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RESEARCH REPORT

STUDY OF THE EFFECT OF GSR TECHNIQUE ON HUMAN ELECTROPHYSIOLOGICAL PARAMETERS
(final report)

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ABSTRACT

The report consists of 41 pages, including 15 figures and 18 references.

STUDY OF THE EFFECT OF GSR TECHNIQUE ON HUMAN ELECTROPHYSIOLOGICAL PARAMETERS

The study examines human physiological parameters reflecting vegetative reactions during a GSR therapy session.

The study's objective is to determine the dynamics of key physiological parameters, such as heart rate, heart rate variability, galvanic skin response level, respiratory rate, and brain electrical activity during a GSR therapy session. The methodology involves registration of multimodal physiological signals of participants during a psychotherapy procedure. The data obtained allow for assessment of effect of each session segment on physiological and neurophysiological state of a human.

The report describes the methodology used, physiological data collected, data processing and analysis methods used, as well as the findings reflecting dynamics of the parameters during a therapy session. In addition, the report includes metadata with information on the participants and parameters of the signals registered.

The study was performed as part of research of physiological and psychological effects of GSR technique in collaboration with the Centre for Bioelectric Interfaces (Institute for Cognitive Neuroscience, HSE University).

CONTENTS

INTRODUCTION

The report provides results of a comparative analysis of physiological parameters dynamics in participants receiving psychotherapeutic GSR session and participants of a placebo group watching a video recording of a GSR session.

The analysis of post-session test results revealed that the number of participants believing they received actual therapy was similar in both groups, thus confirming placebo control adequacy.

The objective of the study was to register variations in physiological parameters, specific to the participants of an actual online GSR session.

The study used methods of primary processing of physiological signals, key quantitative metric calculation (such as amplitudes and frequencies of photoplethysmogram, time and spectral parameters of EEG), as well as analysis of the parameter dynamics at different session segments. To assess the effect of a GSR session on psychoemotional state of the participants, additional psychometric inventories were used, namely Positive and Negative Affect Schedule (PANAS), and State-Trait Anxiety Inventory (STAI).

The data obtained allow for assessment of physiological effect of GSR methodology and suggestion of hypotheses regarding the underlying mechanisms.

1 Relevance and Goals of the Study

1.1 Range of Problems

Currently, one of the major limitations in assessment of psychotherapy method efficiency is the absence of objective physiological criteria. In most cases, therapy effect is assessed predominantly by the subjective data, self-reports or interviews of the participants, which makes the conclusions less reproducible and valid (Kazdin, 2007). This study has set an objective of obtaining physiological metrics objectively reflecting changes in the state of a patient during a therapy session. Another major issue is low coverage of physiological reaction dynamics at different segments of a psychotherapeutic experience (Deits-Lebehn et al., 2020). Studies including a detailed analysis to determine which segments (symptom articulation by a specialist, result reinforcement, etc.) have the maximum effect on the physiological processes are rare.

One shortcoming in the majority of existing studies on this subject is the absence of multimodal monitoring of the physiological state. Usually, such studies are limited to registration of one or two physiological parameters, e.g. heart rate variability only (López-Florit et al., 2021). This project involved simultaneous registration of galvanic skin response (GSR), photoplethysmogram (PPG), respiratory rate, and electroencephalography (EEG), providing a more comprehensive picture of psychophysiologic state of the participants and of individual reactions to the therapy.

1.2 Objective and Goals

The study is aimed at finding patterns in physiological parameters dynamics during a GSR psychotherapy session.

Goals of the study:

1. To develop an experiment design enabling comparative analysis of measurements taken from the participants receiving a GSR session and from the participants of the placebo group.
2. To perform multimodal registration of the following physiological parameters: galvanic skin response (GSR), photoplethysmogram (PPG), electromyography (EMG), eye tracking, respiratory activity, and electroencephalography (EEG), of participants during a standard psychotherapeutic GSR session, and of psychological parameters (PANAS, STAI) before and after the session.
3. To analyse the physiological parameters dynamics at different session segments.
4. To perform comparative analysis of physiological parameters dynamics at different segments of an experimental session in two groups of participants.

2 Methodology

2.1 Participants

The experiment involved 14 participants aged 20 to 60 y.o. with a history of receiving GSR psychotherapy sessions for at least one time and no more than eight times. All participants were divided into two groups (7 persons per group):

In Group 1, participants received a real-time GSR therapy session online.

In Group 2, participants watched a video recording of a psychotherapy session performed earlier for a participant from Group 1.

Customers of LLC GSR System meeting the inclusion criteria (age 20 to 60 y.o., a history of 1 to 6 GSR therapy sessions) were invited to take part in the study. As a compensation for participation, all participants were offered a GSR psychotherapy session free of charge. Participants in Group 2 (video recording) were offered an online session after completion of all experiment procedures.

Before the experiment, all participants signed an informed consent form. The informed consent form provided detailed description of study objectives, procedures, and potential risks, as well as the description of the rights of the participants, including a permission to quit the study at any moment without giving any reasons or bearing any negative consequences. Participation in the study was completely voluntary.

Metadata in .xlsx format, including details on participant sex and age, history of GSR sessions, physiological data record date and time, are available in Yandex Disk cloud at: https://disk.yandex.ru/i/YXq7ZMtYJ7hG-Q.

2.2 Intervention

Experimental session protocol:

At the beginning of the procedure, participants signed an informed consent explaining study objectives, describing all experiment segments, potential risks and rights of the participants. Also, the participants signed a consent for personal data processing (see Appendix 1). Further on, a diagnostic online GSR session was performed by a specialist in order to specify psychoemotional state of the participants and collect extra information to customise further segments. Then the participants filled in psychological inventories, namely Positive and Negative Affect Schedule (PANAS) (Crawford & Henry, 2004) and State-Trait Anxiety Inventory (STAI) (Spielberger, 2010) (see Appendix 2).

After the inventories were filled in, physiological sensors were placed to record an electroencephalogram (EEG), photoplethysmogram (PPG), galvanic skin response (GSR), electromyography (EMG), and respiratory activity. Eye tracker was calibrated for further eye movement tracking.

Physiological measurements were taken during the following segments of the experimental session:

- resting state with eyes closed (2 minutes),
- resting state with eyes open (2 minutes),
- resting state with eyes open while the GSR specialist is on screen and is moving within the field of view (2 minutes),
- GSR psychotherapy talking session (duration defined individually by the specialist),
- segment of acceptance of the talking session results,
- GSR psychotherapy silent session (duration defined individually by the specialist),
- segment of acceptance of the silent session results,
- re-registration at resting state with eyes closed (2 minutes),
- re-registration at resting state with eyes open (2 minutes).

After that, the participants once again filled in psychological inventories, namely Positive and Negative Affect Schedule (PANAS) and State-Trait Anxiety Inventory (STAI).

Such procedure allowed for registration of basic physiological metrics before and after exposure and for detailed tracking of physiological dynamics during the psychotherapy.

The procedure took ca. 1.5–2 hours per participant.

2.3 Equipment

NVX52 Multichannel Amplifier (Medical Computer Systems, Zelenograd) was used to recording the data. This device is intended for simultaneous registration of various physiological signals including:

- electroencephalogram (EEG),
- photoplethysmogram (PPG),
- galvanic skin response (GSR),
- respiratory activity,
- electromyography (EMG).

Data were recorded using the standard .edf format (European Data Format) ensuring convenient further processing and analysis. Sampling rate for physiological signal registration was 1000 Hz, ensuring high precision of signal behaviour over time.

For additional eye movement registration, GP3 HD V2 eye tracker (Gaze Point, Canada) was used. It ensures high-precision tracking of gaze direction and fixation.

Data recorded in the edf format are available in Yandex Disk cloud at: https://disk.yandex.ru/d/13jWD5ssK_XjHQ.

2.4 Data Preprocessing

2.4.1 Electroencephalography (EEG).

Prior to calculation of spectral characteristics, a comprehensive signal preprocessing was performed in order to improve signal quality and remove artifacts. A standard 10–20 system was used for all records. Artifacts due to eye movement, muscle activity and other interference sources were corrected using the independent component analysis (ICA) method (Urrestarazu & Iriarte, 2005). ICA was performed using the Infomax algorithm. Afterwards, the components underwent a visual check, and artifact components (such as myographic noise or eye movement glare) were eliminated from the signal. Pre-processed .edf data are available in Yandex Disk cloud at: https://disk.yandex.ru/d/0HxAmbYXzj5UVQ.

MNE-Python library was used to analyse EEG signals. First, data on each of the participants were divided into nine key segments corresponding to different session segments. Segmentation was made based on START and STOP labels in the record files. For each segment, start and end time and duration were recorded.

To assess spectral characteristics of EEG, Welch's power spectral density estimate was used. Calculation was performed within a frequency band of 1 to 50 Hz by windowed Fourier transform.

Mean signal power was calculated for each segment separately in the following frequency bands:

- Delta (1–4 Hz),
- Theta (4–8 Hz),
- Alpha (8–13 Hz),
- Beta (13–30 Hz),
- Gamma (30-45 Hz).

The power was calculated separately for each EEG signal. Resulting data were saved in a form of a summary table providing information on EEG power in each frequency band for all registration

channels and all segments singled out. *Data in the xlsx format are available in Yandex Disk cloud at: https://disk.yandex.ru/i/6o8twRt5_bMxpQ.*

2.4.2 Photoplethysmography

NeuroKit2 library was used to analyse PPG signals (Makowski et al., 2021). Data processing was based on the records made during experimental sessions and stored using the .edf format.

A filter with a range of 5–70 Hz was applied to the data, allowing for removal of low-frequency oscillations and high-frequency noise not related to physiological components of the signal. Furthermore, the signal underwent z-score normalisation, and values deviating by more than 5 standard deviations were considered to be outliers. These omitted values were interpolated and smoothed by a median filter. The signal was divided into intervals corresponding to the session segments labelled beforehand. In valid segments, pulse peaks were detected, then interval-related metrics were obtained using the nk.ppg_intervalrelated() function. Metrics obtained were combined with segmentation data (start time, duration, segment type) and entered into the summary table. *Data in the xlsx format are available in Yandex Disk cloud at: https://disk.yandex.ru/i/lKdMsBp0qtvYMA.*

2.4.3 Spirometry

NeuroKit2 library was used to analyse the respiratory activity. A cutoff filter of 0.05–1.5 Hz corresponding to standard respiratory rate (3–18 cycles per minute) was used. Amplitude outliers above 0.1 conventional units were considered artifacts and were replaced with omitted values, followed by interpolation. Afterwards, the signal was divided into time intervals as per the labels corresponding to session segments. For each segment, the signal was refined and labelled using the nk.rsp_process() function. Interval-related respiratory characteristics were determined for valid segments with sufficient number of respiratory cycles. The results were combined with the segmentation data (start time, duration, segment description) and summarised in the final table. *Data in the xlsx format are available in Yandex Disk cloud at: https://disk.yandex.ru/i/RtmVSZFlllkzjg.*

2.4.4 Galvanic skin response (GSR)

NeuroKit2 library was used to analyse the galvanic skin response. The signal was divided into segments using the time labels corresponding to the segments of the psychotherapy session. After clearing the outliers, the signal was interpolated by a time scale, then smoothed with a median filter with a 15-point window to suppress noise and ensure stability of the metrics obtained. Each valid segment was processed using the nk.eda_process() function, a comprehensive algorithm

including automatic smoothing, isolation of tonic and phasic components, and detection of galvanic skin response peaks. To improve segment comparability, the metrics were normalised by the segment length, i.e. all quantitative measurements were converted to a value per minute of record. The results were combined with the segmentation data (start time, duration, segment description) and summarised in the final table. *Data in the xlsx format are available in Yandex Disk cloud at: https://disk.yandex.ru/i/9WglqspCTI68-w.*

2.4.5 Electromyography (EMG)

Only two channels of myographic sensors (placed above the left eyebrow and on the right cheek) out of a multichannel record were used. To suppress low-frequency components (such as movements and baseline shifts), a high-frequency filter with a bottom cutoff of 10 Hz was applied. After deducing a mean value, artifact areas were identified by threshold overshooting, the threshold defined as a median + 5 standard deviations. The outliers were replaced with a median value for the whole signal. The refined rectified signal was smoothed by a low-frequency filter (below 20 Hz) to generate a signal envelope representing muscle activity dynamics. The results were combined with the segmentation data (start time, duration, segment description) and summarised in the final table. *Data in the xlsx format are available in Yandex Disk cloud at: https://disk.yandex.ru/i/hAVgZN8clDKY-g.*

2.4.6 Eye tracking

To assess gaze character and behaviour in the participants at different session segments, the following metrics were calculated based on the data from a Gazepoint eye tracker:

Valid eye point percentage (valid_eye_pct). This parameter shows a percentage of records where the device succeeds in tracking both eyes of a participant.

valid_eye_pct = (number of points with LPV = 1 and RPV = 1) / (total number of points in a segment)

Percentage of points lying within the screen (in_screen_pct). The indicator shows how stable the participant's gaze position within the screen was. Calculation is done based on the FPOGX and FPOGY gaze fixation coordinates normalised in the [0, 1] range.

in_screen_pct = (number of points with $0 \leq$ FPOGX ≤ 1 and $0 \leq$ FPOGY ≤ 1) / (total number of points in a segment)

Mean fixation duration (mean_fixation_dur). It is calculated as a mean duration of a fixed point of gaze (FPOGD [ms]) for the valid points (FPOGV = 1). Standard deviation of fixation duration

(std_fixation_dur). This parameter represents variability of staring duration, thus enabling assessment of visual stability strategy. Mean saccade magnitude (mean_saccade_mag). This parameter estimates gaze movement amplitude between points of gaze and is calculated as a mean of the SACCADE_MAG column for valid points. Mean coordinates of fixed point of gaze (mean_FPOGX, mean_FPOGY). These metrics indicate mean horizontal and vertical position of gaze on normalized coordinates (where 0 is the screen edge, 0.5 is the centre, and 1 is the opposite edge). They are used to analyse distribution of focus over the screen.

The results were combined with the segmentation data (start time, duration, segment description) and summarised in the final table. Data in the xlsx format are available in Yandex Disk cloud at: https://disk.yandex. ru/i/FKbiQz4pJhJCjg.

2.4.7 Psychological inventories

Data from PANAS and STAI psychological inventories in the .xlsx format are available in Yandex Disk cloud at: https://disk.yandex.ru/d/nwiZGUATHk2HLA.

2.5 Statistical Data Analysis

The following key quantitative parameters describing the state of the participants were calculated for each physiological signal. The metrics recovered were averaged by the time segments identified and, if necessary, by functional zones of interest (for EEG).

The basic statistical analysis method was two-way ANOVA with measures repeated by the segment factor and by intergroup factor (GSR / placebo). For each metric, major effects of factors and correlations thereof (Group × Segment) were analysed.

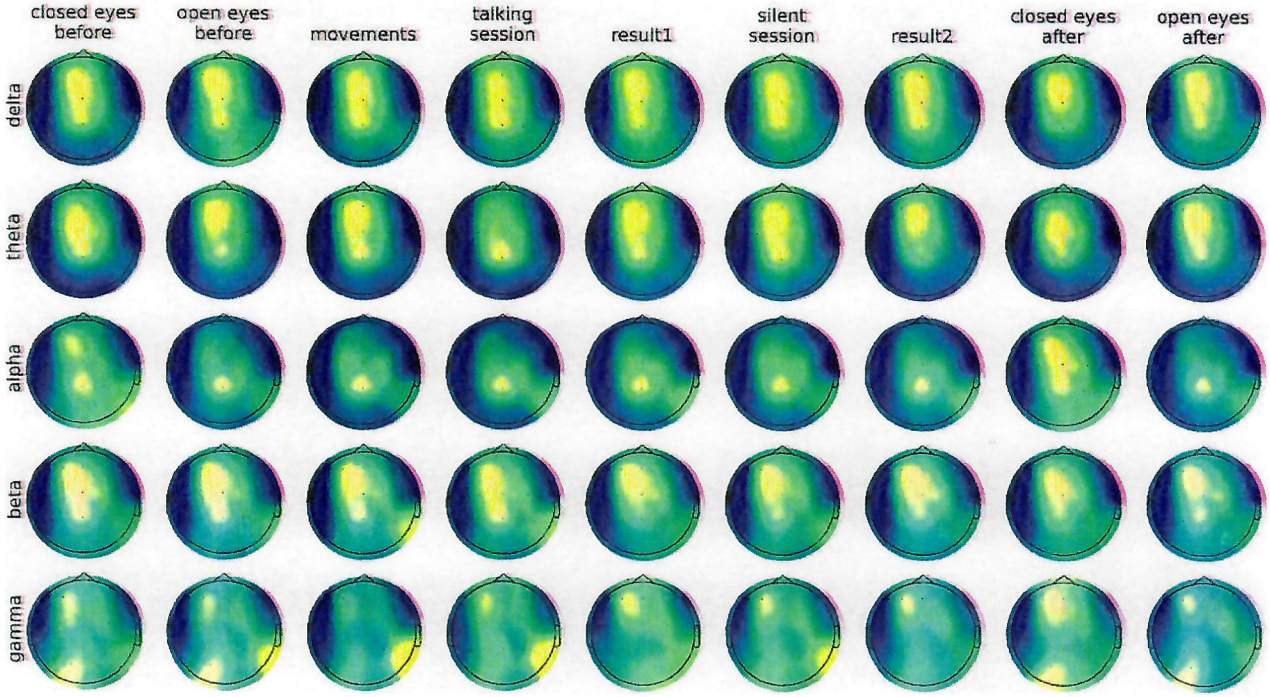
In case of a statistically relevant correlation, a post hoc analysis (Tukey HSD or paired t-tests) was performed between key segments within groups, allowing for localisation of apparent changes.

Similar simulations with time (before / after) and group factors were used for the PANAS and STAI scales, and changes were compared between the groups.

3 Results

3.1 Electroencephalography (EEG)

To assess spatial distribution of activity in different EEG frequency bands, topographic power maps were compiled for each segment of the psychotherapy session and each of the two groups. Spectral power was calculated for the following standard bands: delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–45 Hz). Figure 1 contains topographic maps of EEG power distribution in all frequency bands, for each group separately. Figure 2 shows a difference between topographic maps of the Groups, demonstrating different EEG power distribution for various conditions.



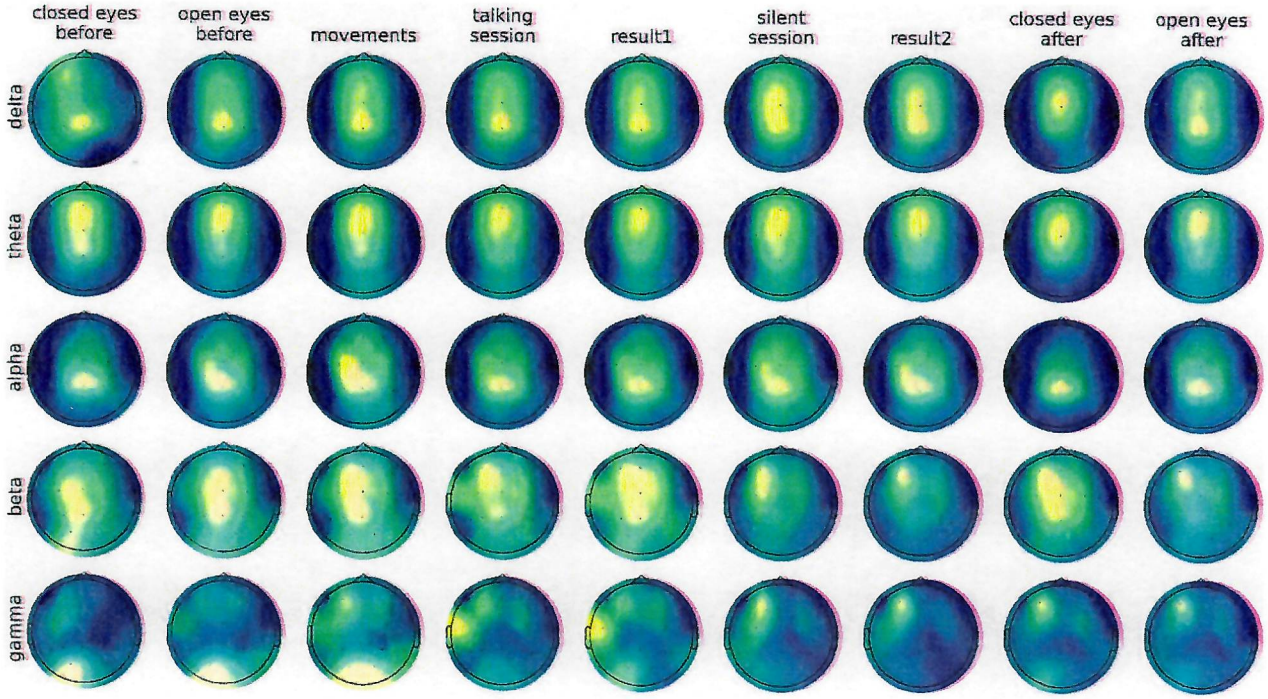


Figure 1. Mapped EEG power distribution in different frequency bands by the segments of the psychotherapy session. The upper block corresponds to Group 1 participants (GSR, online session), the bottom block corresponds to Group 2 participants (placebo, video recording).

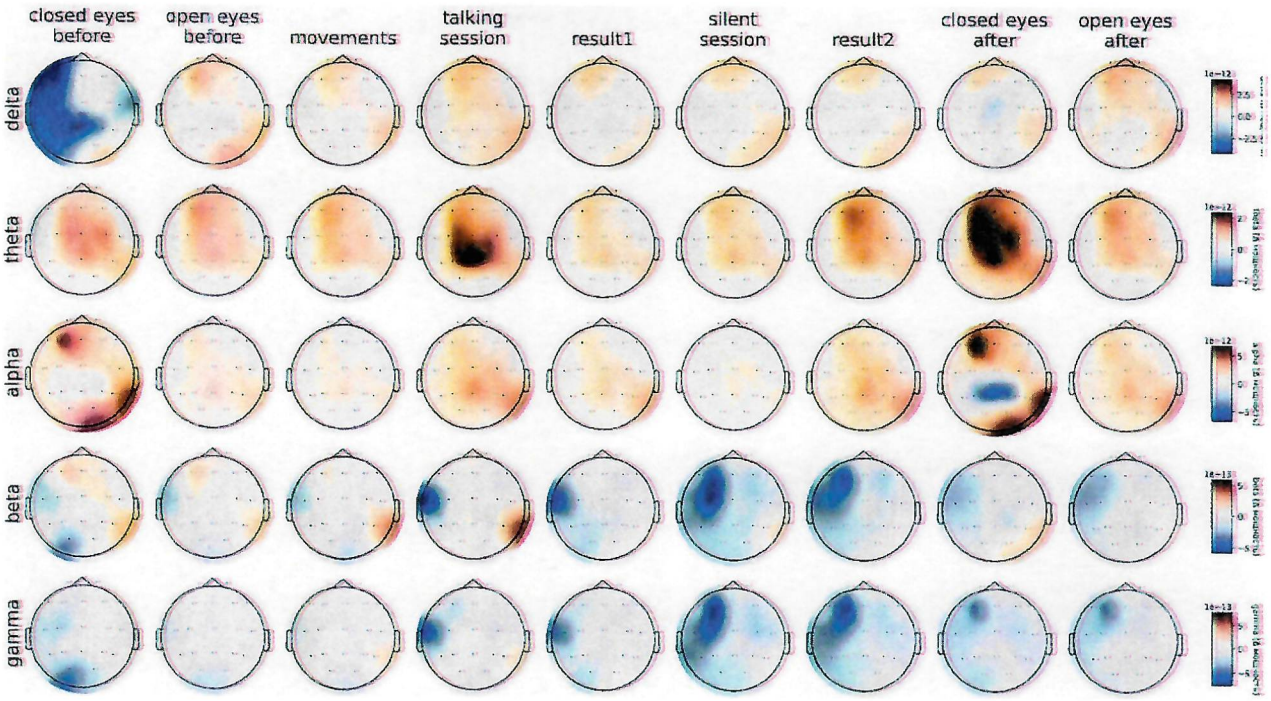


Figure 2. Difference of EEG power maps between Group 1 (GSR, online session) and Group 2 (placebo, video recording) in different frequency bands by the segments of the psychotherapy session. Negative values (blue areas) correspond to larger power in the placebo group, while positive values (red areas) show larger power in the GSR group.

For quantitative comparison of EEG signal power between the two groups, a repeated measures ANOVA was performed with an intergroup factor (group type: placebo vs. GSR) and an intragroup factor.

EEG deflections were grouped in advance into three regions, each including 5–7 electrodes:

- frontal region (Fp1, Fp2, F7, F3, Fz, F4, F8),
- central region (T3, C3, Cz, C4, T4),
- parieto-occipital region (T5, P3, Pz, P4, T6, O1, O2).

Mean EEG power values were calculated for each frequency band for all deflections included in the corresponding group. A repeated measure ANOVA was performed next with a group factor (GSR vs. control) and a segment factor (9 time segments). Statistically significant differences were obtained in the theta rhythm power in the frontal region and gamma rhythm power in the central region.

3.1.1 Frontal theta rhythm

A combined effect of Segment × Group factors on the theta rhythm power in the frontal region was demonstrated: $F(8, 96) = 2.2850$, $p = 0.02767$ (Fig. 3). Post hoc analysis identified a valid increase in theta rhythm power in the frontal region during the segment of rest with eyes closed after the session in comparison to all other segments.

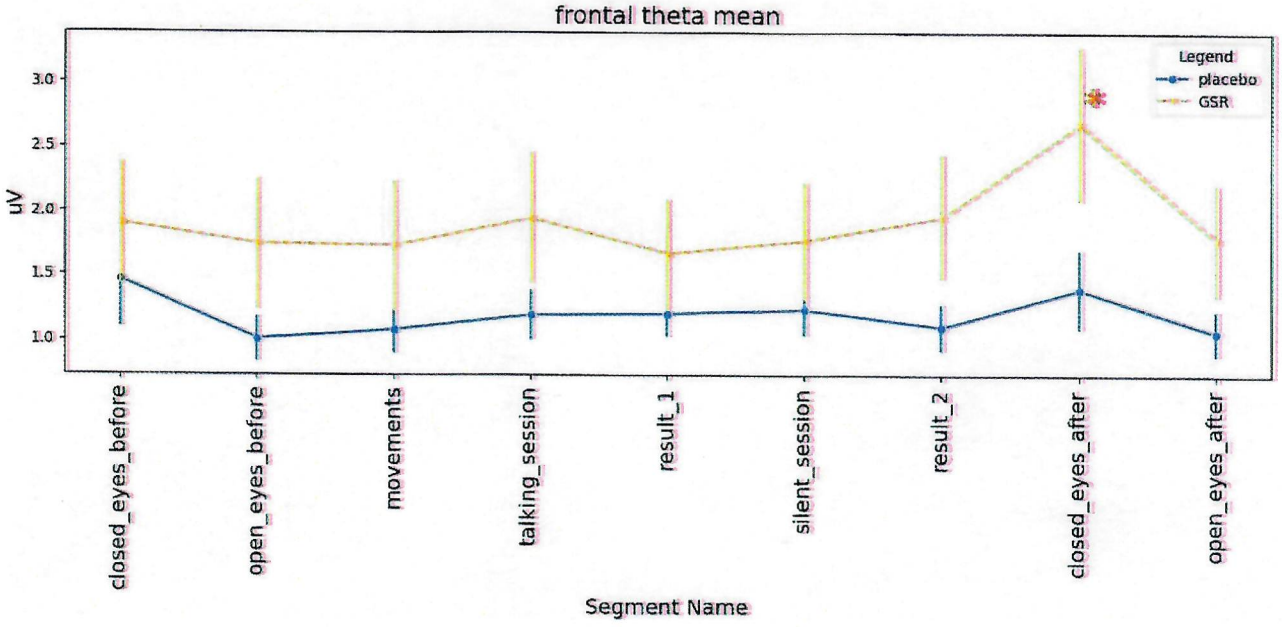


Figure 3. Mean theta activity (4–8 Hz) in the frontal region by session segments in the test (GSR) group and the control (placebo) group. Orange dot line means the test group (online GSR session) while the blue line means the control group (video recording).

3.1.2 Central gamma rhythm

Repeated measure ANOVA revealed an additional tendency to combination of Segment × Group factors for the gamma rhythm (30–45 Hz) power in the central region $F(8, 96) = 1.90$, $p = 0.068$ (Fig. 4). This effect was due to gamma rhythm power increase during the silent session segment in the placebo group. The increase was statistically significant compared to the first three session segments. GSR group participants did not show such power growth in the gamma band, and activity remained stable through the whole session.

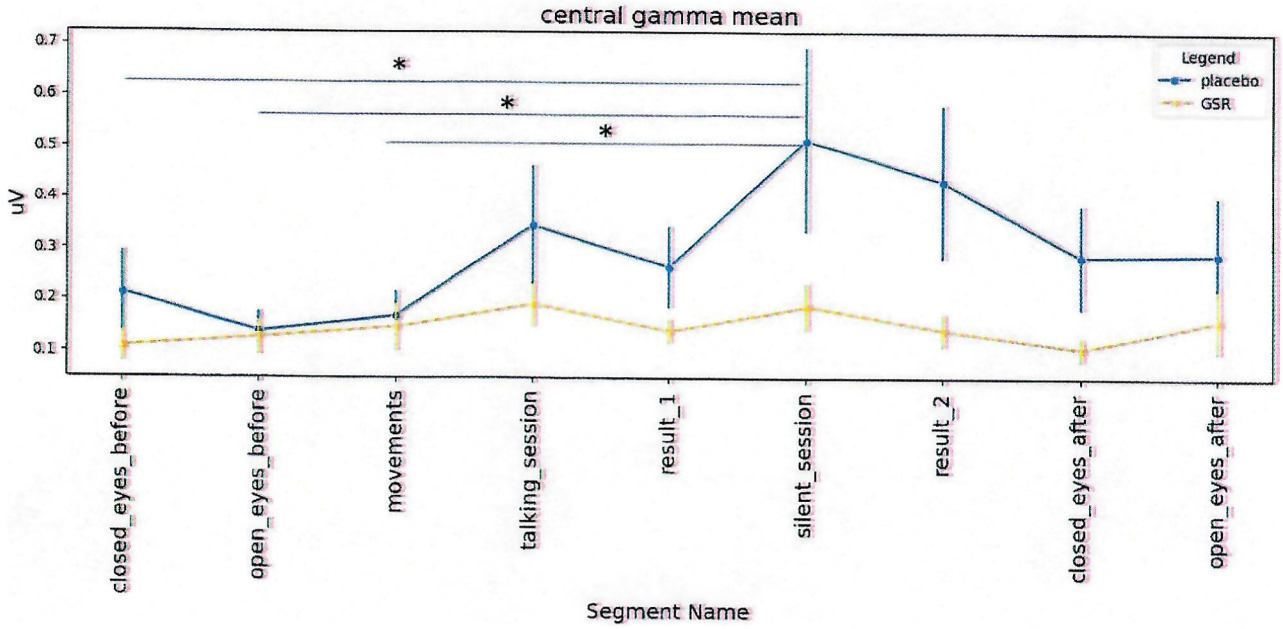


Figure 4. Mean gamma activity (30–45 Hz) in the central region by session segments in the test (GSR) group and the control (placebo) group. Orange dot line means the test group (online GSR session) while the blue line means the control group (video recording).

When analysis included two segments only, i.e. talking session (talking_session) and silent session (silent_session), a combined effect of Segment × Group factors on gamma rhythm power in the central and parieto-occipital regions was identified.

In the central region (Fig. 5), the control group displayed a statistically significant increase in gamma activity during the silent segment compared during the talking segment (combined factors $F(1, 12) = 5.41$, $p = 0.038$, difference between the segments in the placebo group: $p = 0.03$). A similar effect was observed in the parieto-occipital region (Fig. 6), where gamma rhythm power increased significantly in the control group during the silent segment (combined factors: $F(1, 12) = 10.97$, $p = 0.006$, difference between the segments in the placebo group: $p = 0.005$). Changes in gamma activity in the test group (GSR) were statistically insignificant.

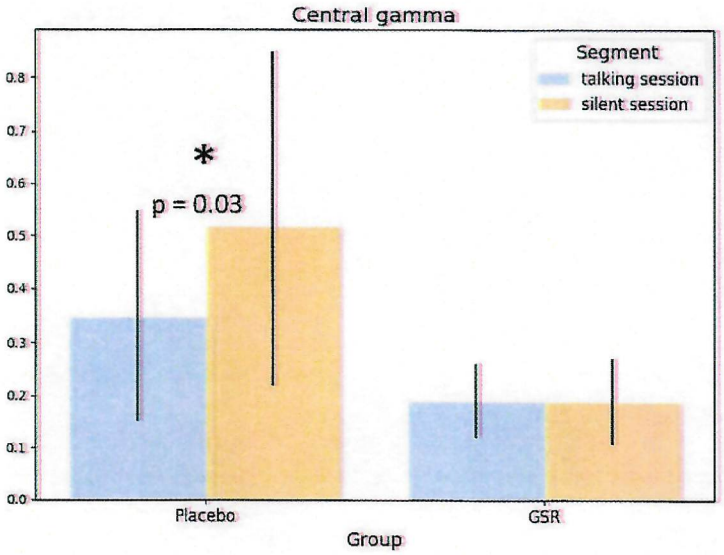


Figure 5. Gamma rhythm power in the central region during the talking segments (blue bar) and silent segments (orange bar) for the placebo group (to the left) and the GSR group (to the right). The control group (placebo) demonstrated a significant increase in power during the silent session segment (p = 0.03).

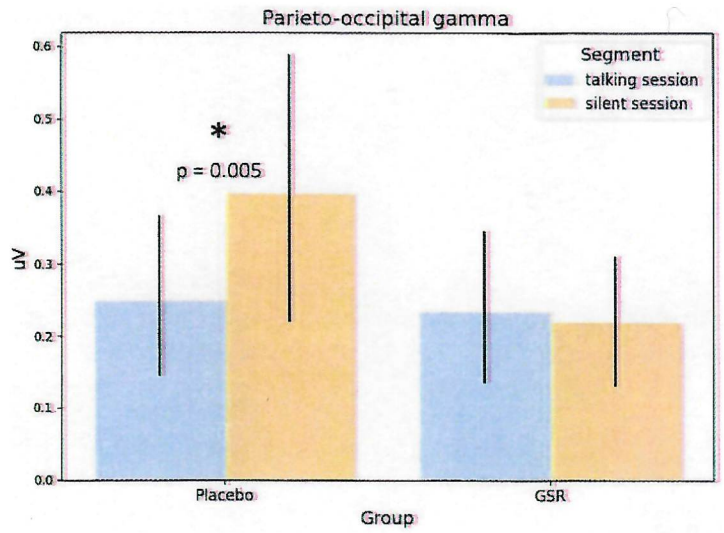


Figure 6. Gamma rhythm power in the parieto-occipital region during the talking segments (blue bar) and the silent segments (orange bar) for the placebo group (to the left) and the GSR group (to the right). In the control group (placebo), a significant increase in power during the silent session segment was observed (p = 0.005).

3.2 Photoplethysmography

3.2.1 Heart Rate

Comparative analysis of heart rate dynamics during the session did not show any differences between the two groups. Both groups displayed gradual heart rate increase (Fig. 7).

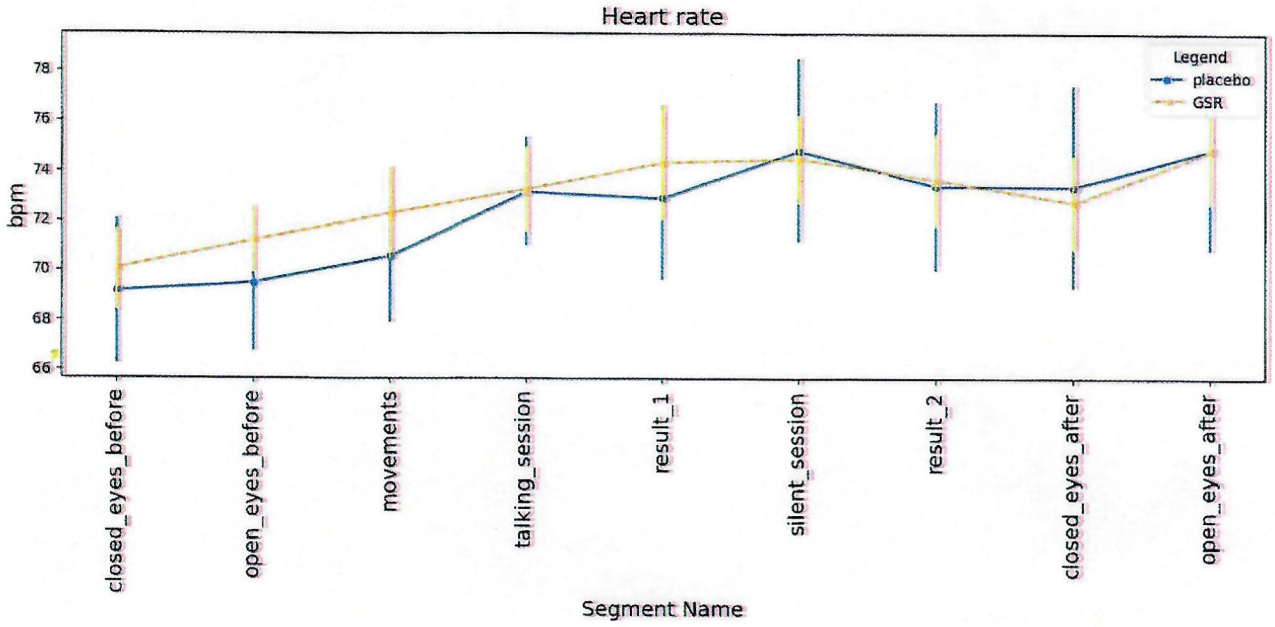


Figure 7. Heart rate dynamics by segments of the psychotherapy session in the GSR (orange dot line) group and the placebo (blue line) group.

3.2.2 Heart Rate Variability

Heart rate variability analysis showed no differences in dynamics between the groups for all participants. Yet a more detailed analysis revealed two participants with outstanding values in the control group. After exclusion of these two participants, a significant synergy of Segment × Group factors was identified for SDNN (standard deviation of NN intervals) ($F(8, 80) = 2.149$, $p = 0.04$). This parameter is one of the most widely used indicators of total heart rate variability, describing the balance between sympathetic and parasympathetic regulation. SDNN grows when balance shifts towards activity of the parasympathetic nervous system. In the GSR group, this parameter increased after completion of a session. The difference between resting state with eyes open after the session and resting state with eyes open before the session vs. watching the specialist before the session reaches a statistical significance.

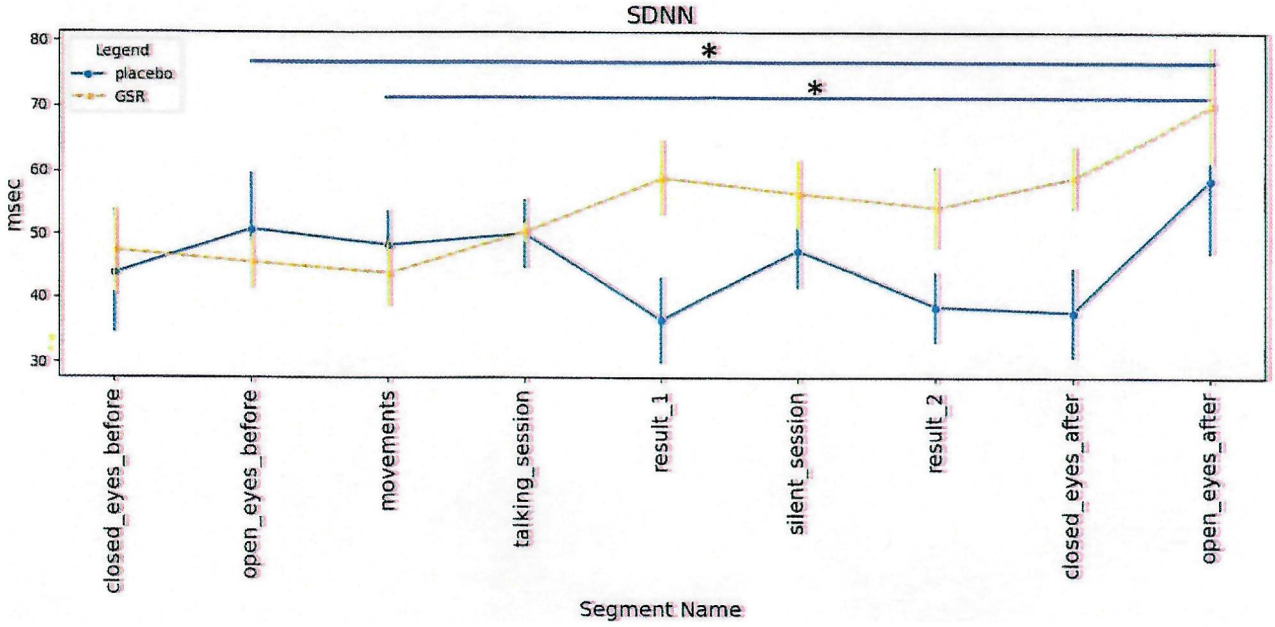


Figure 8. SDNN dynamics by segments of the psychotherapy session in the GSR (orange dot line) group and the placebo (blue line) group.

3.3 Spirometry

To analyse respiratory dynamics during a psychotherapy session, respiration rate (breaths per minute) was calculated for each of the nine segments in the GSR group and the control group separately. Results of repeated measure ANOVA showed a statistically significant synergy of Group × Segment factors: $F(8, 96) = 2.5367$, $p = 0.015$ for respiratory rate. In the GSR group, a gradual reduction of respiratory rate after the talking segment was observed (Fig. 9). A post hoc analysis showed that respiratory rate during the result acceptance segment of the second session and during the segment of rest with eyes open and eyes closed after a session was significantly lower than during the talking segment ($p = 0.014$, 0.037, 0.026), which may be indicative of a stable physiological relaxation achieved by the session.

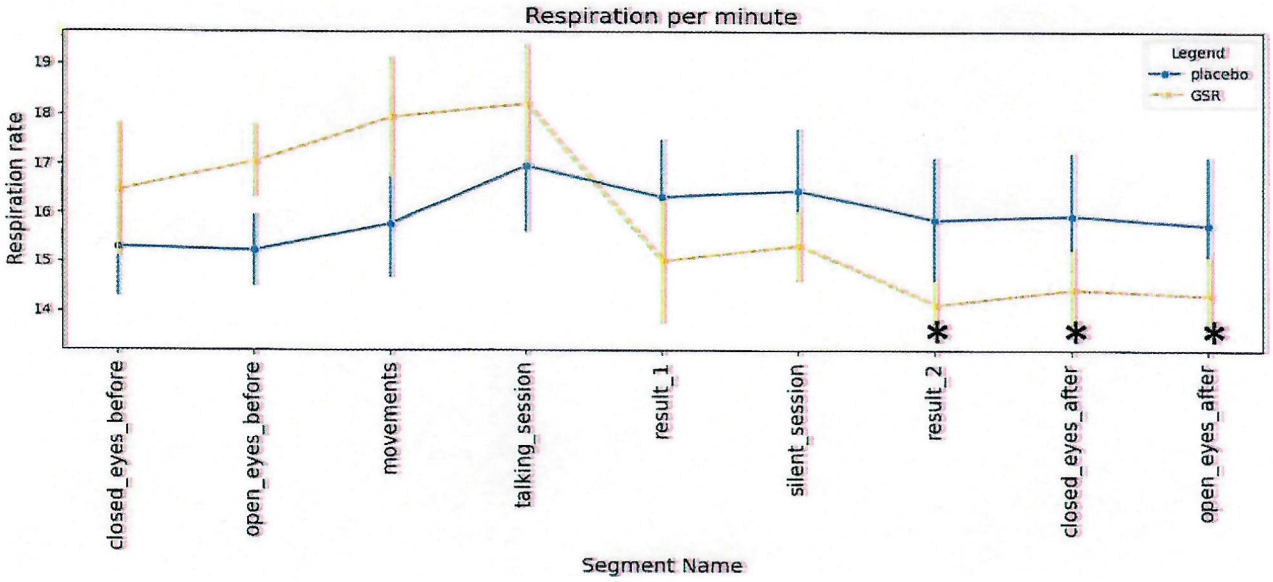


Figure 9. Respiratory rate (breaths per minute) dynamics by session segments in the GSR (orange dot line) group and the placebo (blue line) group.

A separate comparison of respiratory rate during the two key session segments (talking segment and silent segment) was performed. The synergy of Group × Segment factors was reaching the level of a trend ($F(1, 12) = 3.7321$, $p = 0.077$). Intragroup analysis showed a significant reduction in respiratory rate in the GSR group in silent session phase, compared to the talking session phase ($p = 0.027$), see Fig. 10. It may be indicative of parasympathetic regulation activation and deeper relaxation in this phase for the participants exposed to therapy.

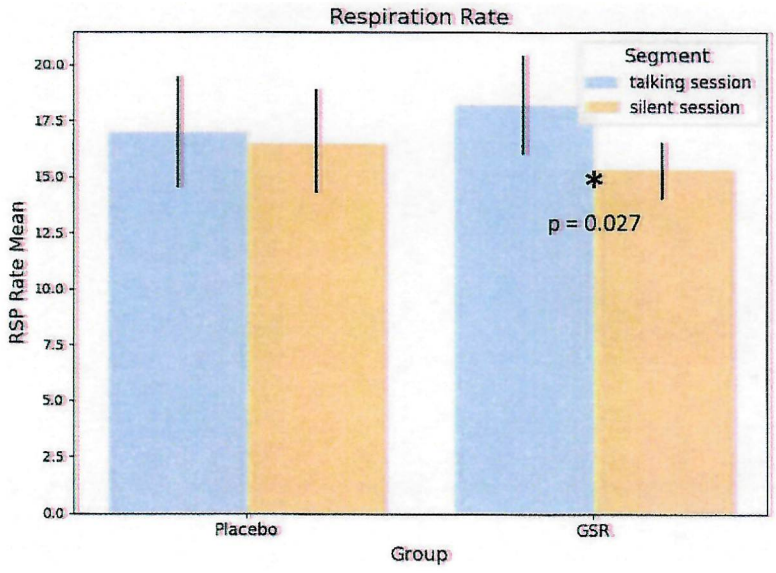


Figure 10. Mean respiratory rate during the talking segments (blue bar) and silent segments (orange bar) for the placebo group (to the left) and the GSR group (to the right). In the GSR group, a significant reduction of respiratory rate during the silent segment was observed ($p = 0.027$).

3.4 Galvanic Skin Response

Galvanic skin response measures during the experimental session showed no differences between the groups.

3.5 Electromyography

3.5.1 Activity of frowning muscle (Musculus corrugator supercilii)

To assess muscle tension in the forehead region, electromyogram of the frowning muscle was used. This metric is considered indicative of concentration, emotional tension, negative emotions. Fig. 11 shows mean EMG signal amplitudes per session segments for both groups. ANOVA results demonstrated a borderline synergy of Group × Segment factors in terms of statistical significance ($F(8, 96) = 2.0056$, $p = 0.054$). GSR group displayed increased activity of the frowning muscle during the talking segment, compared to other segments.

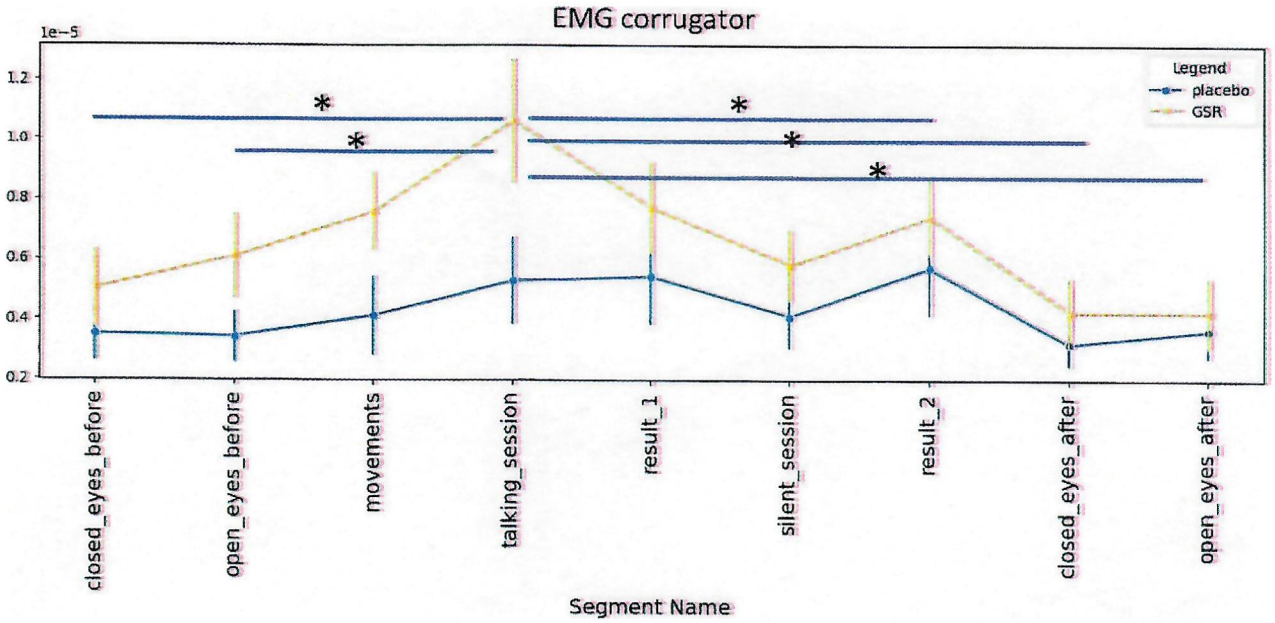


Figure 11. Mean EMG signal amplitude of a frowning muscle (corrugator) per session segments in the GSR group and the placebo group.

Comparative analysis of talking and silent segments showed that Group and Segment factor synergy did not reach the statistical significance level ($F(1, 12) = 2.70$, $p = 0.126$). However, an intragroup post hoc analysis demonstrated significant reduction in muscle activity in the GSR group at a silent session segment compared to the active phase (talking session) ($p = 0.041$), Fig. 12. These findings may indicate higher muscle relaxation in participants of an actual GSR session compared to the control group.

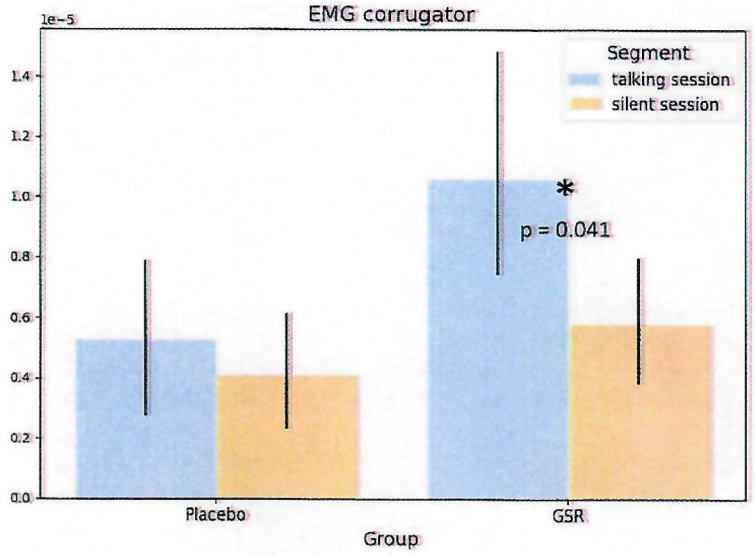


Figure 12. Mean EMG signal amplitude of the frowning muscle during the talking segments (blue bar) and silent segments (orange bar) for the placebo group (to the left) and the GSR group (to the right). In the GSR group, a significant reduction of muscular activity during the silent segment was observed (p = 0.041).

3.5.2 Activity of zygomaticus major muscle (Musculus zygomaticus major)

Electromyographic activity of a zygomaticus major muscle did not differ between the two groups (Fig. 13).

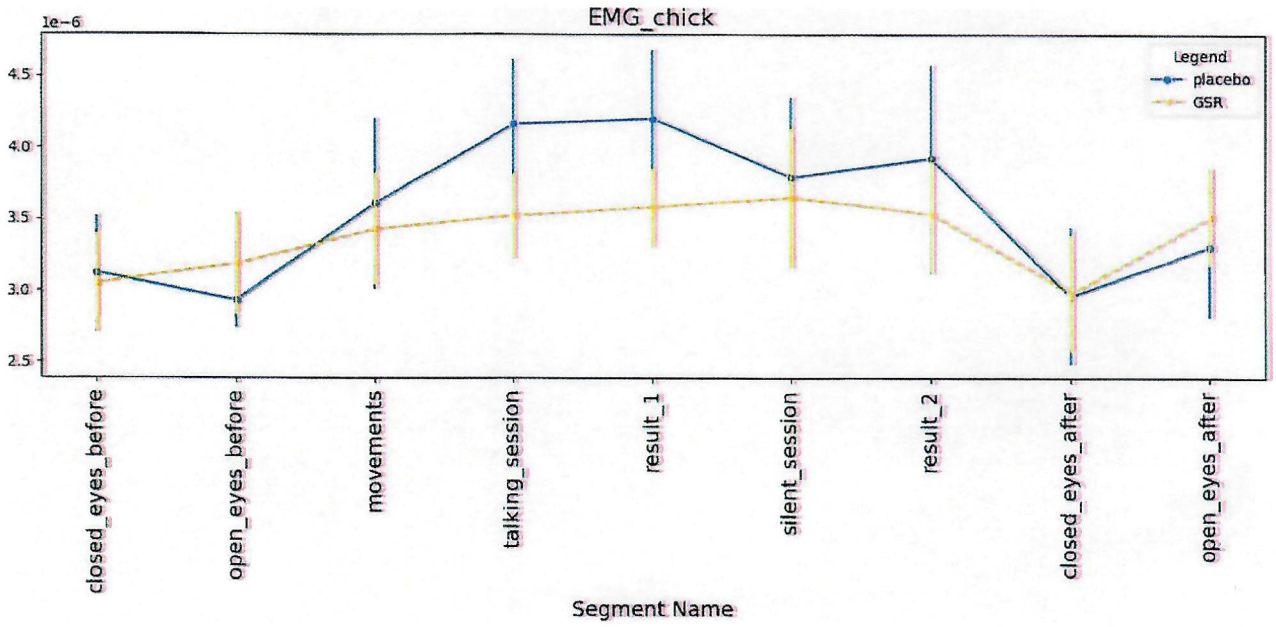


Figure 13. Mean EMG signal amplitude of the zygomaticus major muscle (Musculus zygomaticus major) by session segments in the GSR group and the placebo group.

3.6 Eye Tracking

Eye movement parameters did not differ in the groups during the experimental session.

3.7 Psychological Inventories

To assess GSR session effect on psychoemotional state, the participants were asked to fill in Positive and Negative Affect Schedule (PANAS) (Fig. 14) and State-Trait Anxiety Inventory (STAI) (Fig. 15) before and after the session. None of the groups demonstrated statistically significant changes in the inventory scores.

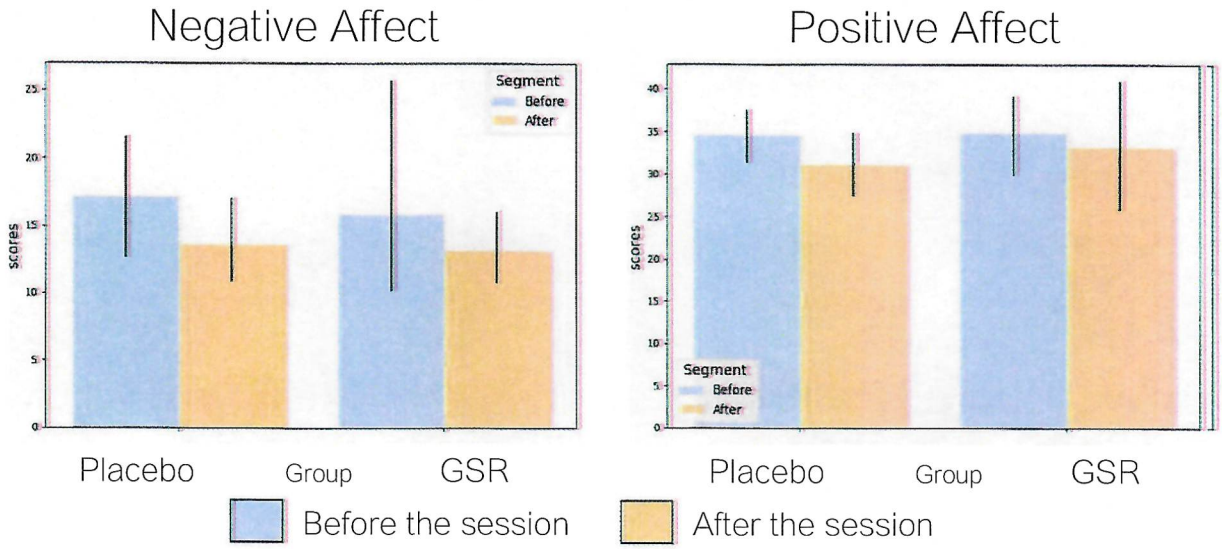


Figure 14. Negative and positive affect as per the PANAS scale before and after the session in the GSR group and the placebo group.

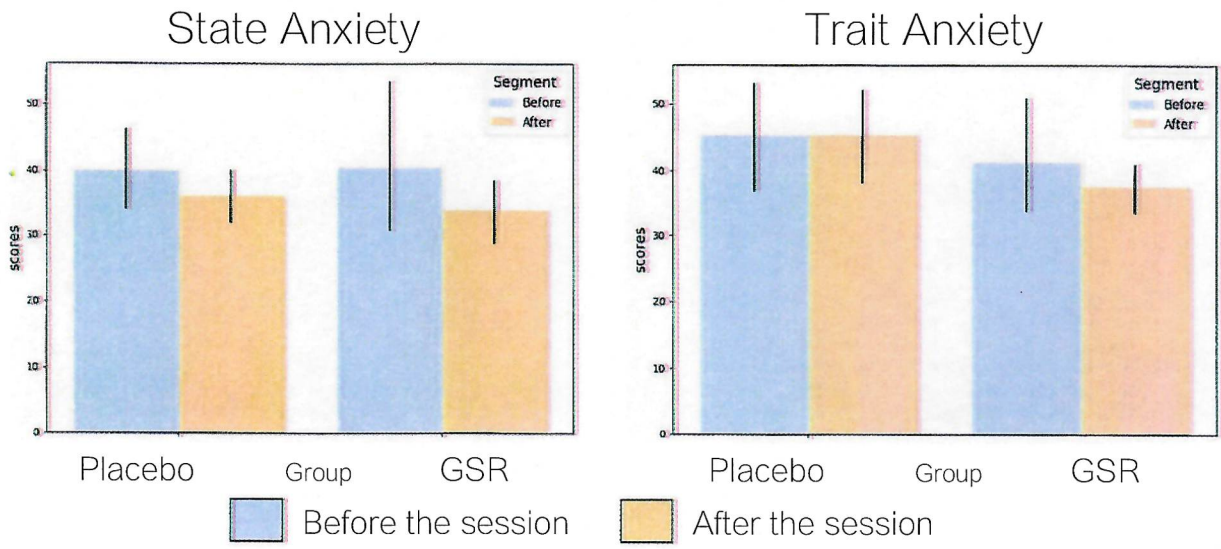


Figure 15. State and trait anxiety as per STAI before and after the session in the GSR group and the placebo group.

After the session, the participants expressed their subjective opinion on whether they had received actual GSR stimulation or were watching a video recording. The analysis of test results showed that the share of participants believing they received actual therapy was similar in both groups, thus confirming placebo control adequacy.

DISCUSSION

The study was aimed at finding patterns in physiological parameters dynamics during a GSR psychotherapy session. Using objective multimodal data (EEG, GSR, PPG, respiratory rate, EMG, eye tracking) combined with psychometric scales (PANAS, STAI) for comprehensive assessment of a human state was a key requirement. To achieve the objective, an experiment protocol with registration of physiological signals through 9 standard segments was implemented.

Statistically significant differences between the GSR group and the control (placebo) group were observed for a number of physiological parameters.

The GSR group displayed increased theta rhythm power in the frontal region with closed eyes after the session. Similar effects can be caused by meditation (mindfulness) techniques (Tang et al., 2019), (Hudak et al., 2021). It was also found that theta oscillations in the anterior prefrontal cortex facilitate control of automatic emotional behaviour, helping people suppress habitual emotional reactions in favour of more mindful actions (Bramson et al., 2018). Increased theta rhythm power in the prefrontal cortex correlates directly to success of emotion regulation strategies (Ertl et al., 2013), especially cognitive reappraisal (Zouaoui et al., 2023). Some studies show that increased theta activity in the frontal lobe can be related to inhibited addictive behaviours (Garland et al., 2022) and better emotional wellbeing (Lomas et al., 2015). Boosted theta activity in our study might be caused both by a state of introspection and self-control, and by a fatigue due to emotional experience during the session. Notably, the placebo group did not display any significant increase in theta rhythm power after the session. Probably, it indicates a more distinct emotional and cognitive engagement in the process among GSR group participants.

Theta rhythm increase in the GSR group was observed solely in resting state with eyes closed, directly after completion of the session. The effect disappeared after two minutes of resting state with eyes open. These data suggest that the change in activity in the theta band could be related either to post-stimulation relaxation/internal attention amplified when eyes are closed and external sensory load decreases, or to a temporary change in functional state of a brain under effect of GSR.

However, the observations available do not allow for conclusive determination of whether this increase is due to the closed-eye state or is caused by a temporary GSR effect wearing off over time. To differentiate these factors, further research is required, involving control conditions with different time points of measurement.

In addition, higher gamma activity was registered in the central and parieto-occipital regions in the control group during watching a video recording of a different person's silent GSR session. Such increase can be indicative of high muscle activation level and possibly weak engagement with the things happening on screen. In particular, muscle artifacts caused by muscle activity can contribute greatly to the EEG gamma band, especially in the areas above these muscles (Hipp & Siegel, 2013). Thus, such muscular artifacts can mask or simulate neural gamma activity. On the contrary, gamma activity in the GSR group remained stable and low through the whole silent session, which may indicate lower motion activity and possibly higher engagement with the things happening on screen. One of the possible mechanisms of this effect is that the GSR group participants have already completed the previous talking phase, which might have caused deeper emotional engagement. It stabilised the state of concentration and internal submergence maintained through the next sages even in the absence of audio stimulation.

In addition, it is suggested that higher cognitive and emotional engagement during a talking session could lead to higher fatigue or, on the contrary, to a deeper submergence accompanied by reduced background motion activity. This state can be manifested as lower predisposition to movement, facial expression, or other form of muscle activity, which, in turn, reduces the number of artifacts in the gamma band and can be considered to be indicative of increased attention and internal engagement with the current visual stimulus.

Thus, the difference between the groups in terms of gamma activity dynamics can be indicative of differences in emotional and cognitive engagement level, where the GSR group demonstrates more stable attention and lower distraction.

Suggested higher engagement of participants in the GSR group during a talking session is confirmed by the data on frowning muscle activity at this segment. This activity is an indicator of attention focus, cognitive effort, and/or negative experience.

Data on autonomic regulation in participants of an actual GSR session are also supporting the hypothesis of higher physiological relaxation observed after the session. Thus, the test group showed increased heart rate variability parameter, SDNN (standard deviation of R-R intervals, reflecting total heart rate variability), interpreted as intensified autonomic regulation (Otzenberger et al., 1998). Maximum SDNN was registered at the final phases of a session, especially in resting state with eyes open after interaction. Previous research revealed that increased SDNN in rhythmic breath sessions can be related to stress reduction and improved emotional state (Edmonds et al., 2009). Respiration analysis showed significant decrease in respiratory rate in the GSR group after the active verbal interaction segment (talking session). During the final segments starting from

acceptance of a silent session results, respiratory rate was statistically lower compared to the early segments, which is also indicative of a relaxation state. Key phase analysis revealed much lower respiratory rate in the GSR group as early as during the silent segment. This effect was not observed in the control group. Subjective data analysis using PANAS and STAI scales demonstrated a common trend towards a decrease of negative and anxious affect after a session, though no statistically significant differences between the groups were found.

CONCLUSION

Thus, the data obtained essentially indicate that an actual talking GSR session produces higher cognitive and emotional engagement compared to the placebo condition (passive watching of another person's session), as confirmed by the differences in dynamics of physiological metrics between the groups.

Specifically, the GSR group demonstrated higher theta rhythm power in the frontal region in EEG in a state with closed eyes after the session. Similar effects can be achieved by meditation (mindfulness) techniques. It was also found that theta oscillations in the anterior prefrontal cortex facilitate control of automatic emotional behaviour, helping people suppress habitual emotional reactions in favour of more mindful actions. Increased theta rhythm power in the prefrontal cortex correlates directly to success of emotion regulation strategies, especially of cognitive reappraisal. Some studies show that increased theta activity in the frontal lobe can be related to inhibited addictive behaviours and better emotional wellbeing. This boost might be caused both by a state of introspection (retreat) and self-control, and by a fatigue due to emotional experience during the session. Data showing autonomic nervous system activity, such as reduced respiratory rate or higher heart rate variability, indicate an apparent physiological relaxation of participants after an actual GSR session, as opposed to the placebo group.

These differences indicate that the GSR method involving verbal description of the state of participants is efficient in activating self-referential and regulatory processes, which makes it a useful tool in practical psychotherapy.

At the same time, the participants showed no signs of active engagement in a silent session. The only difference from the placebo group during the silent segment was lower number of distraction indicators in the GSR group. However, the current study design does not provide for a definite conclusion on whether it is due to a higher engagement in the silent phase itself, or it is a delayed effect of the previous talking session. A more detailed understanding of these processes requires further research with a condition priority control and increased time intervals between the sessions.

It is necessary to keep in mind that the conclusions are based on the results of a pilot study with a small sampling population. Statistical analysis did not include adjustment for multiple testing during the segment of EEG activity parameter analysis. A statistically significant result for changes in heart rate variability was obtained after elimination of data from two participants from the analysis.

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APPENDICES

Appendix 1

Participant ID: _____

Informed Consent

for Study Participation

Investigation team of the Centre for Bioelectric Interfaces of HSE University and LLC Brainstart invites you to take part in a study aimed to examine effects of GSR sessions on activity parameters of brain, peripheral nervous system, and other systems of the participants.

Before you agree to participate in said study, we would like to provide you information on this study, its proceedings, and potential risks.

Participation conditions
You can participate in the study if:

- you have full legal capacity (i.e. of full age, free of mental disorders, **not taking any drug products or other products affecting brain activity or psycho-emotional sphere);**
- you are 20 to 60 years old;
- your native language is Russian;
- you have not been diagnosed with psychiatric, neurological, or cardiovascular diseases;
- you **have not suffered head injuries** in the last three years;
- you have attended **at least one but not more than ten GSR sessions;**
- you give consent to processing of your personal data without data disclosure to third parties (for details, see Appendix 1).

Voluntary participation
Your participation in the study must be absolutely voluntary. This consent must not be granted as a result of a deception, mental or physical abuse, or confinement. Your consent must not be given under pressure of complicated circumstances (struggling financial situation) and/or a dependency of any kind on the researcher(s).

You may opt **out** of the study now or at any stage of the study without any negative consequences.

Confidentiality
Your full name and position will not be mentioned anywhere in connection with the information provided by you. All results will be submitted on a non-attributable basis. All data obtained during the study will be available to researchers only. We intend to publish the study findings in peer-reviewed journals. Your personal data will be kept for 10 years or less. For details, see Appendix 1.

Study procedure
Study stages:

1. A diagnostic GSR session, where you will discuss your issue do be worked on during the main GSR session with a specialist (online).
2. Filling psychological inventories
3. Placement of sensors to record physiological parameters (EEG, PPG, EMG, galvanic skin response, spirogram, and eye tracking)

EEG (electroencephalography) is a method of electric brain activity registration. Recording procedure involves mounting of registration electrodes attached to an electroencephalographic headset. Conductive gel is applied under each electrode. **PPG (photoplethysmography)** is a method of pulse wave registration. The recording procedure involves placement of a sensor on a finger. **EMG (electromyography)** is a method of electric muscle activity registration. The recording procedure involves placement of skin electrodes on the areas of muscles examined. During the recording, a participant may be requested to make specific movements and muscle contractions. Registration of **galvanic skin response** (skin conductivity) involves placement of skin electrodes on fingers. **Spirometry** is a method of breath registration. In our study, we use a temperature-sensing probe attached under the participant's nose. **Eye tracking** is performed using a non-contact eye tracker placed on a table in front of the participant.

4. GSR session procedure (online).
5. The session will include recording of EEG, ECG, EMG, galvanic skin response, respiratory graph, eye tracking, and recording of the video conferencing.

NONE of the registration methods used INVOLVES active STIMULATION of the brain and body in general.

6. Total duration of the procedure is 1.5–2 hours.

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7. You may be assigned randomly to one of the test groups. Participants in Group 1 will take part in a GSR session. Participants in Group 2 will watch a video recording of a GSR session. We will disclose which group you had been assigned to after the experimental session is completed. If you are assigned to Group 2, you will be offered to undergo a free online GSR session after the study.

Potential inconveniences
No emergencies are anticipated in this study, but in case of any contingencies you will be provided with all necessary assistance. The study procedure does not involve exposure to factors that may affect your physical state negatively.

This study was reviewed and approved by the Ethics Committee of the HSE University.

CONFIRMATION OF AN INFORMED CONSENT TO PARTICIPATE IN THE STUDY
By signing this informed consent form, I hereby confirm that I have read and understood the objectives, procedure, methods, and potential inconveniences of participation in the study. I have been informed of the test duration and general timelines of similar studies. I have been informed of actions to be taken in case of unexpected health impacts. I had a possibility to ask all questions of concern. I have received satisfactory answers and clarification regarding all questions I had in connection with this study. This consent is not influenced by a deception, mental or physical abuse, or confinement. My consent is not given under pressure of complicated circumstances (struggling financial situation) and/or a dependency of any kind on the researcher(s). I hereby grant my consent for participation in the study.

Signature of the study participant	Date: __ _____ 202_

I have explained the above form of informed consent to the respondent, and answered all questions of the respondent regarding participation in the study. His or her decision to participate in the study is not imposed, it is informed and voluntary, as confirmed by this consent.

Full name and signature of the interviewer	Date: __ _____ 202_

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Consent to Processing of Personal Data

Hereby I, _____ (full name), passport series _____ No. _____ issued on _____ by _____ (date, issuing authority), registered at _____, provide the following personal information to a Federal State Autonomous Educational Institution for Higher Education "National Research University – Higher School of Economics" (HSE University), registered at: 20, Myasnitskaya St, Moscow 101000, namely the Centre for Bioelectric Interfaces of HSE University, for the purpose of research of brain networks in charge of information perception and processing:

1. full name;
2. date of birth and age;
3. contact information: phone number, e-mail, social media address, other (indicate) _____;
4. behavioural study data, including inventories (stored under reference numbers);
5. screening inventory data, including information on the health status;
6. other (indicate) _____.

Personal data processing includes collection, recording, systematisation, accumulation, storage, refining (updating, modification), extraction, use, depersonalisation, blocking, deletion, destruction.

List of personal data operations authorised by this consent:

- Preprocessing, main analysis, measurement of key parameters will be performed using dedicated software integrated in the recording and navigation equipment.
- Statistical data analysis will be performed using Python, STATISTICA, Jamovi software, etc.
- Personal data will be stored solely on the computers owned by HSE University, LLC Brainstart, and LLC GSR System. All personal data are confidential and are not to be distributed or transferred to third parties. Only the researchers will have access to all personal data.

I agree that the study findings will be published in the peer-reviewed journals. None of the data to be referenced in publications will include my contacts. First or family name and other data identifying me as a test participant will not be mentioned.

The consent shall remain valid for ten (10) years. I am aware that I have the right to recall this consent by a written claim to be sent to HSE University at: 20, Myasnitskaya St, Moscow 101000.

Terms and definitions used in this consent have been explained to me.

_____(Full name)

_____(Signature)

[logo]

Appendix 2

Positive and Negative Affect Schedule (PANAS)

This method uses an inventory aimed to diagnose a wide range of positive and negative emotional states. High level of positive affect is defined as a state of pleasant engagement, high energy, and full awareness, as opposed to despondence and sluggishness. High level of negative affect is defined as a state of subjective suffering, uncomfortable engagement (e.g. anger, repulsion, disdain, guilt, fear, irritation) as opposed to peace and serenity. Positive and negative affect metrics reflect emotional states, but they are also linked to personal traits corresponding to persistent individual differences in inclination to emotional reactions of a certain type.

The inventory includes 20 adjectives describing emotional states. A respondent must rate experience of a respective emotion during specific time period on a 5-point Likert attitude scale (in theory, any time period can be used, even an indefinite time). Interpretation: Positive affect (PA): total score of items 1, 3, 5, 9, 10, 12, 14, 16, 17, 19.

Negative affect (NA): total score of items 2, 4, 6, 7, 8, 11, 13, 15, 18, 20.

Directions. This inventory includes a list of adjectives describing various feelings and emotions. Read each adjective and put a rating next to it, indicating the degree you've experienced it in the recent time (instruction may say "currently" / "today (during this day)" / "in the last several days" / "in the last week" / "usually"). Use the following response options:

1	2	3	4	5
Very slightly or not at all	A little	Moderately	Quite a bit	Extremely

1._____ enthusiastic
2._____ distressed
3._____ excited
4._____ upset
5._____ strong
6._____ guilty
7._____ scared
8._____ hostile
9._____ interested
10._____ proud
11._____ irritable
12._____ alert
13._____ ashamed
14._____ inspired
15._____ nervous
16._____ determined
17._____ attentive
18._____ jittery
19._____ active
20._____ afraid

State-Trait Anxiety Inventory (STAI)

Directions. Carefully read each of the statements below, describing the way you feel right now, and select the closest matching option (circle the appropriate number):

1 – not at all; 2 – somewhat; 3 – moderately so;

4 – very much so.

Do not spend too much time on any one statement, but give the answer which seems to describe your present feeling best. There are no right or wrong answers.

	Current state	**1**	**2**	**3**	**4**
1.	I feel calm	1	2	3	4
2.	I feel secure	1	2	3	4
3.	I am tense	1	2	3	4
4.	I feel regret	1	2	3	4
5.	I feel at ease	1	2	3	4
6.	I feel upset	1	2	3	4
7.	I am presently worrying over possible misfortunes	1	2	3	4
8.	I feel rested	1	2	3	4
9.	I am alarmed	1	2	3	4
10.	I feel satisfied	1	2	3	4
11.	I feel self-confident	1	2	3	4
12.	I feel nervous	1	2	3	4
13.	I am jittery	1	2	3	4
14.	I feel strained	1	2	3	4
15.	I am relaxed	1	2	3	4
16.	I feel content	1	2	3	4
17.	I am worried	1	2	3	4
18.	I feel agitated and uncomfortable	1	2	3	4
19.	I am glad	1	2	3	4
20.	I feel pleasant	1	2	3	4

Directions. Read each of the statements below carefully, and circle the most matching digit in the right side depending on your usual feeling.

Digits at the right correspond to the following answer variants:

1 – almost never (scores one point); 2 – sometimes (scores two points);

3 – often (scores three points);

4 – almost always (scores four points).

	How do you generally feel	**1**	**2**	**3**	**4**
1.	I feel pleasant	1	2	3	4
2.	I tire quickly	1	2	3	4
3.	I feel like crying	1	2	3	4
4.	I wish I could be as happy as others seem to be	1	2	3	4
5.	I am losing out on things because I can't make up my mind soon enough	1	2	3	4
6.	I feel rested usually	1	2	3	4
7.	I am calm, cool, and collected	1	2	3	4
8.	I am worried over possible difficulties	1	2	3	4
9.	I worry too much over something that really doesn't matter	1	2	3	4
10.	I can be quite happy	1	2	3	4
11.	I take things very much to heart	1	2	3	4
12.	I lack self-confidence	1	2	3	4
13.	Usually, I feel secure	1	2	3	4
14.	I try to avoid facing crises and difficulties	1	2	3	4
15.	I feel blue sometimes	1	2	3	4
16.	Time to time I feel satisfied	1	2	3	4
17.	Unimportant thoughts run in my mind and bother me	1	2	3	4
18.	I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
19.	I am a steady person	1	2	3	4
20.	I get in a state of turmoil as I think over my recent concerns and interests	1	2	3	4

[logo]

Appendix 3

Summary Table with Links to the Report Data.

Description	Data in Yandex Disc cloud
Metadata in .xlsx format, including details on participant sex and age, history of GSR sessions, physiological data record date and time.	https://disk.yandex.ru/i/YXq7ZMtYJ7hG-Q
Recorded data in .edf format.	https://disk.yandex.ru/d/13jWD5ssK_XjHQ
.edf data after preprocessing and ICA.	https://disk.yandex.ru/d/0HxAmbYXzj5UVQ
Data in .xlsx format, including EEG parameters, such as rhythm power at different frequencies and in different cortical areas during different session segments.	https://disk.yandex.ru/i/6o8twRt5_bMxpQ
Data in .xlsx format, including PPG parameters, such as heart rate and heart rate variability metrics.	https://disk.yandex.ru/i/lKdMsBp0qtvYMA
Data in .xlsx format, including spirometry parameters, such as mean respiratory rate and respiratory variability metrics.	https://disk.yandex.ru/i/RtmVSZFlllkzjg
Data in .xlsx format, including galvanic skin response (GSR) parameters, such as number and mean amplitude of skin responses, as well as tonic and sympathetic activity metrics.	https://disk.yandex.rU/i/9WglqspCTI68-w
Electromyography (EMG) data in .xlsx format, such as mean amplitude and variability of facial muscle activity.	https://disk.yandex.ru/i/hAVgZN8clDKY-g
Eye tracking data in .xlsx format, including such parameters as mean and standard duration of fixations, saccade amplitude, spatial coordinates of fixations, and percentage of valid data of gaze fixed on a screen.	https://disk.yandex.ru/i/FKbiOz4pJhJCjg
Data from PANAS and STAI psychological inventories in .xlsx format.	https://disk.yandex.ru/d/nwiZGUATHk2HLA

The document is signed and submitted via EDM operator, JSC Production Company SKB Kontur

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Signatures of the recipient:	LLC GSR SYSTEM Vera Askarova, GENERAL DIRECTOR	Not required to sign the document	02BE2E7F00E0B14CAF469F43F0E 33D139E 03.09.2024 10:33 through 03.12.2025 10:33 GMT +03:00	26.05.2025 16:12 GMT +03:00 The signature matches the document file