Hyperscanning during Psychotherapy for Test Anxiety Reveals Evidence for Inter-Brain Plasticity as Mechanisms of Change

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Author's note

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Abstract

Objective

There is a growing consensus that interpersonal processes are key to understanding psychotherapy. However, neuroscientific inquiries of therapeutic processes have been limited to (offline) assessments of patients outside of treatment sessions. The current study examines, for the first time, *online* interpersonal neurological processes between patients and therapists during sessions. Recent research proposes that inter-brain synchrony is a biomarker of interpersonal interaction quality. We hypothesized that over the course of therapy inter-brain synchrony between patients and therapists would gradually increase, and that that this increase – i.e., inter-brain plasticity - would be associated with therapeutic change.

Method

8 participants enlisted in a 6-session treatment for test anxiety (N = 8 patients). During three of the sessions, therapist and patient brain activity was measured using functional near-infrared spectroscopy (fNIRS), focusing on the inferior-frontal gyrus (IFG). Patient-therapist inter-brain synchrony was calculated using wave transform coherence; perceived session quality, test anxiety symptoms, and therapeutic alliance were assessed using baseline, session-by-session and follow-up questionnaires.

Results

Inter-brain synchrony in the IFG was associated with reduced symptoms, improved wellbeing and perceived session quality, but not with a stronger therapeutic alliance. Importantly, inter-brain synchrony significantly improved over the course of treatment, suggesting that inter-brain plasticity has occurred.

Conclusion

While these findings require replication, they demonstrate that fNIRS imaging during psychotherapy is a promising research method, that inter-brain synchrony has potential as an indicator of effective therapy sessions and that inter-brain plasticity might be a biological mechanism underlying therapeutic change.

Psychotherapy can lead to profound changes in the ways patients feel, think and behave. As the brain is the main organ responsible for emotions, thoughts and behavior, researchers have been interested in the way the brain changes over the course of psychotherapy, and indeed many types of changes were found (Barsaglini et al., 2014). However, these studies almost universally involve brain imaging of the patient at various points in time outside of the therapy sessions (offline). As such, they cannot shed light on the neural processes which occur *during* (online) psychotherapy. Beyond that, these studies focus on one brain – the patient's – while most forms of therapy involve at least one other brain – that of the therapist. Existing clinical research has highlighted the importance of interpersonal phenomena and relationships in symptomatology (e.g., Girard et al., 2017), in formations of psychopathology (Hopwood et al., 2021), and – in research on the therapeutic alliance – as a mechanism of change (Doran, 2016). Studying these interpersonal phenomena from a neuroscientific perspective requires examining both of the brains involved (Redcay & Schilbach, 2019), also known as hyperscanning (Babiloni & Astolfi, 2014).

What would we expect to find in the brains of therapists and patients during psychotherapy sessions? One possible approach would be to examine inter-brain synchrony (Hasson et al., 2012) – the synchronization of activity between therapists' and patients' brains. Behavioral synchrony (e.g., in motion, tone of voice, language, etc.) in psychotherapy has been thoroughly studied in recent years, and – with occasional caveats – has been associated with a stronger working alliance and improved outcomes (Koole et al., 2020; Wiltshire et al., 2020). As for inter-brain synchrony, outside of psychotherapy it is generally associated with more cooperative and prosocial interactions (Czeszumski et al., 2022). The few studies examining inter-brain synchrony in single-session consultations have found that inter-brain synchrony is

higher in therapy than in casual conversation, and that it is associated with a stronger working alliance (Lecchi et al., 2019; Y. Zhang et al., 2018). Thus, there is reason to believe that inter-brain synchrony could be associated with a variety of beneficial outcomes, but this has never been examined in actual therapy.

Finally, inter-brain synchrony could even drive change in psychotherapy, through inter-brain plasticity (Shamay-Tsoory, 2020) – defined as experience-dependent changes in interbrain synchrony. Inter-brain plasticity may contribute to the interaction partener's ability to synchronize over time as they are exposed to situations with high synchrony. Existing research has shown that various disorders are associated with a reduced capacity for inter-brain and behavioral synchrony; that this capacity might be associated with interpersonal difficulties; and that, at least for behavioral synchrony, it might improve after therapy, suggesting that inter-brain plasticity might underlie some benefits of psychotherapy (Sened et al., 2022).

Thus, the current study goes beyond single consultations to provide the first examination of inter-brain synchrony and plasticity over the course of actual treatment. To do so, we used functional near-infrared spectroscopy (fNIRS; Ferrari & Quaresima, 2012) to perform brain imaging of in a traditional clinic setting, with imaging performed using special caps worn by participants. Based on previous studies showing that inter-brain synchrony in the inferior-frontal gyrus (IFG) is associated with increased behavioral synchronization (Gamliel-Nathan et al., 2021) and increased interpersonal synchrony during cooperative behavior (Gvirts & Perlmutter, 2020; Shamay-Tsoory et al., 2019), we focused on changes in synchronization in the IFG between sessions. This allows us to examine several questions which cannot be answered in a single sessions. First, in line with research on behavioral synchrony, is inter-brain synchrony

associated with therapeutic effectiveness? Second, does inter-brain plasticity occur during psychotherapy?

Method

The study was approved by the institutional IRB and was registered after data collection ended but before statistical analyses were run on clinicaltrials.gov, identifier NCT05336734. Due to the exploratory nature of the study, the statistical analyses were not pre-registered.

Participants

Participants were recruited through social media posts in student discussion groups. 22 people indicated interest in the study. 14 could not participate due to scheduling issues, leaving 8 participants - 6 female and 2 male who completed the full course of the study. 7 participants were Jewish and 1 was Arab-Christian. Inclusion criteria were a Test Anxiety Inventory (TAI; Spielberger, 2010) score of at least 50, no suicidality (a value of 1 or less in the BDI-II suicide item), no current psychotherapy addressing test anxiety, and no comorbid disorders with the exception of anxiety disorders and single-episode MDD (as assessed by the DIAMOND clinical interview; Tolin et al., 2018). Participants were treated for free and received no other compensation. All participants completed the whole study course. In five treatment sessions and three interview sessions one of the imaging recordings failed due to technical issues; In one treatment session and one interview session the recording succeeded but no channel passed data cleaning (see below), leaving 18 session recordings and 12 interview recordings.

Therapists and Interviewers

All participants were treated by the first author, who is a licensed clinical psychologist with over five years of clinical experience at the time the study took place. The therapist was

supervised by a licensed clinical supervisor who has supervised multiple therapists in the administration of the treatment protocol. Interviewers were BA and MA psychology students.

Procedure

The study consisted of a total of eight sessions per participant – a screening session, six therapy sessions, and a follow-up session. Participants who indicated interest in the study were sent an online questionnaire which included the TAI and the BDI-II. Participants with a high enough level of test anxiety and no suicidality were asked to come to a baseline session. During the session, they signed a consent form and completed the DIAMOND screening questionnaire. Then, the participant and an interviewer gave saliva samples (saliva hormone measurements are not discussed in the current study) and the interviewer and participant were connected to an fNIRS imaging system (see details below). The interviewer then administered a verbal interview which consisted of the TAI, used as a structured interview, as well as the DIAMOND initial interview. Participants and interviewers were disconnected from the fNIRS devices, and the interviewer proceeded to administer the rest of the DIAMOND questionnaire. Finally, participants completed a set of questionnaires on a computer.

One week later, participants began a course of six sessions of psychotherapy for test anxiety administered once per week. Treatment involved imagery work and cognitive behavioral therapy, as described by Prinz et al. (2019). At the beginning of each meeting, participants completed a set of questionnaires. On the first, third and fifth treatment sessions, participants and therapists also gave a saliva sample and were then connected to fNIRS devices for the duration of the session. After each session, participants and therapists completed additional questionnaires.

One week after the last therapy session, participants underwent a follow-up session, in which an interviewer who they have never met before administered a verbal interview identical to the one administered in the first session (the TAI and the DIAMOND initial interview). Both interviewers and participants gave saliva samples and were connected to fNIRS devices during the interview. Participants also completed follow-up questionnaires.

Measures

Note: for session-level measures we reported reliability for assessing within-person change (Cranford et al., 2006) noted as R_C (values are comparable to Cronbach's alpha).

Test Anxiety. Test anxiety was measured during the background and the follow-up sessions using a Hebrew version of the Test Anxiety Inventory (TAI; Spielberger, 2010), in which participants rate how often 20 test anxiety related situations happen to them (e.g., "I freeze in important tests on a 4 - point Likert-type scale (1 – almost never; 4 – almost always). Reliability was high at baseline and follow-up (Cronbach's alpha = .89 in both cases).

State Test Anxiety. State test anxiety was measured using a Hebrew version of the state test anxiety scale used by Prinz and colleagues (2019), originally adapted from Lawrence and Williams (2013). The scale consists of 6 statements about the participants worries regarding upcoming tests (e.g., "I feel stressed and upset about performing the upcoming test"), rated on a 7 – point Likert-type scale (1 – completely disagree, 7 – completely agree). Reliability was acceptable (R_C = .77).

Therapeutic Alliance. Therapeutic alliance was measured using a Hebrew version of the Session Alliance Inventory (Falkenström et al., 2015). The measure consists of 6 statements (e.g., My therapist and I respected each other), rated on a 6-point Likert-type scale (0 – not at all, 5 – completely). Reliability was acceptable (R_C = .66).

Perceived Session Quality. Perceived session quality was assessed using the Session Evaluation Scale (SES) 5-item version (Lent et al., 2006), administered after the session. The measure consists of 5 statements (e.g., "I thought that this session was helpful"), rated on a 5-point Likert-type scale (1 –strongly disagree, 5 – strongly agree), with two reversed items.

General outcome. General wellbeing was assessed using the Outcome Rating Scale (ORS; Miller et al., 2003), administered both before and after each session. ORS is presented as 4 visual slider items, each asking the participant to rate their wellbeing in a different domain (e.g, in close relationships). Scale endpoints are marked as "Very low" and "Very high" wellbeing. Each slider position is mapped to a number between 0 (very low) and 100 (very high). Reliability was acceptable to high (Before session R_C = .81, post session R_C = .76).

Overall Subjective Satisfaction. Overall subjective satisfaction was assessed on follow-up using five items. Participants rated how satisfied they were with the treatment in general (1 – not at all, 4 – very satisfied), and how the use of fNIRS affected their experience (1 – interfered with my treatment experience very much, 5 – improved my treatment experience very much). Reliability was acceptable (R_C = .7).

Brain Activation. Coupling between brain signals was measured, using a BRITE 24 fNIRS measurement system (Artinis Medical Systems). Optode location was chosen using the international EEG 10-20 system (see Figure 1). Measurements were performed at a 50 Hz rate. Imaging data was corrected with respect to the participant's scalp thickness, which is calculated based on the participant's age. Preprocessing was preformed using the HOMER3 Matlab package (Huppert et al., 2009). We used a 1 Hz low-pass filter to avoid confounds with high-frequency physiological processes (e.g., heartbeat, blood flow), and used Principal Component Analysis (PCA) to correct for motion artifacts. Channels with above a 0.5 positive correlation

between oxyhemoglobin and deoxyhemoglobin were discarded. We focused on measured changes in brain activity using the oxyhemoglobin signal alone, as it was found to be more sensitive to changes in blood flow in fNIRS research (Hoshi, 2007).

Synchrony. Each session was divided into 1-minute length segments. Channels were divided to three regions of interest (see Figure 1): left inferior frontal gyrus (IFG), right IFG, and non-IFG. We used wavelet transform coherence (Grinsted et al., 2004; X. Zhang et al., 2020) using the R biwavelet package (Gouhier et al., 2021) to assess synchrony. Resulting synchrony r values were transformed using fisher's z, outliers of over 5 standard deviations were removed, and synchrony values for periods of 1 to 10 seconds were averaged to create a single score for each minute. We then dropped the first and last minute of every session to avoid artifacts originating by the very beginning and end of the session. Since sessions were of different lengths, we truncated sessions to the length of the shortest session. Thus, when analyzing treatment sessions, we used the first 40 minutes; when analyzing interviews and when comparing treatment sessions with interviews, we used the first 5 minutes. No significant differences were found between the regions of interest and as such we used mean synchrony across regions for all analyses.

Analysis

Unless otherwise stated, data was analyzed using mixed linear models using the R package nlme (Pinheiro et al., 2018) to account for repeated measures. Analyses included random effects for each participant and, for minute-level analyses, for each session and brain region under study. Analyses also included an auto-regression correlation structure to account for similarity between measures taken consecutively. Effect sizes were calculated using the methods suggested by Rights and Sterba (2019) using the R package misty (Yanagida, 2022). Partial

effect sizes of specific variables were calculated by subtracting the effect size of a model which omitted the examined variable from the total effect size of the model.

Results

Descriptive Statistics

Descriptive measures for all variables are provided in Table 1.

Treatment Effects

We tested person-level changes in test anxiety, as measured in the baseline and followup questionnaires, as well as in state test anxiety and overall wellbeing as measured in the first and last meetings, using paired t-test analyses. While all changes were in the expected direction (reduced symptoms, improved wellbeing) with small to medium effect sizes, only changes in post-session ORS were significant, and they did not remain significant after applying Holm's (1979) correction for multiple comparisons (Test anxiety mean change -3.125, $t(7) = -1.758$, $p = .122$, 95% CI -7.327, 1.077, $d = .622$; state test anxiety mean change -4.875, $t(7) = 2.1464$, $p = .069$, 95% CI -10.245, $d = .496$; pre-meeting ORS mean change 19.25, $t(7) = .748$, $p = .479$, 95% CI -41.587, 80.087, $d = .265$; post-meeting ORS mean change 50.429, $t(7) = 2.798$, $p = .031$, 95% CI 6.33, 94.528, $d = 1.056$).

We then assessed change over time in state test anxiety as well as overall wellbeing using multilevel regression analyses with session number as the independent variable. All changes were in the expected direction, and changes in state test anxiety and post-session wellbeing were significant after correction for multiple comparisons (State test anxiety $b(SD) = -1.083(0.428)$, $t(35) = -2.533$, $p = .016$, 95% CI -1.951,-.214, $d = .809$; pre-meeting wellbeing $b(SD) = 7.175$, $t(35) = 1.775$, $p = .084$, 95% CI -1.03, 15.379, $d = .269$); post-meeting wellbeing $b(SD) = 10.171(3.666)$, $t(34) = 2.774$, $p = .009$, 95% CI 2.72,17.62, $d = .375$).

The effect of fNIRS Imaging on treatment experience

To assess how well participants tolerated the use of fNIRS, we examined the effects of fNIRS measurement (coded 0.5 for sessions with fNIRS and -0.5 for sessions without) on therapeutic alliance, session quality and overall wellbeing measured post-session, controlling for session number as fNIRS was used in earlier sessions (1,3,5 as opposed to 2,4,6). Effect sizes were negligible (all ds < .1) and no effects were significant, suggesting that fNIRS did not have meaningful adverse effects (Alliance *b(SD)* = -.096(0.646), *t(33)* = -.147, *p* = .884, 95% CI -.433,.474, partial d = .043; session quality *b(SD)* = -.168(0.473), *t(33)* = -.355, *p* = .725, 95% CI -1.13,.795, partial d < 0; post-session wellbeing *b(SD)* = 1.29(7.11), *t(33)* = .182, *p* = .856, 95% CI -13.163,15.755, partial d = .0286).

We also examined post-treatment satisfaction questions. When asked about treatment satisfaction in general 5 participants (62.5%) were “very satisfied” and 3 (37.5%) were “pretty satisfied”; none were “somewhat satisfied” or “not satisfied at all”. When asked if fNIRS measurement affected their treatment experience, 1 participant (12.5%) reported it “somewhat improved” her experience, 4 participants (50%) reported it “did not matter”, and 3 (37.5%) reported it “somewhat worsened” their experience. No participants reported that it “extremely worsened” or “extremely improved” their experience.

Inter-Brain Synchrony and Plasticity

To test whether synchrony in the sample was above chance, we conducted a random permutation test by randomly pairing the fNIRS recordings of the therapist from each session with those of a patient from a different session. The test found that mean synchrony in the true sample (*m(SD)* = .292(.53)) was outside of a 95% confidence interval of randomly permuted samples (95% CI .286,.291); only 6 of 1000 permutations had higher mean synchrony than the

true sample. This indicates that synchrony found in the true sample was significantly beyond chance.

As we expected, synchrony significantly increased over time (between sessions), with a large effect size (*b(SD)* = .007(.002), *t(9)* = 3.859, *p* = .004, 95% CI .003, .011 *d* = 1.338) suggesting that participants' capability to synchronize with the therapist increased over treatment (see Figure 2). Analyses of session-level variables showed that synchrony was also significantly associated with state test anxiety (*b(SD)* = -.003(.001), *t(7)* = -4.218, *p* = .004, 95% CI -.005,-.001, *d* = 1.6); with post-session wellbeing (*b(SD)* = .0005 (.0001), *t(6)* = 6.44, *p* < .001, 95% CI .0003,.0007, *d* = 2.3), an association which held even when controlling for pre-session wellbeing; and with perceived session quality (*b(SD)* = .005 (.002), *t(6)* = 2.64, *p* = .038, 95% CI .0003, .0092, *d* = 1.13). This suggests that synchrony is associated with reduced test anxiety symptoms and with sessions which participants perceived as high quality, in which their wellbeing improved. Findings on test anxiety and time are demonstrated in Figure 2.

<Figure 2 about here>

However, concerning replications of prior results, contrary to our expectations, synchrony was not positively associated with alliance measures, showing a small, non-significant *negative* effect size instead (*b(SD)* = -.001(.003), *t(6)* = -.415, *p* = .692, 95% CI -.007,.005, *d* = .218). Synchrony was also not found to be higher during psychotherapy, when compared to clinical interviews, showing a small, non-significant *negative* effect size instead (*b(SD)* = -.008(.01), *t(21)* = .802, *p* = .432, 95% CI -.028,.012, *d* = .292).

We also examined whether treatment had an effect on participants' ability to synchronize with an interviewer. Contrary to our expectations, we did not find an increase in synchrony between the pre-treatment and post-treatment clinical interviews, finding a negligible, non-

significant *negative* effect size instead (*b(SD)* = -.001(.007), *t(4)* = .088, *p* = .934, 95% CI -.019,.018, *d* = .034).

Discussion

The current study was the first to use fNIRS hyperscanning over the course of a full (albeit short) course of psychotherapy. Our findings suggest that the use of fNIRS was well-received by participants, did not create an undue burden on participants and did not impede treatment. Importantly the results provide initial evidence of inter-brain plasticity in the IFG during psychotherapy, i.e., an increase in inter-brain synchrony over treatment; and they suggest that these changes are associated with symptom reduction and improved wellbeing. On the other hand, these changes did not generalize to a meeting with a new person. Additionally, previous findings on the association between synchrony and the therapeutic alliance did not replicate. Finally, we note that due to the small sample size, both positive and null findings should be replicated in future studies. We discuss our findings in depth below.

Treatment Effects

The current study was not designed or powered to demonstrate treatment efficacy. Indeed, pre-post comparisons of outcome measures did not yield significant results. However, there are several indications that the treatment was effective. First, effects were in the expected direction, with meaningful effect sizes. Second, session-level analyses, which have higher statistical power due to repeated measures, did reveal a significant reduction in symptoms and improvement in wellbeing. Finally, reduction in symptoms was larger than during the comparable period of a larger trial of this treatment (Test anxiety mean change -3.125 in current study, compared to 2.2 between first baseline to first followup in Prinz et al., 2019).

Reception of fNIRS During Treatment

Differences between sessions with and without fNIRS were negligible with respect to therapeutic alliance, wellbeing, or perceived session quality. While some participants reported being mildly inconvenienced by the method, satisfaction with the treatment as a whole was high. Additionally, there was no attrition. These findings suggest that fNIRS measurement does not meaningfully interfere with treatment, supporting the use of fNIRS as a measure in neuroscientific psychotherapy research. Anecdotally, we believe that the use of fNIRS only in alternating sessions contributed to the tolerance of this method by participants.

Synchrony, Psychotherapy and the Therapeutic Alliance

Our study found that inter-brain synchrony in psychotherapy was associated with less test anxiety symptoms and higher wellbeing. Importantly, synchrony was specifically associated with an improvement in wellbeing from pre- to post-session. This supports the notion that inter-brain synchrony may be tracking the effectiveness of interpersonal interaction between therapists and clients during therapy, ultimately leading to better outcomes, although our design is not sufficient to conclude whether changes in synchrony are *driving* the changes in outcomes or merely a byproduct of these changes.

However, we did not replicate the findings of Zhang and colleagues (Y. Zhang et al., 2018) who found increased brain synchrony in a single counseling session when compared to casual conversation, and who found an association between the therapeutic alliance and brain synchrony. Beside the possibility of a null finding due to low power, there are several differences between the current study and this existing study which could explain this discrepancy. First, Zhang and colleagues examined the temporoparietal junction (TPJ) while the current study examined synchrony in the inferior frontal gyrus (IFG). Second, regarding the difference between psychotherapy and casual conversation, it could be the case that the clinical interviews

that we used were too similar to psychotherapy. Additionally, the fact that they were more structured than the beginning of a psychotherapy session (to which they were compared) could have artificially increased synchrony. Finally, regarding the association between synchrony and the alliance, out of the eight participants, three reported only the maximum possible alliance rating or one below it (35 or 36), suggesting that a ceiling effect might have influenced results (removing these participants results in a positive, though not significant, effect).

Inter-brain Plasticity

Our findings have demonstrated a gradual increase in inter-brain synchrony over the course of therapy. This is the first study to support the notion that inter-brain plasticity – i.e., changes in therapists' and participants' brains which afford higher synchrony – has occurred. As higher synchrony was also associated with symptom reduction, and in an increase in well-being over the course of each specific session (as well as over the total course of treatment), it is possible that this gradual increase in inter-brain synchrony is one of the mechanisms driving general symptom reduction. Notably, this change did not generalize to an encounter with an interviewer at the end of treatment. It could be the case that a longer treatment is required to achieve a generalized increase in synchrony, or that the interview task was too structured to show changes in participants capability to synchronize.

Limitations

The main limitation of the current study is the small sample size; results should be seen as pending replication. This has also led to no differences being found between brain areas of interest, limiting the ability to implicate a more specific neural system in these processes. Additionally, the therapist and interviewers were not blinded to study hypothesis, although this is somewhat mitigated by the fact that brain synchrony cannot be consciously manipulated in the

absence of feedback. Finally, the study design does not allow us to causally interpret the association between synchrony and symptom change. Future studies could overcome these limitations by using multiple baseline measurements of synchrony and symptoms, as well as longer treatment protocols, to attempt to understand the causal direction of these effects.

Conclusion

The current study provided evidence showing that inter-brain synchrony increases during psychotherapy, which may indicate the occurrence of inter-brain plasticity. It also showed that synchrony was associated with lower symptom and higher wellbeing, suggesting that this process of improved synchrony may serve as a mechanism of change. Beyond these specific findings, the study also demonstrated that the use of fNIRS measurement during psychotherapy did not interfere with therapy; we are excited to see how future research using this method can shed light on single-person and dual-person neural processes in psychotherapy.

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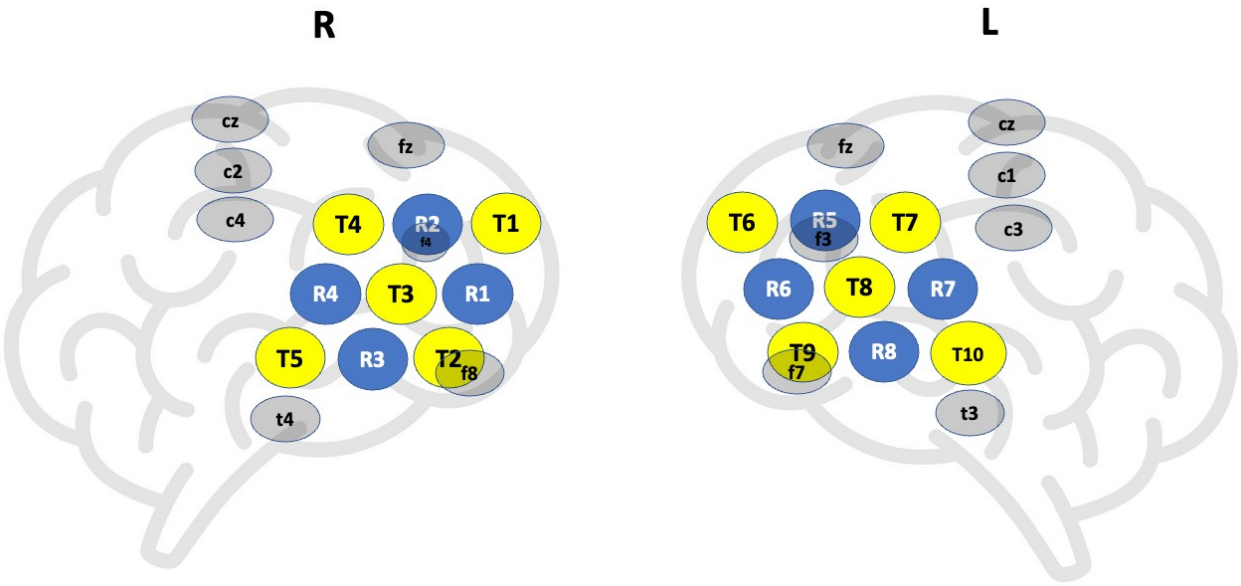
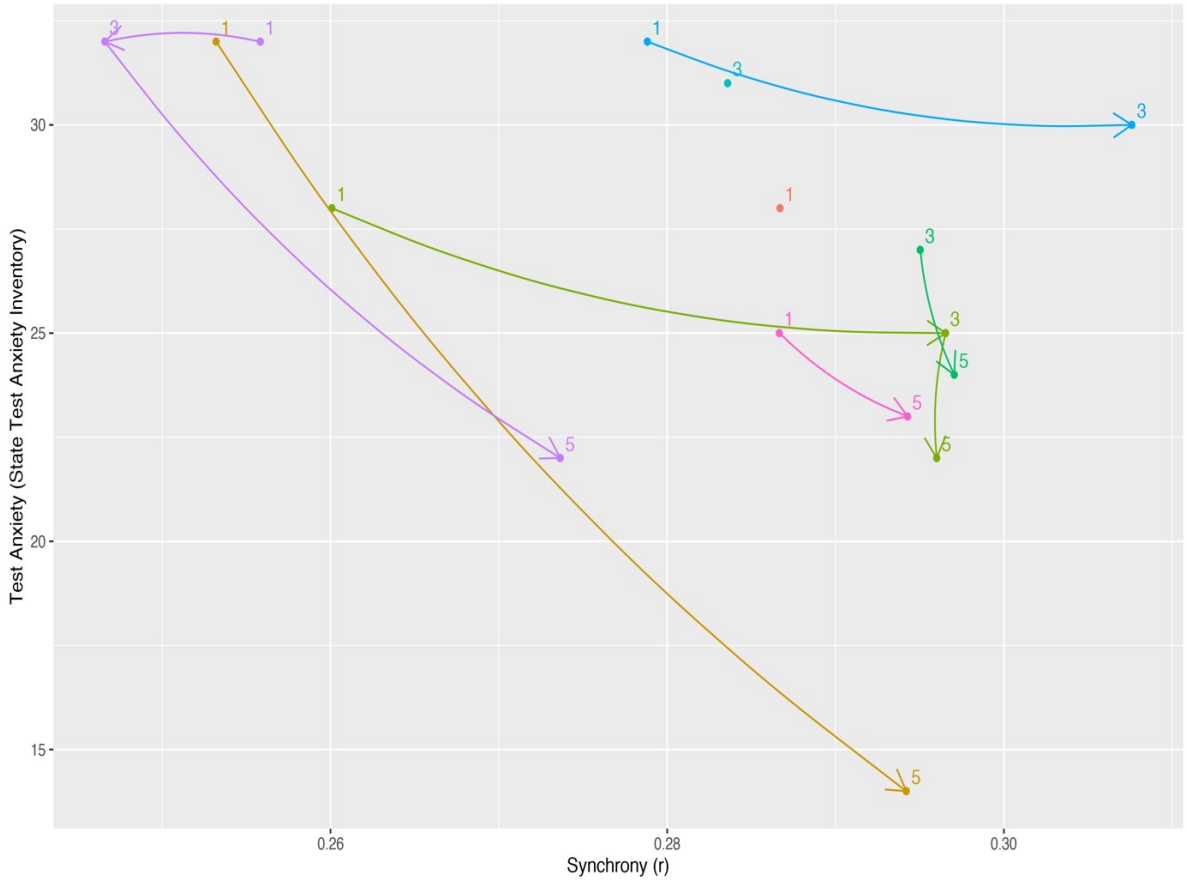
Figure 1. Optode Placement



Optode montage relative to the EEG 10/20 system. The IFG was identified at f7 (left) and f8 (right); Channels T9-R6, T9-R8, T8-R6, T8-R8 were considered the left IFG; Channels T2-R1, T2-R3, T3-R1, T3-R3 were considered the right IFG.

Figure 2 – Changes in test anxiety and inter-brain synchrony over the course of treatment



Colors indicate different participants; Numbers indicate session numbers.

Table 1. Descriptive Statistics

	N	Mean(SD)	Range
Baseline Test Anxiety	8	64.5(10.41)	50-75
Follow-up Test Anxiety	8	61.38(10.64)	44-72
State Test Anxiety	44	27(5.01)	14-35
Pre-session Wellbeing	44	254.86(89.06)	32-383
Post-session Wellbeing	43	260.51(91.08)	44-390
Therapeutic Alliance	43	29.95(5.2)	17-36
Perceived Session Quality	43	22.77(2.67)	14-25
Inter-brain Synchrony (Sessions)	18	.289(.019)	.252-.318
Inter-brain Synchrony (Interviews)	12	.3(.017)	.278-.327