1003588.
- Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational intelligence and neuroscience*, 2011, 1.

- Panagiotaropoulos, T. I., Deco, G., Kapoor, V., & Logothetis, N. K. (2012). Neuronal discharges and gamma oscillations explicitly reflect visual consciousness in the lateral prefrontal cortex. *Neuron*, 74(5), 924-935.
- Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: an integrative review. *Biological psychology*, 41(2), 103-146.
- Pressnitzer, D., Graves, J., Chambers, C., De Gardelle, V., & Egré, P. (2018). Auditory Perception: Laurel and Yanny Together at Last. *Current Biology*, 28(13), R739-R741.
- Roepstorff, A. (2001). Brains in scanners: an Umwelt of cognitive neuroscience. *SEMIOTICA-LA HAYE THEN BERLIN-*, 134(1/4), 747-766.
- Rumelhart, D. E., Hinton, G. E., & McClelland, J. L. (1986). A general framework for parallel distributed processing. *Parallel distributed processing: Explorations in the microstructure of cognition*, 1(45-76), 26.
- Sadato, N., Okada, T., Honda, M., & Yonekura, Y. (2002). Critical period for cross-modal plasticity in blind humans: a functional MRI study. *Neuroimage*, 16(2), 389-400.
- Sergent, C., & Dehaene, S. (2004). Is consciousness a gradual phenomenon? Evidence for an all-or-none bifurcation during the attentional blink. *Psychological science*, 15(11), 720-728.
- Simner, J. (2007). Beyond perception: synaesthesia as a psycholinguistic phenomenon. *Trends in cognitive sciences*, 11(1), 23-29.

- Tardif, A., Chau-Morris, A., Wang, Z. Y., Takahara, E., Hadjis, T., Debrulle, J., & Debrulle, J. B. (2018). How to Find Effects of Stimulus Processing on Event Related Brain Potentials of Close Others when Hyperscanning Partners. *JoVE (Journal of Visualized Experiments)*, (135), e56120.
- Tononi, G., & Edelman, G. M. (1998). Consciousness and Complexity.
<http://doi.org/10.1126/science.282.5395.1846>
- Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature neuroscience*, 8(8), 1096.
- Winkler, A. D., Spillmann, L., Werner, J. S., & Webster, M. A. (2015). Asymmetries in blue–yellow color perception and in the color of ‘the dress’. *Current Biology*, 25(13), R547–R548.

Appendix A: IAPS Image Numbers

The IAPS official image numbers of the images contained in each folder used to make the stimulus sequences are included here.

Folder A

1022.jpg	3190.jpg	6190.jpg	7503.jpg
1604.jpg	3213.jpg	6244.jpg	8158.jpg
1650.jpg	3230.jpg	6300.jpg	8179.jpg
2050.jpg	3266.jpg	6570.1.jpg	8211.jpg
2058.jpg	3500.jpg	6830.jpg	8311.jpg
2152.jpg	3530.jpg	6831.jpg	8312.jpg
2191.jpg	4003.jpg	6834.jpg	8400.jpg
2214.jpg	4537.jpg	6837.jpg	8466.jpg
2230.jpg	4559.jpg	6910.jpg	8600.jpg
2305.jpg	4574.jpg	7023.jpg	8620.jpg
2332.jpg	4598.jpg	7046.jpg	9040.jpg
2345.jpg	4607.jpg	7050.jpg	9050.jpg
2352.1.jpg	4623.jpg	7054.jpg	9090.jpg
2372.jpg	4668.jpg	7092.jpg	9163.jpg
2458.jpg	5040.jpg	7096.jpg	9220.jpg
2575.jpg	5450.jpg	7130.jpg	9332.jpg
2605.jpg	5470.jpg	7242.jpg	9403.jpg
2655.jpg	5471.jpg	7289.jpg	9421.jpg
2695.jpg	5628.jpg	7330.jpg	9424.jpg
2750.jpg	5831.jpg	7380.jpg	9430.jpg
2770.jpg	5836.jpg	7440.jpg	9445.jpg
3016.jpg	5910.jpg	7461.jpg	9480.jpg
3051.jpg	5920.jpg	7475.jpg	9495.jpg
3059.jpg	5991.jpg	7484.jpg	9561.jpg
3069.jpg	6150.jpg	7490.jpg	9630.jpg

Folder B

1033.jpg	2660.jpg	6838.jpg	8160.jpg
1112.jpg	2690.jpg	6840.jpg	8180.jpg
1304.jpg	2791.jpg	7006.jpg	8251.jpg
1310.jpg	2890.jpg	7025.jpg	8370.jpg
1525.jpg	3017.jpg	7032.jpg	8420.jpg
1560.jpg	3131.jpg	7037.jpg	8492.jpg
1601.jpg	3191.jpg	7041.jpg	9008.jpg
1660.jpg	3280.jpg	7052.jpg	9046.jpg
2107.jpg	3350.jpg	7135.jpg	9075.jpg
2153.jpg	4210.jpg	7179.jpg	9102.jpg
2155.jpg	4490.jpg	7184.jpg	9156.jpg
2344.jpg	4599.jpg	7200.jpg	9160.jpg
2346.jpg	4611.jpg	7238.jpg	9171.jpg
2352.2.jpg	4643.jpg	7280.jpg	9182.jpg
2374.jpg	4653.jpg	7325.jpg	9183.jpg
2375.1.jpg	4656.jpg	7361.jpg	9250.jpg
2377.jpg	4660.jpg	7430.jpg	9342.jpg
2389.jpg	4810.jpg	7460.jpg	9360.jpg
2440.jpg	5200.jpg	7497.jpg	9410.jpg
2446.jpg	5270.jpg	7509.jpg	9412.jpg
2457.jpg	5510.jpg	7546.jpg	9415.jpg
2485.jpg	5700.jpg	7900.jpg	9420.jpg
2495.jpg	5829.jpg	8001.jpg	9582.jpg
2516.jpg	6000.jpg	8034.jpg	9599.jpg
2606.jpg	6540.jpg	8118.jpg	9610.jpg

Folder C

1202.jpg	2394.jpg	5201.jpg	7350.jpg
1240.jpg	2399.jpg	5530.jpg	7451.jpg
1300.jpg	2518.jpg	5532.jpg	7489.jpg
1450.jpg	2580.jpg	5600.jpg	7499.jpg
1463.jpg	2597.jpg	5725.jpg	7507.jpg
1603.jpg	2692.jpg	5750.jpg	7620.jpg
1616.jpg	2694.jpg	5830.jpg	8050.jpg
1645.jpg	2720.jpg	5849.jpg	8210.jpg
1661.jpg	2811.jpg	5982.jpg	8300.jpg
1710.jpg	3000.jpg	6021.jpg	8325.jpg
1820.jpg	3015.jpg	6022.jpg	8340.jpg
1850.jpg	3080.jpg	6243.jpg	8496.jpg
2030.jpg	3100.jpg	6314.jpg	8499.jpg
2034.jpg	3101.jpg	6360.jpg	8501.jpg
2045.jpg	3130.jpg	6563.jpg	8540.jpg
2080.jpg	3181.jpg	7009.jpg	9043.jpg
2092.jpg	4090.jpg	7016.jpg	9070.jpg
2210.jpg	4130.jpg	7019.jpg	9184.jpg
2220.jpg	4232.jpg	7080.jpg	9330.jpg
2274.jpg	4300.jpg	7100.jpg	9414.jpg
2299.jpg	4614.jpg	7137.jpg	9435.jpg
2301.jpg	4680.jpg	7180.jpg	9470.jpg
2306.jpg	4690.jpg	7182.jpg	9810.jpg
2387.jpg	4750.jpg	7248.jpg	9903.jpg
2388.jpg	5000.jpg	7340.jpg	9940.jpg

Folder D

1080.jpg	2745.2.jpg	5635.jpg	7290.jpg
1121.jpg	2830.jpg	5720.jpg	7405.jpg
1122.jpg	2981.jpg	5814.jpg	7470.jpg
1271.jpg	3010.jpg	5875.jpg	7502.jpg
1313.jpg	3019.jpg	5891.jpg	7515.jpg
1930.jpg	3053.jpg	5950.jpg	7545.jpg
1947.jpg	3071.jpg	5972.jpg	7547.jpg
2026.jpg	4001.jpg	6211.jpg	7700.jpg
2036.jpg	4302.jpg	6242.jpg	8033.jpg
2038.jpg	4470.jpg	6550.jpg	8170.jpg
2100.jpg	4525.jpg	6555.jpg	8190.jpg
2151.jpg	4536.jpg	6836.jpg	8280.jpg
2170.jpg	4575.jpg	7012.jpg	8330.jpg
2279.jpg	4626.jpg	7017.jpg	8510.jpg
2309.jpg	4650.jpg	7020.jpg	9010.jpg
2342.jpg	4697.jpg	7026.jpg	9186.jpg
2345.1.jpg	4800.jpg	7043.jpg	9265.jpg
2395.jpg	5130.jpg	7053.jpg	9295.jpg
2411.jpg	5220.jpg	7056.jpg	9300.jpg
2490.jpg	5300.jpg	7059.jpg	9341.jpg
2560.jpg	5460.jpg	7192.jpg	9530.jpg
2661.jpg	5533.jpg	7195.jpg	9621.jpg
2703.jpg	5534.jpg	7234.jpg	9623.jpg
2716.jpg	5611.jpg	7281.jpg	9913.jpg
2745.1.jpg	5623.jpg	7282.jpg	9941.jpg

Folder E

1026.jpg	2594.jpg	5301.jpg	7410.jpg
1200.jpg	2600.jpg	5480.jpg	7450.jpg
1201.jpg	2718.jpg	5531.jpg	7472.jpg
1333.jpg	2722.jpg	5551.jpg	7505.jpg
1390.jpg	2730.jpg	5626.jpg	8080.jpg
1620.jpg	2900.jpg	5740.jpg	8120.jpg
1640.jpg	3060.jpg	5781.jpg	8130.jpg
1903.jpg	3062.jpg	6010.jpg	8162.jpg
2010.jpg	3250.jpg	6250.jpg	8208.jpg
2018.jpg	3360.jpg	6415.jpg	8475.jpg
2019.jpg	4250.jpg	6520.jpg	8531.jpg
2053.jpg	4311.jpg	6561.jpg	9005.jpg
2110.jpg	4320.jpg	6562.jpg	9210.jpg
2150.jpg	4535.jpg	7003.jpg	9280.jpg
2190.jpg	4542.jpg	7021.jpg	9290.jpg
2280.jpg	4571.jpg	7036.jpg	9390.jpg
2310.jpg	4616.jpg	7055.jpg	9428.jpg
2331.jpg	4621.jpg	7110.jpg	9429.jpg
2360.jpg	4652.jpg	7160.jpg	9432.jpg
2362.jpg	4664.jpg	7165.jpg	9570.jpg
2375.jpg	4695.jpg	7284.jpg	9600.jpg
2400.jpg	5010.jpg	7285.jpg	9635.jpg
2456.jpg	5202.jpg	7286.jpg	9700.jpg
2520.jpg	5210.jpg	7359.jpg	9800.jpg
2521.jpg	5215.jpg	7390.jpg	9911.jpg

Folder F

1051.jpg	2303.jpg	4605.jpg	7270.jpg
1110.jpg	2314.jpg	4631.jpg	7476.jpg
1113.jpg	2320.jpg	4658.jpg	7512.jpg
1120.jpg	2339.jpg	4672.jpg	7580.jpg
1205.jpg	2383.jpg	4687.jpg	7920.jpg
1230.jpg	2442.jpg	4698.jpg	8030.jpg
1600.jpg	2488.jpg	5629.jpg	8031.jpg
1610.jpg	2511.jpg	5731.jpg	8060.jpg
1720.jpg	2595.jpg	5779.jpg	8200.jpg
1721.jpg	2691.jpg	5811.jpg	8241.jpg
1722.jpg	2749.jpg	5820.jpg	8460.jpg
1900.jpg	2753.jpg	6210.jpg	8485.jpg
2000.jpg	2870.jpg	6213.jpg	9045.jpg
2035.jpg	3005.jpg	6311.jpg	9080.jpg
2055.jpg	3064.jpg	6312.jpg	9187.jpg
2057.jpg	3170.jpg	6350.jpg	9322.jpg
2070.jpg	3215.jpg	6570.jpg	9340.jpg
2075.jpg	3220.jpg	7030.jpg	9395.jpg
2115.jpg	3302.jpg	7057.jpg	9520.jpg
2120.jpg	4007.jpg	7060.jpg	9592.jpg
2130.jpg	4142.jpg	7062.jpg	9901.jpg
2154.jpg	4503.jpg	7150.jpg	9904.jpg
2158.jpg	4505.jpg	7161.jpg	9921.jpg
2160.jpg	4510.jpg	7207.jpg	9925.jpg
2270.jpg	4572.jpg	7260.jpg	9930.jpg

Appendix B: ERPs of participants who had at least one electrode with a significant p-value in any time-window after performing the Monte Carlo permutation test with a false discovery rate correction.

For all ERP figures, black waveforms are the concordant condition and red waveforms are the non-concordant condition. Negative voltages (microvolts) are going up on the y-axis. (Note: for the two participants from the alone group, the red and black waveforms are the ERPs of randomly selected sets of epochs.)

Table of reference:

Participant number	Significant electrodes by time-window				
	75-150 ms	200-350 ms	350-550 ms	350-650 ms	650-950 ms
6	n.s	n.s.	Fp2, F8, Pz, P4, T4, F4, Ft8, Fc4, C4, Tp8, Cp3	Fp2, F8, Ft8	n.s.
8	n.s	T6, T4, Tp8	n.s	n.s	n.s
11	Fp1, F7, F3, Fc3	n.s	n.s	n.s	n.s
12	Pz, P4, P3, T6, T5, T4, F4, Ft8, C4, Tp8, Cp4, Cp3, O2, O1	n.s	n.s	n.s	n.s
15	n.s	n.s	n.s	Tp7	n.s
17	n.s	n.s	n.s	Fp1, F7, Fz, F3, Ft7, Fc3	n.s
19	n.s	F4	n.s	n.s	n.s
20	n.s	n.s	F7, T5, T3, Ft7, Tp7	n.s	n.s

24	F8, Fz, T4, F4, F3, Ft8, Fc4	n.s	n.s	n.s	n.s
25	n.s	F8, Pz, P4, P3, T6, T5, T3, Ft7, Tp8, Tp7, Cp4, Cp3, O2, O1	P3, T5, T3, Tp7	n.s	n.s
27	n.s	Fp2, F8, F7, Fz, Cz, P4, T4, T3, Ft8, Ft7, Fc4, C4, C3, Tp8, Tp7, Cp4, Cp3, P1	F8, F7, Fz, Cz, P4, P3, T5, T4, T3, F4, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8, Tp7, Cp4, Cp3	n.s	n.s
31	n.s	n.s	F8, Pz, P4, P3, T6, T5, T4, T3, F4, Ft8, Fc4, Fc3, Fcz, C4, C3, Tp8, Cp4, Cp3, O2, O1	n.s	n.s
36	Fp2, Fp1, F7, Fz, Cz, Pz, P4, P3, T6, T4, T3, F4, F3, Ft7, Fc3, Fcz, C4, C3, Tp7, Cp4, Cp3	n.s	n.s	n.s	n.s
37	n.s	Fz, Cz, Pz, P4, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Cp4, Cp3, O2	Fp2, Fp1, F8, F7, Fz, Cz, Pz, P4, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp7, Cp4, Cp3, O1	n.s	F7, Fz, Cz, Pz, T3, F3, Ft7, Fc3, C4, Tp7, Cp4, Cp3, O1
40	n.s	Tp8	Tp8	Tp8	Tp8
41	F8, Cz, Pz, P4, P3, T6, T5, T4, T3, Ft8, Ft7, Fc4, Fc3, C4, C3, Tp8, Tp7, Cp4, Cp3, O2, O1	n.s	n.s	n.s	Fp2, Fp1, F8, F7, Fz, Cz, P3, F4, F3, Ft7, Fc4, F3, Fcz, C3, Tp7, Cp4
43	Fp2, Fp1, F7, Fz, T5, T3, F4, F3, Ft7, Fc3, Tp7	n.s	n.s	n.s	n.s
44	n.s	n.s	Fp1, F7, T3, F3, Ft7, Fc3, C3, Tp7	Fp1, F7, T3, F3, Ft7, Fc3, C3, Tp7	n.s
48	n.s	F7, Cz, T6, T5, T4, T3, F3, Ft7, Fcz, C4, C3, Tp8, Tp7,	n.s	n.s	n.s
49	T5, Tp7	n.s	n.s	n.s	n.s

50	Fp1, F7, Fz, Cz, P3, T5, T3, F4, Ft7, Fc4, Fc3, Fcz, C3, Tp7, Cp3	n.s	n.s	n.s	n.s
52	n.s	n.s	n.s	n.s	Fp2, Fp1, F8, F7, Fz, Cz, P3, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3
53	n.s	n.s	n.s	n.s	F7, Fz, Cz, Pz, P4, P3, T6, T5, T4, T3, F4, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8, Tp7, Cp4, Cp3, O2, O1
56	n.s	n.s	n.s	Fz, Cz, Pz, P4, P3, T4, Ft8, Fc4, Fc3, Fcz, C4, C3, Tp8, Cp4, Cp3	n.s
57	n.s	n.s	n.s	Pz, P4, P3, Cp4, Cp3, O2, O1	n.s
62	Fp2, Fp1, F7, F3, Ft7, Fc3	n.s	n.s	n.s	n.s
67	Fz, Cz, Pz, P3, T5, T3, F3, Fc3, Fcz, C4, C3, Tp7, Cp4, Cp3	n.s	n.s	n.s	n.s
68	n.s	Pz, P4, P3, T6, T5	n.s	n.s	n.s
69	Fp2, Fp1, F8, F7, Fz, Cz, Pz, P4, P3, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8, Cp4, Cp3	n.s	Pz, P4, P3, T6, Tp8, Tp7, O2, O1	Pz, P4, P3, T6, Tp8, Cp4, O2, O1	n.s
73	T4	n.s	n.s	n.s	n.s
75	n.s	n.s	Fz, Cz, Pz, P4, T6, T4, F4, Ft8, Fc4, Fc3, Fcz, C4, Tp8, Cp4	n.s	n.s
77	F8, Fz, Cz, Pz, P4, T6, T4, F4, Ft8, Fc4, Fc3, Fcz, C4, C3, Tp8, Cp4, O2	T6, T4, Tp8, O2	n.s	n.s	n.s
80	Fp1, F7, Fz, Cz, Pz, P4, P3, T6, T5, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8, Tp7, Cp4, Cp3, O1	Fp2, Fp1, F8, F7, Fz, Cz, Pz, P4, P3, T6, T5, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3,	Fp2, Fp1, F8, F7, Fz, Cz, Pz, P4, P3, T6, T4, T3, F4, F3, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp7, Cp4, Cp3, O2	Fp2, Fp1, F8, F7, Fz, Cz, Pz, P4, P3, T6, T5, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8,	F7, Fz, Cz, Pz, P4, P3, T6, T5, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8,

		Tp8, Tp7, Cp4, Cp3, O2, O1		Tp7, Cp4, Cp3, O2, O1	Tp7, Cp4, Cp3, O2, O1
81	n.s	Cz, P3, T5, Fcz, C3, Tp8, Tp7, Cp4, Cp3, O2, O1	n.s	n.s	n.s
82	Pz, p3, T6, O2, O1	n.s	n.s	n.s	n.s
84	n.s	n.s	n.s	n.s	Pz, P4, P3, Cp4, Cp3, O2, O1
85	n.s	Fz, Cz, Pz, P4, P3, T4, F4, F3, Fc4, Fc3, Fcz, C4, C3, Tp8, Cp4, Cp3	n.s	n.s	n.s
86	n.s	n.s	n.s	F7, Fz, Cz, Pz, P4, P3, T4, T3, F4, F3, Ft8, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp7, Cp4, Cp3, O2, O1	n.s
AL_2	n.s	F7, Cz, Pz, P4, P3, T3, F3, Ft7, Fc4, Fc3, Fcz, C4, C3, Tp8, Tp7, Cp4, Cp3, O2, O1	n.s	n.s	n.s
AL_11	n.s	F8	n.s	n.s	n.s

