# HYPERSCANNING OF SOCIAL ATTUNEMENT: AN FRN STUDY

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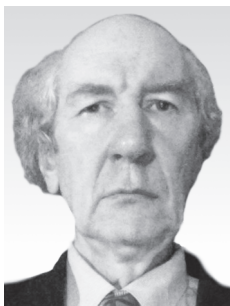
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Absract

Humans often change their views or opinions while interacting with each other. This often leads to behavioral changes. Such changes are often reciprocal and ultimately lead to an agreement or conclusion. One way to experimentally study human reciprocity would be to offer participants to take part in collective problem solving. This study analyzed feedback-related negativity (FRN) components of visual event-related potentials (ERP) in order to examine how the brain activity changes during joint performance of a task aimed at identifying a genuine image of a famous masterpiece as opposed to its mirror reflection as a function of a number of matched answers. The results of our electroencephalographic analysis showed that both erroneous and mismatched choices evoked comparable FRN responses in the brain activity of jointly working participants, possibly reflecting individual learning process based on action-monitoring and error-detection. When the subjects were asked to judge the stimuli for the second time following the peer's feedback, the number of matched answers significantly increased while the amplitude of prediction error signal and FRN decreased, indicating conformity changes, possibly underlying the attunement. Our results agree with previous FRN findings supporting the neurobiological model of reinforcement learning, offering a possible neural mechanism of behavioral reciprocity and social attunement.

Keywords: attunement, brain, neuroimaging, neuronal correlates, evoked potentials.

Introduction

A study of the brain mechanisms of social attunement, which may be reflected in the process of changing behavior of an individual in order to increase its efficacy in interaction with other participants or social group, is in its early days. Attunement is a mechanism of mutual and active changing of opinion in give-and-take or reciprocal influence and is achieved in the process of active interaction between people (Hoffman, Hamm, & Farmer, 2015). In the framework of the attunement concept, changing of individual behavior is firstly a result of a conflict with opinions of other people and can be paralleled by the studies of conformity and social influence (Klucharev, Hytönen, Rijpkema, Smidts, & Fernández, 2009). Secondly, it has a specific connation of reciprocity or mutual influence of one on another in the behavior changes of both actors. Studies of the neurobiological mechanisms of attunement, in contrast to studies of decision making at the individual level, require new approaches.

The current study was aimed at designing an experimental paradigm for investigating brain processes of attunement in collective problem sol-

ving. To our knowledge, there are very few studies of synchronous brain monitoring of participants during their collective behavior mainly during the passive task of movie watching or a discourse (Jääskeläinen et al., 2008; Stephens, Silbert, & Hasson, 2010; Hasson, Nir, Levy, Fuhrmann, & Malach, 2004; Hasson, Yang, Vallines, Heeger, & Rubin, 2008). One exception is a novel MEG study of a real-time auditory interaction between two people (Baess et al., 2012) using the hyperscanning of participants whose stimulus-locked brain responses were synchronously recorded at the two different laboratories separated by 5 km.

The neurobiology of social effects on choice and decision making also requires further experimental evidence. Several independent research groups (Berns, Capra, Moore, & Noussair, 2010; Campbell-Meiklejohn, Bach, Roepstorff, Dolan, & Frith, 2010; Klucharev et al., 2009) have shown that changes in individual decision making under the influence of social opinion result in conformity and can be explained by the activity of brain regions implicated in reinforcement learning (Sutton & Barto, 1998). Thus, a social opinion can be viewed as reinforcement of a specific behavior (Klucharev et al., 2009). According to one of the widely discussed models of social influence (Montague, King-Casas, & Cohen, 2006), the discrepancy between individual decision and social opinion is interpreted by the nervous system as an error signal similar to the reward prediction error, expressed in a modulated activity of dopaminergic system neurons and signaling about the necessity of a change in a behavior. Recently, an fMRI study showed that the activity of the mediofrontal cortex (cingulate gyrus) decreased, whereas nucleus accumbens (NAcc) decreases its activity during the mismatch of a participant's opinion with a social opinion (e.g. Klucharev et al., 2009).

Importantly, the activity of the mediofrontal cortex can be recorded using electroencephalographic (EEG) imaging (e.g. Hermann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004), which makes it possible to study the neurobiological basis of social influence with a good temporal resolution and to relate the data to EEG literature, more specifically, to event-related potentials (ERP) that have recently gained wide popularity in studies of reinforcement learning (Cohen & Ranganath, 2007; Nieuwenhuis, Holroyd, Mol, & Coles, 2004) and even social influence (Shestakova et al., 2013).

Several ERP components can be considered as candidates for investigation of temporal characteristics of reinforcement learning in the studies of social influence and attunement. Among them are feedback-related negativity (FRN), error-related negativity (ERN) and the following positive wave P300 related to the activity of the dopaminergic system (Frank, Woroch, & Curran, 2005).

Our review of the above-mentioned FRN/ERN findings motivated our suggestion that one of the components of the attunement mechanism can include the comparison of one's own opinion with an opponent's view. Using the FRN method, we aimed to test a hypothesis about a neurobiological nature of attunement and to identify spatiotemporal characteristics of the brain responses when a given opinion is in conflict with a peer's view. We further

hypothesized that modulation of the FRN component in the process of attunement would serve as an indication of the error-detection mechanism involvement during the process of the associated behavioral change in order to improve individual's performance on the experimental task (i.e. to increase the number of jointly provided correct answers while differentiating between the original image and its mirror version in order to receive a monetary incentive). We based our FRN hypothesis on our previous ERP study (Shestakova et al., 2013), in which we demonstrated that a conflict with a group opinion evoked a negative deviation of ERP with a maximum about 200 ms in the fronto-central cortex area similar to the FRN. The conformal changes were reflected in a longer latency ERP component, recorded as another negative displacement with a similar distribution with a maximum at 380 ms. Relying on the previous results we have suggested that changing one's behavior in line with a peer's opinion can be mediated by the activity of the error-detection system (Miltner, Braun, & Coles, 1997; Cohen & Ranganath, 2007).

In a social group, actions of an individual can trigger behavioral and consequently neuronal responses of his or her counterpart. For example, in the EEG study (van Schie, Mars, Coles, & Bekkering, 2004) it was shown that when an observer was watching other participants make errors, the observer's brain generated an ERP signal similar to the FRN response, which allowed authors to conclude that controlling their own behavior included a component of reward prediction error and observation of social environment behavior possibly determined by simi-

lar mechanisms. In an EEG study (Marco-Pallarés, Krämer, Strehl, Schröder, & Münte, 2010) the researchers compared FRN responses of players to ERP responses of observers whose reward was proportional to the partner's success, showing that it did not depend on the player's success or was inversed to his/her success.

Studies using FRN provided two important findings. On the one hand, similar ERP responses were recorded from players and observers even in the situation when the win did not depend on the result of a player. On the other hand, effects obtained for an observer were not a simple reflection of a player's brain responses as, for example, in the situation when the player's win led to the observer's loss (Marco-Pallarés et al., 2010), since then the brain responses of the player and the observer were opposite — a greater FRN of the observer was identified when the competing player won. Thus, observing another person playing can activate two different brain responses: (1) an altruistic mechanism triggered by results of the other person's actions which can be associated with empathy and (2) a rational mechanism evaluating event consequences.

One way to study brain mechanisms of cooperation or attunement would be to use the already mentioned magnetoencephalographic hyperscanning when two individual brain recordings are synchronized and the activity is simultaneously monitored as participants are interacting (Baess et al., 2012). As was shown in this study, N100m latencies and source locations were similar for both participants for presented locally tones. The response amplitude effect replicated both for the

local and for the remote presentations. Synchronized brain scanning is employed in the electroencephalographic study reported here. We synchronized EEG scanning of two participants as they were playing together the game of identifying the original image presented along its mirror version.

Our study aimed to investigate neuronal mechanisms of behavioral changes as a function of social interaction. According to our FRN hypothesis based on the reinforcement learning as a mechanism of social influence, a discrepancy between individual and partner's opinion can generate a reward prediction error signal, which can be detected using the FRN component of ERPs. The study reported here examined how brain activity changes as a function of a number of correct collective answers during joint performance on an image-identification task. The dynamics of matching both correct and incorrect answers indicating the result of the participants' attunement was analyzed offline and was used to compare ERP in presenting the results of a collective choice.

Methods

Participants

Fifteen pairs of Russian-speaking participants who were not acquainted before have participated in the study (16 females). The average age was 23 (± 4 years). Each participant was paid 2 USD per hour. The experimental protocol complied with the Declaration of Helsinki, and the participants gave their written informed consent prior to taking part in the study.

Stimuli and Procedure

One hundred digitized color illustrations of famous paintings (e.g., masterpieces of famous painters such as Serov, Chagall, Monét, etc.) were used in the experiment. They were presented on the computer display: 80 of them were randomly interspersed between the two experimental EEG blocks where the ERPs were recorded following their presentation and the participant's indicating their choice. The rest were used during a break between the two blocks when participants were instructed to discuss and share their strategies of identifying original images.

The task required participants to identify the original image of a painting presented along with its mirror image. The influence of internal keys that could help to identify the originality was separately analyzed and will be reported elsewhere.

Individual participant pairs were synchronously presented with a combination of the original image and its mirror reflection next to each other (see Figure 1). The order of image presentation was randomly selected and was unique for each pair.

As Figure1 illustrates, each EEG block trial began with the image exposition that lasted 8 seconds. The disappearance of the stimuli indicated the start of the choice time window within which participants were given a maximum of 52 seconds to indicate whether the original illustration was presented on the right or on the left side of the central fixation cross via a key press. After both participants made their choices, the individual feedback was presented to them on the screen: S1's choice was always

Experimental trial sequence
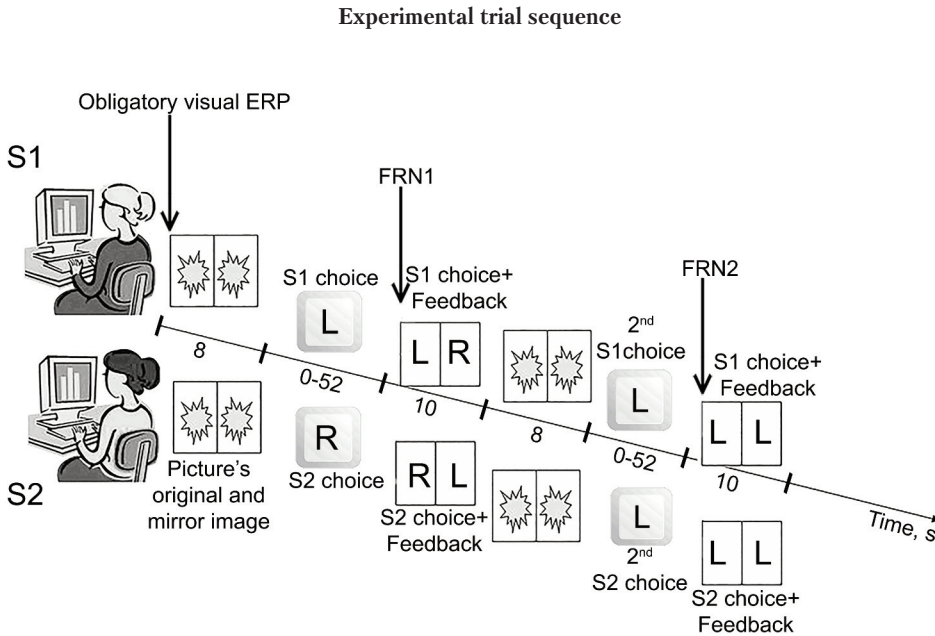
Note. During the EEG session, participants had to choose the side at which the original image of a famous painting was presented as opposed to its mirror image. The timeline separates the sequences of events for the first (S1) and the second participants (S2). Both participants were presented with the pictures and had to give their opinion first without a feedback (Choice 1) and then following their peer's feedback (Choice 2). The responses were always given at the same side of the display. The trial ended up with a presentation of the correct answer in the form of the computer feedback.

presented on the left while S2's choice — on the right. After a 10-second feedback, the same stimuli appeared on the screen again and the participants were offered a 52 s time period to choose the original. The trial ended with the 10-sec presentation of the correct choice (computer feedback). The two EEG sessions were separated by a 10-min break during which participants could discuss their strategies in order to work out an effective joint strategy. Importantly, that time participants received an additional monetary reward based on their joint performance: in the second EEG session, the total of correct joint choices was translated into a monetary reward equal to an amount of money (the maximal reward was 50 USD while the minimal was 1 USD) given to each participant at the end of the experiment. The monetary reward was paid in Russian rubles. The sum was calculated based on the current exchange rate.

EEG recording

During the EEG recording participants sat in a comfortable armchair in a specially equipped room. The computer screen (19") was located at a 1.5-meter

viewing distance. Each participant was instructed to move as little as possible, avoiding blinking or chewing in order to limit the frequency of muscle artifacts. Two participants from the same subject pair sat in the same room but separated by a non-transparent wall of 1 m height. EEG data were recorded using the Russian made Mitsar Medical Diagnostic Equipment. Nineteen scalp electrodes were placed according to the 10–20 system: five electrodes were set on the central line (Fp, F, C, P, O) and seven were located on the left and right sides from the central line of the frontal, central, temporal, parietal and occipital areas. Two referent electrodes were set over the mastoids; the ground electrode was set on the forehead. To record the eye movements, ocular electrodes were set in the corner of the eye and above the right eye. Electrode impedances were kept below 5 k . The EEG was recorded with a 512 Hz sampling frequency (SF) for the first encephalograph and 2048 for the second. The data were recorded with a 0.1–50 Hz band-pass filter and a 45–55 Hz notch filter.

Analysis

EEG data was analyzed by the EMSE Source Signal Inc. program. First, the EEG recording from the second electroencephalographer was offline downsampled to match SF of the first one prior the EEG preprocessing which included artifact removal, off-line filtering (0.5–30 Hz), and baseline correction. Second, the ERPs were averaged and grouped together according to the time of the first stimulus presentation onset in order to see whether the visual obligatory responses

were true (1) as well as the time of the first and the second peer's feedback (Figure 1). Both ERP responses to the stimulus onset and the feedback onset were analyzed in the same 800-ms time window. The ERP responses to the first and the second feedback were analyzed separately. Time peaks of activity for FRN amplitudes measurements were chosen according to an amplitude maximum of a group answer in Cz channel, where effects of the opinion conflict and conformity were maximal. To compensate noise effects during the measurement of ERP component amplitudes, 40 and 20 ms time windows around amplitude peaks maxima, identified by GFP graph, where ERP variance for all channels was maximal (155–177 ms and 325–375 ms, respectively), were used.

To assess the significance of the further mentioned effects of interest, the multifactor analysis of variance (MANOVA) with repeated measurements was performed using the STATISTICA software package.

For each interval, the MANOVA was used to assess the presentation order of feedback results, as well as effects of localizing the lateralization with the following factors: "Block" (the first and the second EEG block); choice matched/unmatched; "Repetition" (the first or the second presentation of a stimulus (either picture or feedback in the same trial)); "Mismatch" (when the peer choices did or did not match; "Correctness" (correct answer vs. incorrect answer); distribution in rostrocaudal direction, or "RCD" ((Fp), (F), (C), (P), (O) lines of electrodes according to the 10–20 system); "Laterality" (left, right or central line of the brain response). The Green-

house-Geisser correction was used where applicable (Greenhouse & Geisser, 1959). Separate ANOVA was also performed on behavioral data.

Behavioral results

In order to monitor the dynamics of behavioral changes following social attunement we analyzed how the group performance on the task changed within and across the blocks on average.

Figure 2 summarizes the results of behavioral data representing the number of matched and unmatched answers in pairs suggesting that participants' choices following the first presentation of stimuli matched in 50% of cases (average 50% and 58%), which corresponds to a random guessing. After the repeated presentation of the same stimuli preceded with the peer's feedback, the average number of matched answers increased almost by half (75% and 83% for the first and for the second EEG blocks, respectively). As was shown by the results of ANOVA analysis, factors of Block and Repetition of the presentation were statistically significant ($F(1,14) = 11.74$, $p = 0.004$, and $F(1,14) = 62.25$, $p = 0.000$).

EEG results

In order to verify the effective operation of our experimental setup, we averaged all ERP responses to the first visual stimulus presentation across the trials in the first EEG block (Figure 3). An ERP pattern presented in this figure well corresponds to a known P1-N1-P2-N2 ERP complex of exogenous potential, with its amplitude maximum at P3, Pz, P4, C3, Cz, C4, O1, Oz, and O2, a classical distribution of a potential in visual stimulation.

Figure 2

Distribution of total matched and unmatched answers separately grouped for the two EEG blocks
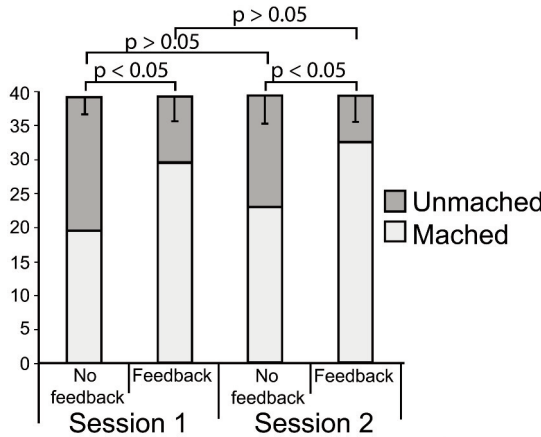
Note. Data is further split across the two parts of the trial — before (No feedback) and after feedback given by the peer. The vertical scale is in % of total number of trials (40). The effect of feedback was significant in the number of matched answers given by the participants from the same pair.

Next we analyzed brain responses to the feedback when the participants' own responses did not match that of their peers. Although the structure of responses to the feedback when the choices matched or unmatched had similar structure, the ERPs on unmatched answers had larger negative displacement in the time window of their interaction in 325–375 time window and bellow are called feedback related negativity (FRN) responses (Figure 4). This difference was statistically significant, which was confirmed by significant interaction of Mismatch factor with RCD ($F(4, 116) = 8.199, p = 0.000$) indicating the fronto-central dominance of the FRN response as a possible projection of the source in the cingulate area.

As Figure 4A and Figure 4B show, in both blocks, a difference between ERPs to matched and unmatched choices was found in the 325-375-ms interval ($F(1, 29) = 4.93, p = 0.034$). The maximal difference was observed in fronto-central channels, which can be seen at FRN topographies presented in

the same figure and further confirmed by the Mismatch × RCD factor interaction ($F(2, 58) = 8.31, p = 0.000$). The effect of Laterality did not reach significance. Overall, in case of the repeated feedback presentation, the FRN amplitude dramatically dropped so that no difference between ERP amplitudes could be found in response to unmatched choices as compared to matched in the time interval corresponding to the first-feedback FRN peak ($F(1, 29) = 5.26, p = 0.003$). No Block effect or its interaction with other factors was found significant.

The decrease in FRN amplitude or even its absence in case of the repeated feedback corresponded well to the observation drawn from behavioral data (Figure 2) showing the increased number of matched answers in the repeated assessment of original image corresponding with decreased portion of unmatched answers.

To evaluate the effect of the correctness of choice (Figure 5), we separately analyzed the difference between correct

Figure 3

ERPs in response to the first image presentation summarized for the both recording blocks and corresponding to a complex of amplitude deviation of visual potential in µV, also called P1-N1-P2-N2 complex

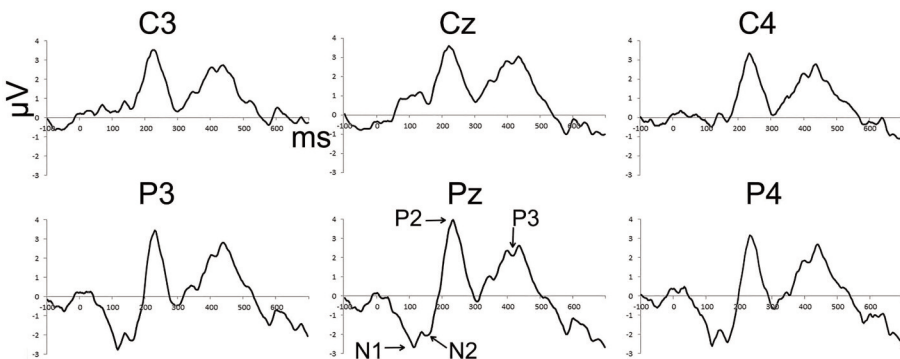**The FRN seen as a difference curve marked as a dashed line between the potentials to matched and unmatched answers and responses recorded during the demonstration of results of the participant's and partner's choice of a picture original in the first and second EEG bocks. The gray bars indicate significant intervals of negative displacements with the central distribution of scalp potential**
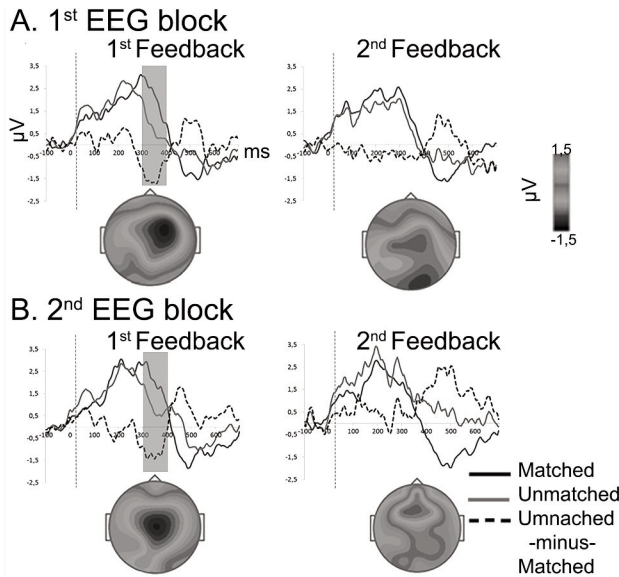
and erroneous answers of participants in order to compare FRN responses for correct choice with ERP responses to incorrect choices. The ANOVA analysis revealed no statistically significant effects in the time interval from 200 to 400 ms.

Discussion

In this study we tested a neurobiologically motivated hypothesis about error-detection mechanisms of social influence (Klucharev et al., 2009). Information exchange or both mechanisms influenced social attunement in the experimental task implying coming to an agreement in order to gain a monetary reward. Using a feedback-related negativity (FRN) component of a visual event-related potential, we analyzed how brain activity changed as a function of a number of matched answers during joint performance on an image identification task. Our results showed that an opinion conflict between two participants evoked FRN, which is often associated with the control function and reinforcement learning (Miltner, Braun, & Coles, 1997; Gehring & Willoughby, 2002; Nieuwenhuis, Holroyd, Mol, & Coles, 2004; Nieuwenhuis, Schweizer, Mars, Botvinick, & Hajcak, 2007).

The FRN component in response to the opinion mismatch had the largest peak in the time window of 325–375 ms. The dynamics of changing the number of matched (but not necessarily

The FRN responses to correct and incorrect choices superimposed at Pz electrode
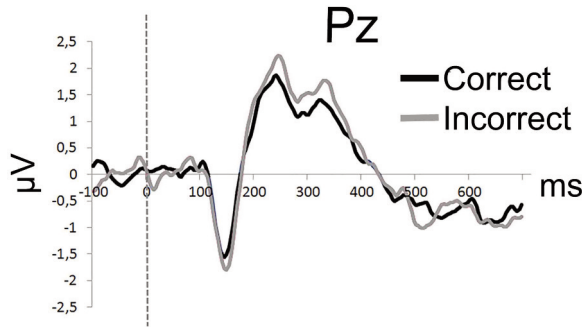
Note. No significant difference of the main effect of a choice being correct with other factors such as Repetition, Block, RCD, and Laterality were found.

correct) answers as a result of attunement in a given pair was studied by comparing ERP responses to presenting the results of the first and second collective choices following viewing 80 pairs of images, obtained by simultaneous recording of EEGs from both participants. In the 10-minute break between two EEG blocks of the experiment, participants could verbalize their strategy in order to work out a more efficient collective approach.

Yet, no significant difference in the FRN amplitude was registered between the two blocks of the EEG study suggesting that additional information about how the peers make their choices did not modulate participants' individual performance as well as group performance. However, the FRN amplitude significantly decreased after a repeated demonstration of the choice results. This observation indicates the activity of a fundamental error-detection system found in this ERP study rather than a decrease in response due to habituation. This finding is in line with the

behavioral data showing the number of matched answers in comparison with those which did not match increased by almost 50% on average in the first block of the EEG study and by 40% in the second block.

The fronto-central distribution of negativity with deviation maxima of the difference wave at 160 and 360 ms recorded on the mismatch of the two participants' opinions indicates the similarity of the ERPs recorded in our study to the previously reported components of prediction error (i.e., the negativity of activity result), or FRN (feedback related negativity) (Marco-Pallarés et al., 2010) and/or error-related negativity (Frank, Woroch, & Curran, 2005; Herrmann et al., 2004). The ERP studies based on the voltage distribution showed that the FRN source was arguably located in the mediofrontal cortex (Frank, Woroch, & Curran, 2005; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). At the same time, FMRI and TMS studies (Klucharev et al., 2009; Klucharev,

Munneke, Smidts, & Fernández, 2011) indicated the role of mediofrontal cortex in social conformity. Both fMRI data and the results of ERP source localization suggest that the prediction error signal is generated in the mediofrontal cortex (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001), which is an integral part of the fundamental system of analysis and correction of activity results.

Thus, the conflict of opinions observed in this study caused the FRN activity, which is in line with both Montague's error-detection theory (Montague, King-Casas, & Cohen 2006) and Klucharev's (Klucharev et al., 2009) model of social influence suggesting that the difference between an individual's opinion and the view of a social environment is interpreted by the nervous system as an "error action" and expressed in a modulated activity of the dopaminergic system neurons signaling about the necessity of a behavior change.

In general, the correlates of attunement observed in our study (FRN recorded in the conflict of opinions comparing to ERP on matching of opinions, time-space structure of observed effect, as well as change in amplitude in a repeated demonstration) are in agreement with the mechanism of social influence inherent to reinforcement learning. However, the theory of reinforcement learning is not the only possible explanation of the attunement effects. One cannot exclude, for example, a possibility of an interaction between the mirror neurons system and processes underlying empathy and emotional reactions (Singer et al., 2004; Singer et al., 2006). A recent meta-analysis of fMRI and PET studies is an attempt to connect the theory of mind to the mirror neurons system in tests aiming to study the mirror neurons system as well as the origin of empathy and self-identification (Agnew, Bhakoo, & Puri, 2007). The studies using modern neurovisualization methods show that imitation and associative learning both in animals and humans are supported by different systems. However, imitation, a behavioral manifestation of the neuronal mechanism of mirror neurons system, is the reverse side of associative learning. The mirror neurons are the brain cells which are activated not only during any individual action, but also during observation of a similar action being carried out by others. In 1990s Rizzolatti's group, studying monkey mirror neurons, suggested that they were implicated in processes of imitation, learning, understanding of social environment, and, as a consequence, development of social skills and human culture in general (Rizzolatti, Fogassi, & Gallese, 2001). A number of EEG studies on decision making in gambling-like game tests aimed at maximizing the win (Marco-Pallarés et al., 2010; Gehring & Willoughby, 2002; Yu & Zhou, 2006) point out a possible role of imitation mechanisms in process of behavioral changes under the influence of social environment. In these and other studies it has been shown that ERPs of participants observing wins and losses were different from ERPs of players and did not depend on correctness of the choice. The evaluation of a correct choice affecting FRN recorded in our study showed that ERP responses following correct choices did not differ from the ERP responses in case of incorrect choice, indicating the similarity

of mechanisms involved in dame test of Marco-Pallarés, Krämer, Strehl, Schröder,& Münte (2010) in our study.

To sum up, our results showed that the mismatch between individual and partners' opinions leads to activating a response similar to FRN, representing processes of individual learning. In a repeated demonstration of a task, when the number of matched answers significantly increased the amplitude of prediction error signal, and FRN decreased, indicating conformity changes possibly underlying the associated attunement process. This study advances previous fMRI and EEG findings and demonstrates the temporal structure of processes leading to conformity change of opinion. These results confirmed the hypothesis that some types of social influence are mediated by activity of a system of behavior and learning control.

Acknowledgments

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Нейрофизиологические механизмы социальной сонастройки: НРД исследование

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Резюме

Мозговые механизмы сонастройки — процесса изменения индивидуальной поведенче-
ской стратегии в пользу повышения ее эффективности при взаимодействии с другим инди-
видуумом или социальной группой — практически не исследовались. Сонастройка подразу-
мевает обоюдное изменение мнения и достигается в процессе взаимодействия между людь-
ми. В данном поисковом исследовании была поставлена задача разработать
экспериментальную парадигму для изучения мозговых процессов сонастройки при совмест-
ном решении задачи, в которой паре испытуемых одновременно предлагалось отличить ори-
гинал изображения произведения от его зеркальной копии. Используя электроэнцефалогра-
фический мониторинг, мы синхронного регистрировали вызванные потенциалы (ВП), назы-
ваемые Негативность Результата Действия (НРД), на предъявление обратной связи до и
после финального решения испытуемого под влиянием мнения его партнера. Согласно гипо-
тезе о механизме социального влияния как следствия активации нейронального сигнала
ошибки предсказания (ОП), рассогласование собственного мнения с мнением партнера
должно было бы приводить к изменению мнения с целью минимизировать ОП. Изменение
мнения также может быть связано с получением дополнительной информации, на основе
которой принимается решение. С целью контролировать влияние информационного фак-
тора на индивидуальный выбор, во время отдельной экспериментальной сессии испытуе-
мым предоставлялась возможность обменяться информацией о выбранной ими стратегии,
после чего ВП-тестирование проводилось повторно. Полученные НРД и поведенческие
результаты согласуются с моделью обучения с подкреплением, согласно которой в процес-
се сонастройки отличие индивидуального мнения от мнения партнера генерирует ОП-сиг-
нал. Мы наблюдали уменьшение НРД одновременно с уменьшением количества несогла-
сованных ответов. После обмена информацией о стратегии выбора значимых изменений в

ВП и поведенческих коррелятах не наблюдалось. Подтверждение НРД-гипотезы позволяет не только подтвердить эффективность приложения модели обучения с подкреплением к процессам социального взаимодействия, но и использовать НРД в качестве индикатора эффективности сонастройки.