Exploring the Neural Correlates of Different Interaction Types: a Hyperscanning Investigation Using the Pattern Game.

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Abstrakt

Hyperscanning affords insight into social interaction brain dynamic by simultaneously scanning two or more individuals' brain responses while they engage in dyadic exchange. The present research aims to provide an experimental paradigm for hyperscanning research capable of delineating among two dimensions of interaction: (1) interaction structure (concurrent vs. turn-based) and (2) goal structure (competition vs cooperation). Dual-fMRI was used to scan 22 pairs of participants as they played the modified Pattern Game, where participants either compete or cooperate. Different patterns of activation between the conditions were found including insula and medial cingulate cortex in cooperation and frontal and parietal activations in competition. Turn-based condition showed supplementary motor area and frontal activations, in concurrent condition angular gyry were activated.

1 Introduction

Humans are without doubt social creatures. We interact with ease daily, we talk to our loved ones, cooperate with our colleagues, compete with our friends on game night, we even frequently interact with complete strangers. Social neuroscience, research field primarily interested in neural mechanisms of social interactions, has revealed the neural underpinnings of many important socio-cognitive phenomena, from face processing to empathic awareness. This type of research usually involves measuring the response of one individual's brain while they evaluate social experimental stimuli. It comprises most of the current brain imaging literature and can be considered to represent "spectator science" (Hari et al., 2015) that describes a person as a detached observer, rather than actively engaged with another in some joint project (Schilbach et al., 2013). Such approach is perfectly sufficient if we are exploring the mechanisms underlying intra-personal phenomena, such as an individual's representation of others' actions and mental states (Konvalinka & Roepstorff, 2012). It offers little or no insight into the neural mechanisms involved in mutual interaction or real-world social behaviour, however. Human social interaction is complex, dynamic and dependent on many situational factors. There is a need in social neuroscience to adopt a more interactive notion. As opposed to "spectator science" (research, where modulations of brain states triggered by the interacting partner's behaviour are neglected (Hari et al., 2015),), a new approach in social neuroscience emerged. As a mean of achieving this goal, hyperscanning emerged this two-brain approach attempts to elucidate functional relationships between two brains during mutually active interactions instead of an isolated brain processing delivered stimuli - two-person nature. Hyperscanning involves simultaneous neuroimaging of two or more individuals during interaction. It thus enables monitoring of the neural dynamics in real world social interaction and monitor activation within, but also between brains of interacting persons. So far, it has been successfully used with different imaging techniques (fMRI, EEG, fNIRS, MEG) on different paradigms like economic games (Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001)(e.g. Astolfi et al., 2012; Billeke et al., 2014; King-Casas et al., 2005), music performance (e.g. Babiloni et al., 2012; Lindenberger, Li, Gruber, & Müller, 2009; Sänger, Müller, & Lindenberger, 2013) or different forms of verbal interaction (e.g. Baess et al., 2012; Jiang et al., 2012; Spiegelhalder et al., 2014). Hyperscanning as a technique is becoming widely popular, however, it is a relatively new method and while it has been successfully used many times, it comes with many challenges. Since it is a very complex research technique, some methodological considerations arise. This includes for example the level of acquaintanceship involved in neuronal coupling. Further it is necessary to identify, develop and optimise analytical techniques capable of exploring interbrain effects measured in hyperscanning settings (Burgess, 2013; Hari et al., 2015). There is also a question of individual personality traits that modulate social interactions. More importantly, since the main aim of hyperscanning is to explore interaction, it is essential to characterise the precise form of interaction investigated in different experimental paradigms (Konvalinka & Roepstorff, 2012). To our knowledge, there is no research in hyperscanning that systematically focuses on several diverse properties of interaction. Here, preliminary results from an experimental hyperscanning paradigm that would consider different types of interaction and partly fill this gap are presented. To define the core properties or dimensions of interaction, I build upon a framework published by Liu and Pelowski (Liu & Pelowski, 2014). They identify three factors that shape interpersonal interaction: (1) interaction structure (concurrent vs. turn-based interaction) (2) goal structure (competitive vs. cooperative interaction) and (3) the task structure (interdependent tasks, where both individual behaviour and outcome are affected by each other vs. independent tasks, where individuals complete the task independently, while outcome (winning or losing) is determined by the other). This three-dimensional construct will provide a framework for tackling the differences that each type of interpersonal interaction brings into hyperscanning. Here, the focus is on half of them, the interdependent tasks (2 interaction structure types x 2goal structure types), since in these tasks we can better see real time dynamics of the interaction, the intertwined behaviour within the task. We modified a simple game called the Pattern Game, introduced by Decety et al. in a competition-cooperation research (Decety, et al., 2004) to match all the interaction types; and scanned pairs of participants with two identical MRI scanners while playing the game iteratively.

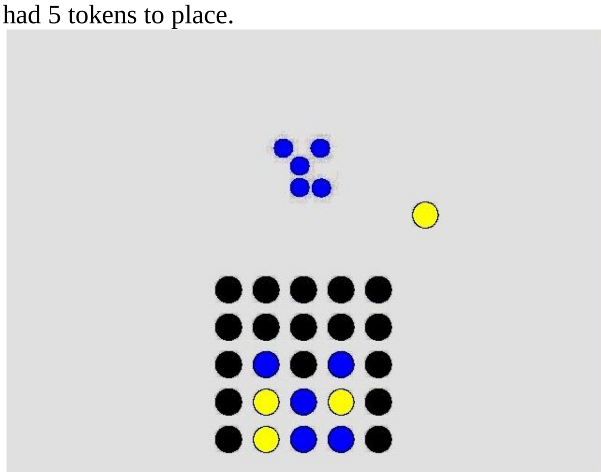
2 Methods

2.1 Participants

We recruited 44 participants (22 women), mainly among students of Masaryk University. They formed 22 pairs matched on gender (11 female-female and 11 male-male pairs); age (maximum age difference of 12 month, mean age difference was 6.3 months); handedness (1 left-handed female pair and 2 left-handed male pairs) and education. Mean age of participants was 22.4 years (SD=1.9). All participants gave their informed consent and the experiment was approved by a local ethical committee.

2.2 Modified Pattern Game

In this paradigm, each participant was assigned with a colour (blue or yellow) that remained the same throughout the experiment. Prior to the beginning of every round, participants saw instructions that specified the role of each player: one of the participants was always the builder, the second participant was either helper or hinderer. Builder's aim was to recreate a simple 5-token pattern on a 5x5 grid (game board). The helper was instructed to help the builder recreate the pattern (cooperation condition), the hinderer's goal was to prevent builder from creating the pattern (competition condition). Participants controlled the game with simple MR compatible controllers with 4 buttons. Each participant's token automatically appeared above the game board on the designated side of the player. Participants then controlled horizontal movement of the token with two buttons (left/right) until it was positioned above the selected column. Then, after the press of the third button (down), the token fell on the last available position (as if subjected to gravity). Patterns, as well as players' roles, change every round and all of them were constructed to be impossible to recreate without the help of the other player (three supporting tokens are needed for each pattern; see Obr. 1). The control condition required one participant to recreate the pattern as well as possible (reach maximum of correctly placed tokens) and during this condition the second participant had to watch without interference. In each round, each participant had 5 tokens to place.



Obr. 1: Example of successful cooperation round in the Pattern game. Blue player is the builder and yellow is the helper.

2.3 Experimental paradigm

Prior to the experiment, all participants filled an online questionnaire; the Personality Styles and Disorder Inventory (Kuhl, Kazén, 2002). Participants of each pair were introduced to each other and instructed together. After they filled the informed consent, security questionnaire for MRI laboratory and read instructions for the Pattern Game, they both separately completed 4 practice rounds of the game. During the practice, they did not interact or played the game together, it was constructed to simulate the actual game without the need of the co-player.

After participants confirmed their understanding of the Pattern game, they were prepared for the fMRI, where first the anatomical scans were obtained and then they played 2 blocks of 48 rounds of the Pattern Game. Each block consisted of 16 cooperation, 16 competition and 16 control rounds (always with 8 rounds where the blue player was the builder and 8 rounds where the yellow player was the builder). Each round started with the instructions displayed for 3 seconds and a 1 second fixation cross. The only difference in the first and the second block was that in the first block participants were placing their tokens alternatively (e.g. builder placed his first token than helper placed his first token, then builder placed his second token etc.; Turn-based condition); in the second block players placed their tokens concurrently (both players were placing their tokens at the same time; Concurrent condition).

2.4 Functional MRI data acquisition

For each participant, structural and functional fMRI data was simultaneously recorded with two identical 3T Siemens Prisma scanners. To ensure temporal synchronisation of the signal, an external signal generator (Siglent SDG1025) was used. This resulted in pairs of fMRI signal that had no bigger acquisition delay than 20 msec. For the purposes of localisation and co-registration, structural MR images were acquired before the functional runs (MPRAGE; TR=2300 msec; matrix=240x252x224 mm; 1x1x1 mm voxels). Blood-oxygen-level dependent (BOLD) images were acquired with a T2*-weighted echo-planar imaging (EPI) sequence with parallel acquisition (TR = 2000 msec; matrix = 68x68x34; 3x3x4 mm voxels). Slices were acquired in interleaved order. Functional imaging was performed in two runs, both comprising 570 volumes (19 minutes).

2.5 Analysis of fMRI data

For each of the subjects and each of the two time-series, data were pre-processed separately using tools from FMRIB Software Library (FSL, Jenkinson et al., 2012). Motion correction was performed using MCFLIRT with the middle volume reference. Slice-timing correction was conducted. To identify any signal related to noise sources probabilistic independent component analysis was performed using MELODIC (Beckmann, 2012), resulting 50 independent components. Artefactual components were then identified automatically with the Spatially Organized Component Klassifikator (SOCK; Bhaganagarapu, Jackson & Abbott, 2013), and signal relating to these noise components was regressed out of the time-series. Lastly, time-series was registered to native space.

This work presents preliminary results of general linear model analyses. Responses of one player to other's player successful moves were modelled (e.g. builder's response to helper's successful placing of the token). For each blue-yellow pair the condition-specific (competition, cooperation, control) correlation in BOLD signal was calculated between spatially corresponding voxels. These correlation coefficients were then converted to z-scores using Fishers-transformation. Group results presented here are familywise error corrected.

3 Results

3.1 Behavioural results

The maximum of successfully placed tokens in cooperation rounds by both builder in each block was 80 (there were 16 cooperation trials in each block, in each cooperation trial, builder placed a maximum of 5 successful tokens, 16*5=80). In turn-based condition, an average of successful placements in cooperation trials was M= 74,5 (SD=4.1); in the concurrent condition the average was M=75.8 (SD=7.1). These numbers suggest that participants understood the task well and were able to cooperate successfully. In competition, in turn-based condition builders' average success was M=31.4 (SD=2.8), in concurrent condition it was M=36.1 (SD=5.1). As the success to the builder is significantly lower, this indicates, that participants successfully posed as hinderers in preventing builder from creating the pattern.

3.2 Builder

First; we looked at the activations in the builder's brain when the helper successfully placed a supporting token. In Turn-based condition (Fig. 1) we found bilateral activity in frontal and parietal cortex, in supplementary motor area, cerebellum and medial and anterior cingulate cortex. In Concurrent condition (Fig. 2), we saw massive activations including frontal, temporal and occipital cortex, insula, caudate nucleus, putamen, hippocampus and amygdala. Bilateral activations were also present in posterior and medial cingulate cortex. When the hinderer successfully placed a token that prevented builder from making the pattern (e.g. placed token on a position, where builder wanted to place it); during Turn-based trials (Fig. 3) builder showed activations in parietal cortex, insula and medial and anterior cingulate cortex bilaterally, left medial frontal gyrus, right superior frontal gyrus and right cerebellum. In Concurrent trials (Fig. 4) activations were present bilaterally in anterior and medial cingulate cortex.

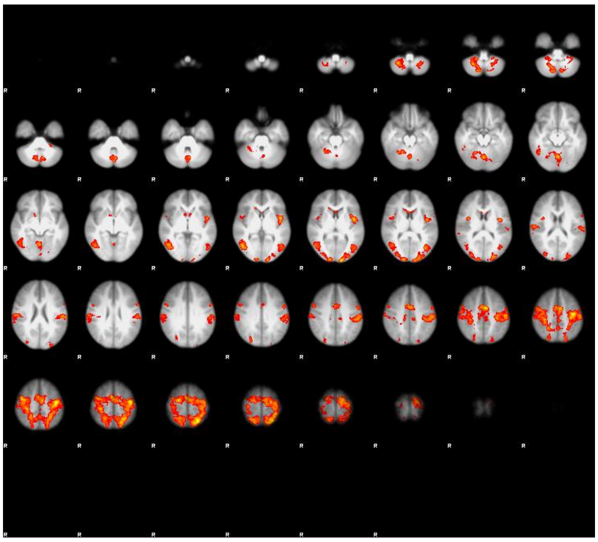


Fig. 1: Builder's reaction to helper correctly placing the token in Turn-based cooperative trials.

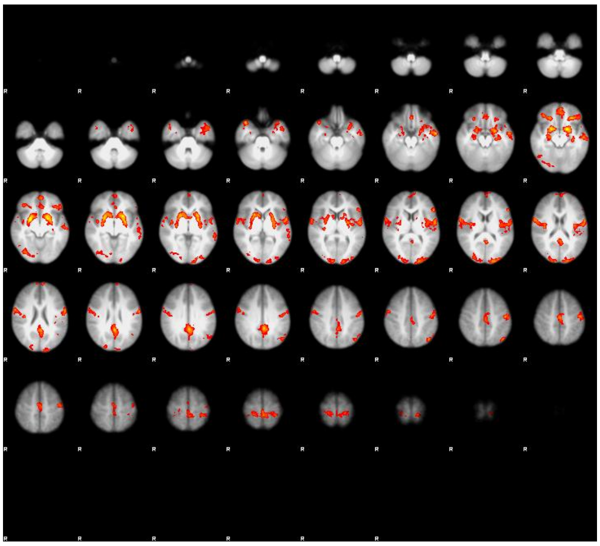


Fig. 2: Builder's reaction to helper correctly placing the token in Concurrent cooperative trials.

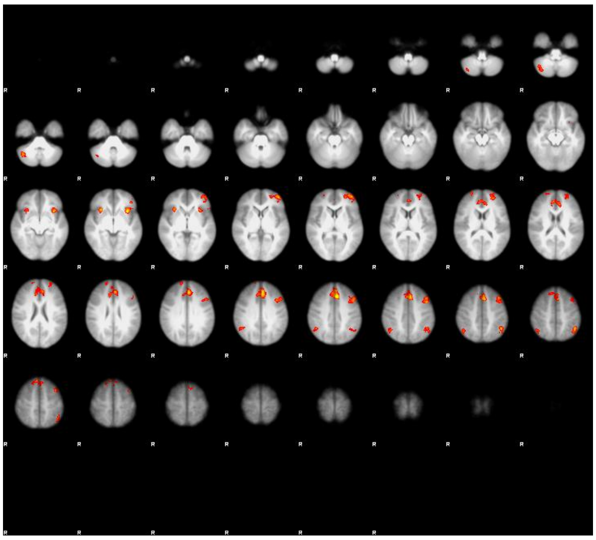


Fig. 3: Builder's reaction to hinderer placing the preventive token in Turn-based competitive trials.

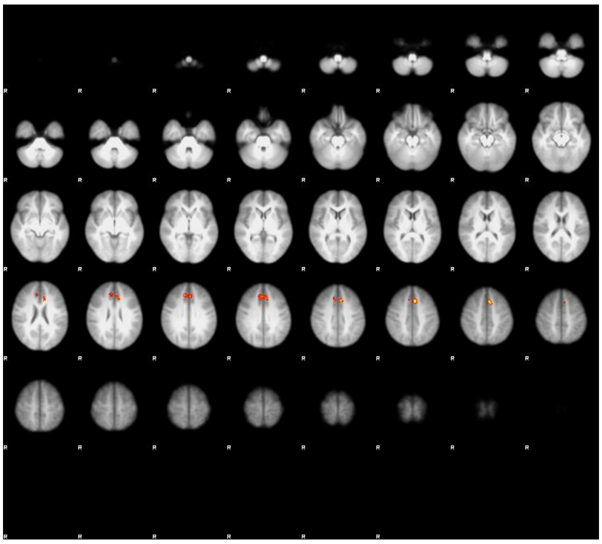


Fig. 4: Builder's reaction to hinderer placing the preventive token in Concurrent competitive trials.

3.3 Helper

When a builder placed a token on a right position in cooperation trial, in both Concurrent and Turn-based condition his co-player, the helper, showed activations in precuneus and cuneus, anterior and medial cingulate cortex, medial prefrontal cortex, right and left hippocampus and insula and also bilaterally putamen (Fig. 5 and 6).

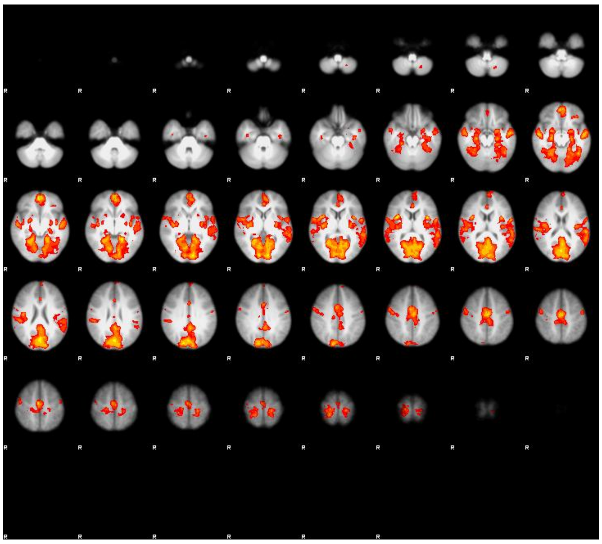


Fig. 5: Helper's reaction to builder correctly placing the token in Turn-based cooperative trials.

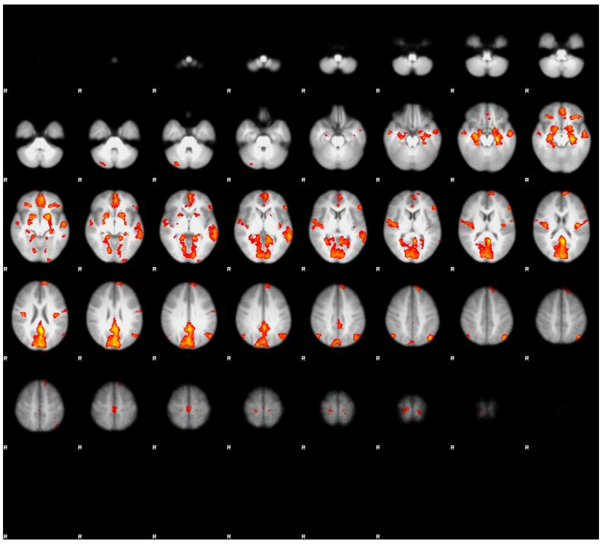


Fig. 6: Helper's reaction to builder correctly placing the token in Concurrent cooperative trials

3.4 Hinderer

Hinderer presented activations, in both Concurrent and Turn-based condition, in superior frontal lobes, parietal cortex, insula, thalamus and cerebellum when builder correctly placed a token in competition trials (Fig. 7 & 8).

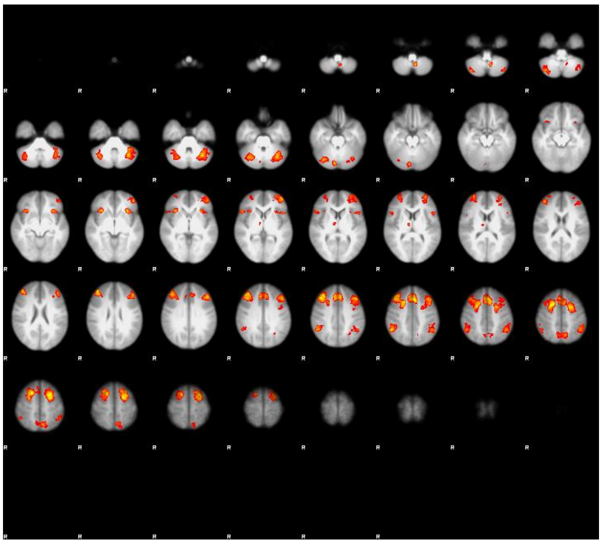


Fig. 7: Hinderer's reaction to builder correctly placing the token in Turn-based competitive trials

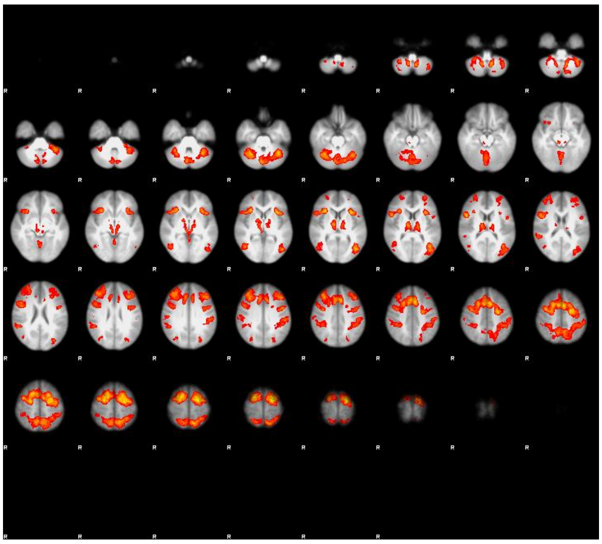


Fig. 8: Hinderer's reaction to builder correctly placing the token in Concurrent competitive trials

3.5 Turn-based and concurrent condition

In turn-based trials, where participants alternated in placing the tokens the activations were much more prominent. We found extensive activations in precentral cortex and supplementary motor areas, inferior frontal gyrus and middle and superior occipital lobes (Fig. 2). In concurrent condition activations in left medial and inferior areas and right cerebellum as well as in angular gyry bilaterally were found (Fig. 3).

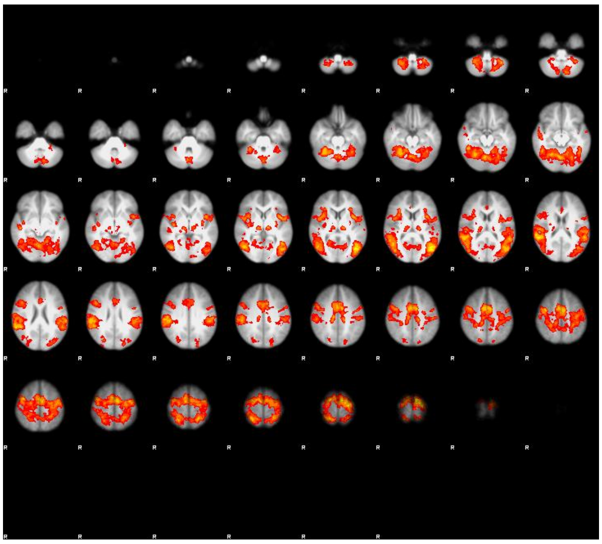


Fig. 9: Activations present in turn-based condition as opposed to concurrent condition.

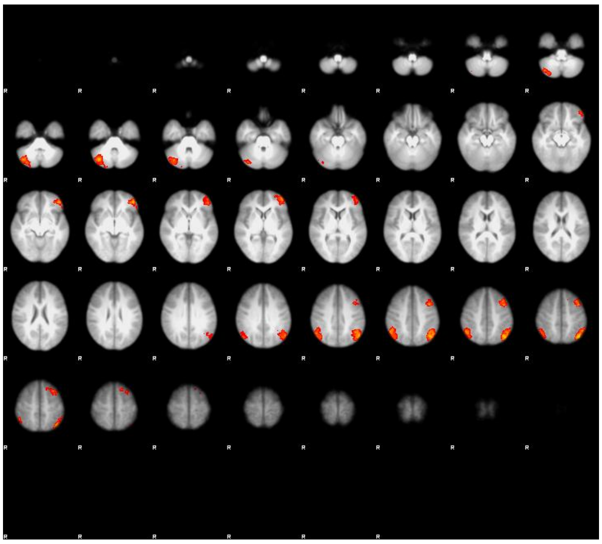


Fig. 10.: Activations present in concurrent condition as opposed to turn-based condition.

3.6 Inter-subject correlations

In all four conditions, we found correlated activity in superior frontal gyrus bilaterally. In cooperation rounds in concurrent condition we also found inter-subject correlations left medial temporal gyrus and precuneus bilaterally. In competitive rounds in turn-based condition, left precuneus showed correlated activation.

4 Discussion and conclusion

In this research, Dual-fMRI was used to scan 22 pairs of participants- each pair matched on gender, age, education and handedness- as they played the Pattern Game. In this simple interactive task, on player attempts to recreate a pattern of tokens while the second player must either help (cooperation) or prevent the first from achieving the pattern (competition). Each pair played the game iteratively, alternating their roles every round. The game was played in two consecutive sessions: first the players took sequential turns (turn-based), but in the second session they placed their tokens concurrently (concurrent). Conventional GLM analyses revealed activation throughout a diffuse collection of brain regions. In builders, during cooperation rounds we found bilateral activity in supplementary motor area, cerebellum and posterior, medial and anterior cingulate cortex, insula, caudate nucleus, putamen, hippocampus and amygdala. Insula, anterior and posterior cingulate cortex as well as amygdala have been repeatedly connected to different social cognitive processes, for example risk assessment (Bickart, Dickerson, & Feldman Barrett, 2014, Takahashi, Izuma, Matsumoto, Matsumoto, & Omori, 2015) or emotion communication (Anders, Heinzle, Weiskopf, Ethofer, & Haynes, 2011). Supplementary motor area and frontal cortex activations may be reflecting the planning of the next move. In the turn-based condition we can also see stronger activations of supplementary motor area that may reflect the same thing. This is possibly because, while one player is placing the token, the other has time to plan his next move. In the concurrent condition, player is placing his token and simultaneously is evaluating other player's moves, hence there is much less time to plan the next move. In competitive Turn-based trials builder showed activations in parietal cortex, insula and medial and anterior cingulate cortex bilaterally, left medial frontal gyrus, right superior frontal gyrus and right cerebellum. In Concurrent trials activations were present bilaterally in anterior and medial cingulate cortex. Anterior cingulate cortex has been widely connected to social cognition, decision making and empathy (Laura Astolfi et al., 2010; Schilbach et al., 2013) as well as conflict monitoring and cognitive control (Sebanz, Rebbechi, Knoblich, Prinz, & Frith, 2007). Helpers showed activations in precuneus and cuneus, medial cingulate cortex, right and left hippocampus and insula and also bilaterally in putamen. Precuneus activations are also reported in social cognition research, probably linked to self-other distinction processes (Fett, Shergill, & Krabbendam, 2015; Spiegelhalder et al., 2014), but precuneus has also been connected to Theory of mind processes (Carlson, Koenig, & Harms, 2013). Putamen activity was reported in cooperation tasks (Krill & Platek, 2012; Pfeiffer, Vogeley, & Schilbach, 2013). Hinderers showed activation in frontal lobes, parietal cortex, insula, thalamus and cerebellum when builders correctly placed a token in competition trials. Cerebellum is associated mostly with motor control, however there is more and more evidence suggesting that the role of cerebellum is much more diverse and that it may even take part in mirror network and mentalizing processes (Van Overwalle, Baetens, Mariën, & Vandekerckhove, 2014). Frontal and prefrontal activation most likely represent the attentional and executive demands of the task. The differences in turn-based and concurrent condition indicate less time for planning and bigger attentional load in concurrent condition. In inter-subject correlations, we found several clusters with correlated signal, mainly in superior frontal cortex for all conditions and in precuneus. This analysis, however, was only distinguishing between different conditions, not between more specific events. These results show an extensive pattern of activations in each of the conditions, with engaging many structures involved in social cognition. However, here we present only very simple analyses and further investigations are in progress, mainly focusing on inter-brain effects (e.g. generalised psychophysiological analyses- modelling activations in one player's brain per seed region in other player's brain), since we believe, that this is the biggest advantage that hyperscanning can provide.

Acknowledgements

This proceeding was supported by platform Czech-BioImaging within Czech-BioImaging Open access project. Stimulus materials were kindly provided by Tao Liu, Phd.

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