# Effects of attachment styles on prefrontal cortex during social interaction: An fNIRS hyperscanning study

Burcu Yargicoglu-Sahin[1], Murat Perit Cakir[1], Bora Baskak[2]

[1]Department of Cognitive Science, Middle East Technical University, Ankara, Turkey, [2]Department of Psychiatry, School of Medicine, Ankara University, Ankara, Turkey

## Introduction

- As a recently emerging methodology in social neuroscience, hyperscanning have opened up important opportunities for investigating neural correlates of behaviorally observed individual differences such as attachment orientation w.r.t. attachment theory (AT) in realistic social contexts.
- This study investigates the neural correlates of human social interactions in a more naturalistic context, similar to real life situations, and aims to reveal possible differences of prefrontal cortex (PFC) activity as well as brain-to-brain coordination across the PFCs of dyads during social interaction from an AT perspective by employing functional near-infrared spectroscopy (fNIRS) hyperscanning.

**Research Question I:** What are the effects of attachment styles during competitive and cooperative social interaction tasks observed at the prefrontal cortex?

**Research Question II:** What are the effects of naturalistic competitive and cooperative social interaction tasks on the degree of inter-brain interactions observed at the prefrontal cortices of the participants?

## Methods

An experiment with 48 male subjects was performed within Cognitive Science Lab at METU. Hyperscanning technique was used during the experiment in which PFC measurements from the grouped participants were captured simultaneously (2 Hz) using fNIRS devices attached to each participant as depicted in Figure 1.

**Participants**: 48 adult right-handed male

**Attachment styles**: 27 secure and 21 insecure

**Questionnaires**:
- Edinburgh handedness test (Oldfield, 1971)
- Turkish Experiences in Close Relationship Scale (Sumer, 2006)

**Monitoring areas**:
- Dorsolateral Prefrontal Cortex
- Dorsomedial Prefrontal Cortex
- Frontopolar Cortex
- Brodmann's Areas 9, 10, 45, 46

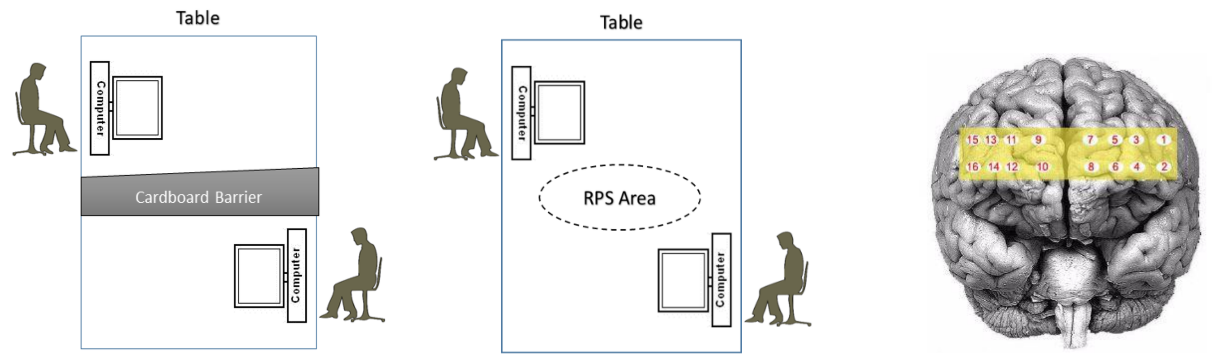


**Figure 1: Left: Experiment setup during solo task, Middle: Experiment setup during social task, Right: Monitoring areas of fNIRS device**

**Tasks:** Regular (normal) and reverse cooperative and competitive versions of the well-known rock paper scissors (RPS) game were introduced for facilitating standardized social interaction:

| **Competition Normal** | **Cooperation Normal** |
|---|---|
| Well-known RPS game | Involves showing same shape and memorizing previous hand |
| **Competition Reverse** | **Cooperation Reverse** |
| Winning rules are reversed (e.g. Rock loses to scissors) | Involves showing different shape and memorizing previous hand |

**Experiment:** Dyads were asked to play each version of the RPS task twice first by themselves (solo) then face to face with each other (social) following the task instructions on the monitor in a predefined task order (see Figure 2).

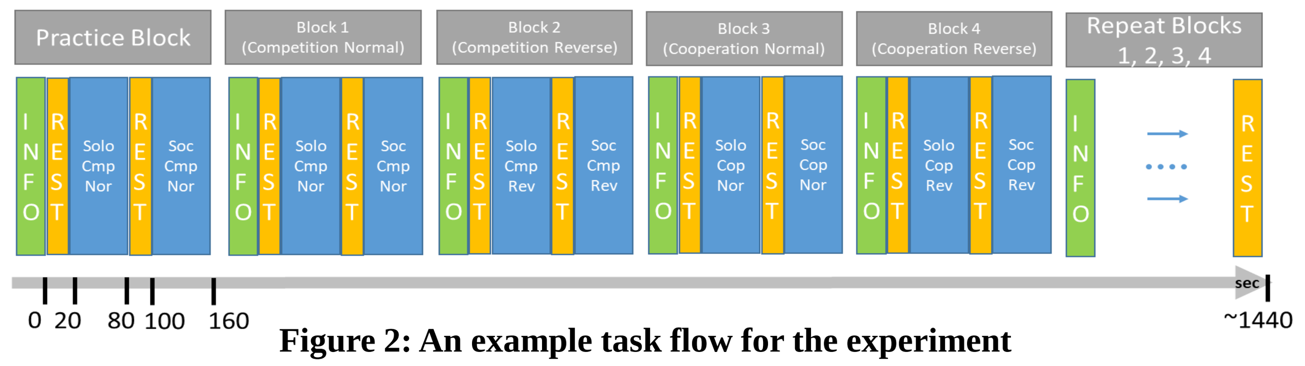


**Figure 2: An example task flow for the experiment**

## Results - I

Raw light intensity measurements and marker files were analyzed using fnirSoft software (Ayaz, 2010). For each optode belonging to each subject, raw data signal is observed and specified as OK to be processed for further analysis or not. During this specification, signals showing signs of saturation, measurement failure and noise such as motion artifact were identified and discarded from further processing.

Using fnirSoft, following preprocessing steps were done on the raw FNIRS data:
- FIR filtering (LowPass Order: 20 Hamming)
- Changes in the relative concentrations of oxy-hemoglobin (HbO) were calculated using default baseline and filtered data, employing Beer-Lambert Law
- First order linear detrending is applied on the HbO data

Output data files were exported as Matlab files for further processing and HbO concentration changes were analyzed for each optode that belong to insecure and secure subject groups:
- Mean HbO concentration change calculations (w.r.t. both baseline and rest periods prior to each task) were performed according to all tasks w.r.t. attachment styles
- Two sample t-test was employed to measure mean HbO concentration change significance between insecure and secure subject groups

2 sample t-test results (1-p values) among secure and insecure HbO activation levels w.r.t. baseline and prior rest period were depicted in Figure 3 respectively and t-test statistics were provided in Table 1. Only initial tasks were analyzed w.r.t. baseline.

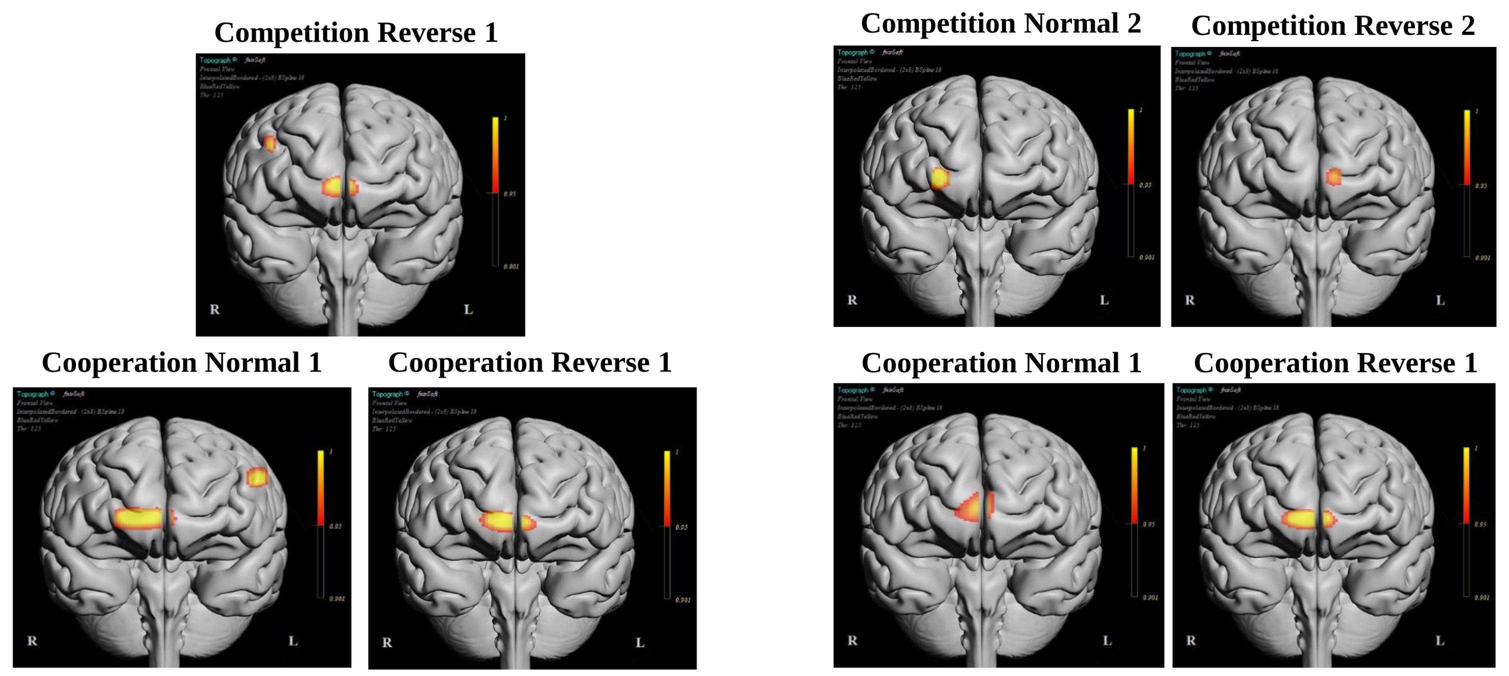


**Figure 3: 2 sample t-test results (1-p values) (left: w.r.t. baseline (BL), right: w.r.t. rest (RST))**

*Table 1: 2 sample t-test results showing significant attachment style differences in HbO concentration changes w.r.t. baseline (BL), and prior rest period (RST) and mean HbO concentration changes in secure and insecure participants*

| Optode # | Task | w.r.t. | t-statistic (df) | p-value | effect-size r | mean-hbo-secure | mean-hbo-insecure |
|---|---|---|---|---|---|---|---|
| Optode 1 | Cooperation Normal I | BL | t (34) = 2.1608 | .038 | .347 | 0.6613 | 0.0371 |
| Optode 8 | Competition Reverse II | RST | t (31) = 2.3385 | .026 | .387 | -0.0049 | -0.6400 |
| Optode 10 | Competition Reverse I | BL | t (28) = 2.1990 | .036 | .383 | 0.3219 | -0.3947 |
| | Cooperation Normal I | BL | t (28) = 3.7784 | .001 | .581 | 0.5523 | -0.4829 |
| | | RST | t (28) = 2.3427 | .026 | .404 | 0.2746 | -0.6221 |
| | Cooperation Reverse I | BL | t (27) = 2.6622 | .012 | .455 | 0.5439 | -0.6137 |
| | | RST | t (27) = 2.0742 | .048 | .370 | 0.2646 | -0.6620 |
| Optode 12 | Cooperation Normal I | BL | t (32) = 2.2701 | .030 | .372 | 0.5685 | -0.0386 |
| | Competition Normal II | RST | t (30) = 2.6687 | .012 | .438 | 0.1371 | -0.7019 |
| Optode 13 | Competition Reverse I | BL | t (37) = 2.0277 | .049 | .316 | 0.2325 | -0.2398 |

## Results - II

Wavelet Transform Coherence (WTC) was used to assess relationships between the fNIRS signals generated by pair of participants in this study. WTC is a method of measuring the cross-correlation between two time series as a function of frequency and time (Grinsted et al., 2004). In order to calculate WTC of pairs, the wavelet coherence MATLAB package was used.

For each optode that belongs to each pair, WTC coherence values were extracted specific to the rest and task blocks using HbO data. Period for rest and task blocks were taken between 64 and 128, since task blocks were 60 seconds long and the sampling rate was 2 Hz.

Novel coherence increase measures were introduced:

| | | |
|---|---|---|
| **A** | **"Solo coherence increase":** | Mean solo coherence – Mean rest before solo coherence |
| **B** | **"Social coherence increase":** | Mean social coherence – Mean rest before social coherence |
| **C** | **"Social coherence difference":** | Mean social coherence – Mean solo coherence |
| **D** | **"Social coherence increase difference":** | B - A |

In order to obtain significant coherence increase regarding optodes and different forms of solo and social tasks, one-sample t-test on the group level is employed for every type of coherence increase computation. T-test calculations have been performed on only the eligible data for that optode and task.

*Table 2: One-sample t-test results for competition tasks*

| Optode # | Task | Type | t-statistic (df) | p-value | effect-size r |
|---|---|---|---|---|---|
| Optode 2 | Competition Reverse II | B | t (13) = 1.8258 | .045 | .451 |
| | | C | t (13) = 3.6976 | .001 | .715 |
| Optode 6 | | C | t (10) = 2.3207 | .021 | .591 |
| Optode 9 | Competition Normal I | C | t (14) = 3.0845 | .004 | .636 |
| Optode 11 | | C | t (14) = 2.3463 | .017 | .531 |
| Optode 14 | | C | t (15) = 2.8590 | .006 | .593 |

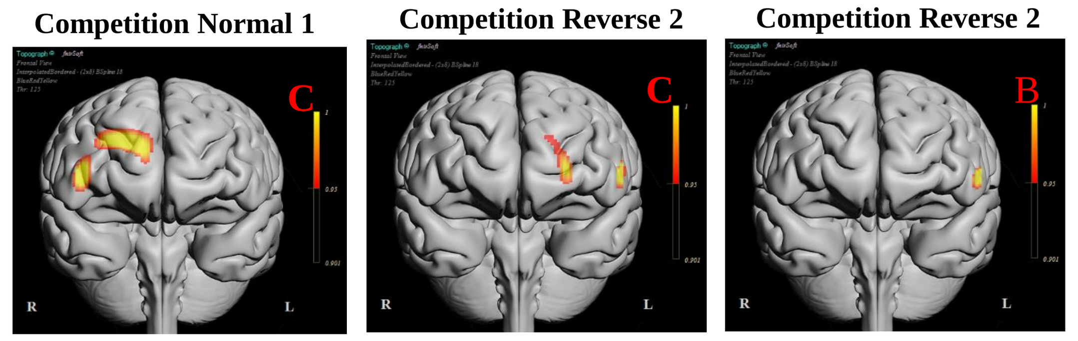


**Figure 4: Significant coherence increase results (1-p values) for competition tasks**

*Table 3: One-sample t-test results for cooperation tasks (left: normal, right: reverse)*

| Opt # | Task | Type | t (df) | p | r |
|---|---|---|---|---|---|
| **7** | Coo-N-I | C | t (10) = 2.2637 | .023 | .582 |
| **9** | Coo-N-II | C | t (12) = 2.4084 | .016 | .570 |
| | | D | t (12) = 1.8723 | .042 | .475 |
| **11** | | B | t (12) = 2.0436 | .031 | .508 |
| | | C | t (12) = 2.7209 | .009 | .617 |
| | | D | t (12) = 2.9019 | .006 | .642 |
| **15** | | C | t (7) = 2.0995 | .037 | .621 |
| **16** | | B | t (12) = 1.8420 | .045 | .469 |
| | | D | t (12) = 1.9533 | .037 | .491 |
| | Coo-N-I | C | t (15) = 1.9692 | .033 | .453 |

| Opt # | Task | Type | t (df) | p | r |
|---|---|---|---|---|---|
| **1** | Coo-R-I | B | t (13) = 1.9465 | .036 | .475 |
| | | D | t (13) = 1.9308 | .037 | .472 |
| | Coo-R-II | D | t (10) = 2.1317 | .029 | .558 |
| **2** | Coo-R-I | B | t (13) = 2.2559 | .021 | .530 |
| | | D | t (13) = 1.8194 | .046 | .450 |
| | Coo-R-II | D | t (12) = 1.9059 | .040 | .482 |
| **3** | Coo-R-I | B | t (14) = 2.8317 | .006 | .603 |
| | | C | t (14) = 2.4650 | .013 | .550 |
| | | D | t (14) = 2.6188 | .010 | .573 |
| | Coo-R-II | D | t (12) = 1.8797 | .042 | .476 |
| **7** | Coo-R-I | C | t (10) = 2.9733 | .007 | .685 |
| **9** | | C | t (13) = 2.1387 | .026 | .510 |
| **10** | | C | t (7) = 2.4735 | .021 | .682 |
| **11** | | C | t (13) = 2.0259 | .031 | .489 |

## Results – II – cont.

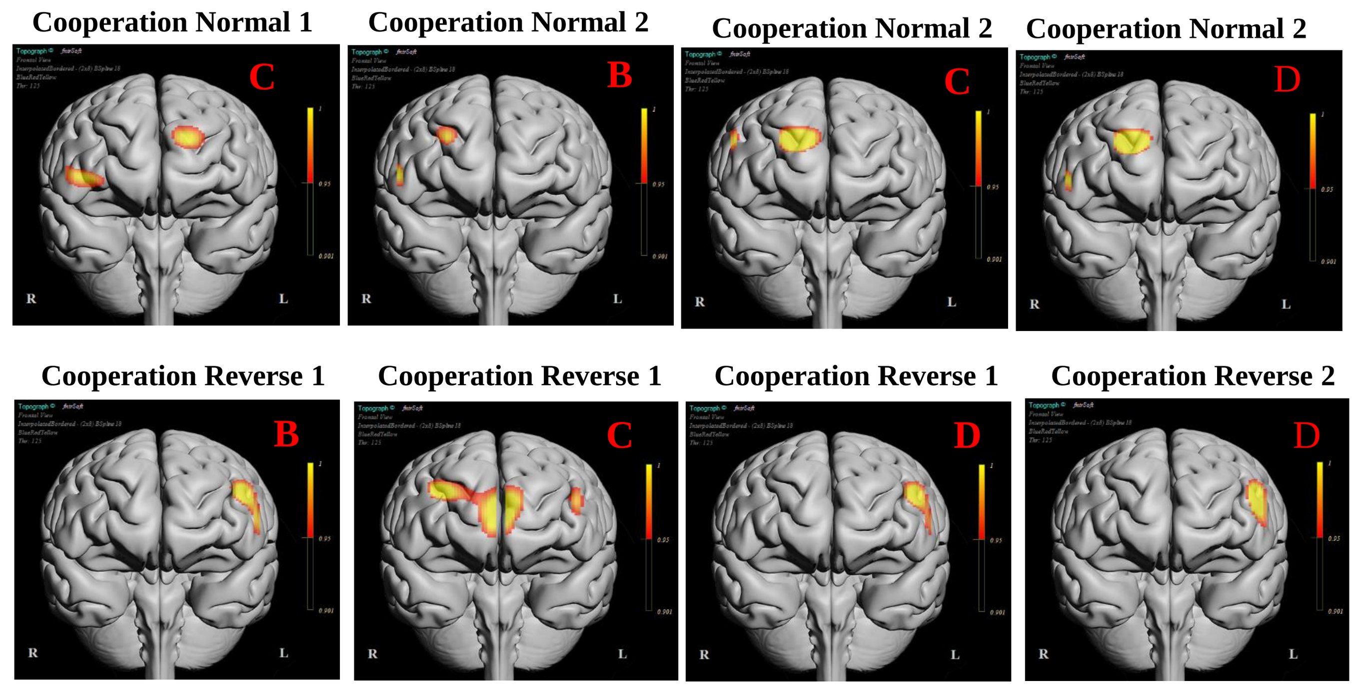


**Figure 5: Significant coherence increase results (1-p values) for cooperation tasks**

## Conclusion

- Current findings based on 27 secure and 21 insecure participants reveal novel attachment style effects on frontopolar cortex (FC) oxygenated hemoglobin (HbO) activation during both cooperative and competitive tasks.
  - ➢ Very high significant ($p < 0.01$) right frontopolar HbO activation difference during initial normal cooperation task was observed along with high significant activation differences during normal and reverse competition and cooperation tasks
  - ➢ Secure attachment orientation was observed to exhibit stronger hemodynamic response compared to insecure considering mean HbO concentration changes
  - ➢ These results signal that there can be attachment style differences regarding frontopolar cortex activation during social interactions, which may be considered as a neurological factor underlying behaviorally observed differences
- Inter-brain coherence increase is observed in FC and DLPFC during both competition and cooperation tasks bilaterally in a lateralized manner depending on the task type.
  - ➢ Both normal competition and cooperation tasks lead to significant coherence increase at right DLPFC
  - ➢ Using novel mean coherence difference measurement method, significant coherence increase is observed in FC as well for both competition and cooperation tasks
  - ➢ Reverse competition and cooperation tasks were observed to elicit significant coherence increase in left DLPFC
- Overall, our findings suggest that FC, thought as a hub for metacognition (Burgess, 2013), while contributing to social interaction, interestingly elicits activation differences w.r.t. attachment styles as well, with secure attachment orientation exhibiting stronger hemodynamic response, which may serve as a putative neuro-biologic marker underlying individual differences.

## References


- Ayaz, H., 2010. Functional Near Infrared Spectroscopy Based Brain Computer Interface. School of Biomedical Engineering, Science & Health Systems. PhD Thesis Drexel University, Philadelphia, PA, p. 214
- Burgess, Paul & Wu, Hsuan-Chen. (2013). Rostral prefrontal cortex (Brodmann area 10): metacognition in the brain.
- Grinsted, A., Moore, J.C., Jevrejeva, S. (2004). Application of the cross wavelet transform and wavelet coherence to geophysical time series. Nonlinear Processes Geophys. 11, 561–566.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia, 9(1), 97-113
- Sümer, Nebi. "Yetiskin baglanma ölçeklerinin kategoriler ve boyutlar düzeyinde karsilastirilmasi." Türk Psikoloji Dergisi 21.57 (2006): 1.


**Contact: Burcu Yargicoglu-Sahin: e199630@metu.edu.tr**