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NEURAL MARKERS OF ETHNIC IMPLICIT ATTITUDES OBTAINED BY TIME-FREQUENCY ANALYSIS OF DATA OF THE SUBLIMINAL EVALUATIVE PRIMING PROCEDURE: PILOT STUDY

Viktors Veliks,
Doctor of Biology, Researcher at the Faculty of Medicine and Life Sciences,
University of Latvia (Riga, Latvia),
Baltic International Academy (Riga, Latvia)
ORCID ID: 0000-0002-4380-9534
viktors.veliks@lu.lv

Juris Porozovs,
Doctor of Biology,
Professor at the Faculty of Education Sciences and Psychology,
University of Latvia (Riga, Latvia)
ORCID ID: 0000-0001-7023-031X
juris.porozovs@lu.lv

Irina Plotka,
Doctor of Psychology, Professor at the Department of Psychology,
Baltic International Academy (Riga, Latvia)
ORCID ID: 0000-0003-0478-2823
irinaplotka@inbox.lv

Nina Blumenau,
Doctor of Engineering Sciences,
Associate Professor at the Department of Psychology,
Baltic International Academy (Riga, Latvia)
ORCID ID: 0000-0001-9335-397X
nina.blum@gmail.com

Dmitrijs Igonins,
Doctor of Psychology, Consultant at the Department of Psychology,
Baltic International Academy (Riga, Latvia),
University of Latvia (Riga, Latvia)
ORCID ID: 0009-0005-8508-4147
latenta@balticom.lv

Abstract. To study implicit ethnic attitudes, subliminal evaluative priming procedure (SEP) is mostly used, but its neurocognitive correlates are insufficiently studied. The aim of research is to find the neural markers of implicit attitudes obtained by time-frequency (TF) analysis of the SEP procedure data with stimulus onset asynchrony (SOA) 200 ms and 300 ms. 9 participants identified themselves as belonging to an ethnic minority group. The SEP – TF plots analysis was conducted. Different frequency patterns were observed for different SOAs. E.g., SOA 300 ms likely associated with the preferred ethnic group in case of self-referential compatible stimulus groups and differed from SOA 200 ms patterns associated with the alternative incompatible stimulus group. The study experimentally substantiates the use of promising SEP methods in combination with the neurophysiological TF and ERP Electroencephalography analysis method.

Key words: Electroencephalography (EEG), Time-Frequency analysis (TF), Event-Related Potential (ERP), Subliminal evaluative priming, Implicit ethnic attitude.

Introduction

The concept of attitude could be characterized as a positive or negative evaluative reaction towards somebody or something which is expressed as an opinion, feeling or intended behavior. The attitude is the mental association in memory between an object and one's summary evaluation of that object (Fazio, 2007, Petty et al., 2009). The process of actualization of attitudes may require some efforts and be controlled or occur spontaneously and automatically. In the first case we can tell about the explicit attitudes, in the second case – about the implicit attitudes. The explicit attitudes have been understood as a product of primarily propositional, in fact logical processes, and the implicit ones – as a result of associative processes. The propositional processes are deliberate, conscious, slow, the associative processes – fast, automatic, unconscious. Implicit estimates are a reflection of mental associations, formed in the early stages of acquisition of the social experience (Plotka et al., 2016, 2017, De Hart et al., 2006; Rudman, 2004). The term "implicit" is applied to attitudes in three different ways: (1) when talking about the lack of awareness of the information processing operations that underlie attitudes, (2) when the attitude itself is implicit, and (3) when the attitude is implicitly measured. Physiological measures can address each of these issues. One of classic definitions of the term "attitude" is "a mental and neural state of readiness". Physiological measures are useful for the measurement of implicit attitudes because implicit attitudes are independent of their subjective awareness by the research participant. Physiological measures do not typically require participants to be informed of the psychological construct of interest (Ito & Cacioppo, 2007). Physiological measures can be used in a manner similar to other indirect measures of implicit attitudes, such as response latency measures based on spreading of activation (Fazio et al., 1986, Ito & Kubota, 2024).

Modern implicit measures are based on measuring participants' reaction time (RT) when they perform various tasks and their attention is focused on performing these tasks rather than on the attitude object (Rudman, 2011). One of the main methods is the subliminal evaluative priming (SEP) procedure, which is based on the priming effect, understood as the influence of a preceding stimulus on the cognitive processing of a subsequent one. In all cases, the RT of participants was measured, on the basis of which the system of describing the measured implicit attitudes was built. The major task was to use RT to obtain information on the implicit attitude studied. This information is based on the hypothesis of Fazio and his co-authors (Fazio et al., 1986, p.231), from which it follows that if a person has a formed positive attitude towards the prime, then the response to positive target words will be faster, and to negative target words – slower than in the absence of the prime. Also, with the formed negative attitude towards the prime, the response to negative target words will be fast, and to positive ones – slow. We used the converse statement. If the response to positive target words is fast, and to negative target words is slow, then the attitude is positive. We assume that this lines up with reality. To describe the results of RT measurements using the SEP, three measures of implicit attitudes were developed: "Facilitation variable (R)", described in Rudman's book (2011), characterizing the presence of the priming effect – the difference of RT with the priming stimulus and without it; "Attitude variable (RR)" – the difference between the facilitation variables for the target stimuli of different valence. The sign of this variable indicates the emotional orientation of the attitude, and its absolute value is the strength of the attitudes expressed in units of time; "Indices of implicit preference (RRR)" – the difference between the variables of attitudes for different primes. These three variables were developed and applied in our research of ethnic implicit attitudes using the SEP procedure (Plotka, 2016, 2017, 2023). We were studying implicit ethnic attitudes at different times of stimulus onset asynchrony (SOA). The variable RRR showed statistically significant correlations with explicit measures of attitudes and D-scores of the Implicit Association Test (IAT). The study of correlation graphs made it possible to make the assumption that for different SOA times there is a separate cognitive processing of context-related and basic associations related to the object of attitudes (Plotka et al., 2016, 2017). The analysis of SEP effects was conducted in terms of an approach based on the spread of activation in a semantic network, which includes nodes for representing knowledge elements and the connections between them (Collins & Loftus, 1975; Collins & Quillian, 1969).

Other researchers have found that there is a relation between the results of implicit measurements (e.g., Implicit Association Test (IAT), SEP procedure) and their neural correlates, including those obtained as a result of measurements by electroencephalography (EEG) (Williams & Themanson, 2011; Healy et al., 2015; Perry, 2022; Huang et al., 2025). Nevertheless, neural correlates are not yet fully understood.

EEG is used to investigate the time windows of event-related potential (ERP) indicating brain regions in the implicit measurements. Various studies suggest that the late positive potential (LPP) is modulated by basic evaluative processes, and some studies suggest that in-/outgroup relative position affects ERP responses.

The LPP results show that later electrophysiological reactions may be coherent with implicit measures of attitudes, since, in indigenous participants, higher amplitudes that are related to stimuli (words) in an unfavorable context were observed for the ingroup. In research of the priming effect, it was demonstrated that the valence of a target word is categorized more quickly when the word is preceded by a prime word of the same valence (congruent trials) than by prime word of the opposite valence (incongruent trials) (Fazio et al, 1986; Chen et al., 2020). The research of neural correlates of this effect showed that more negativity to incongruent targets in two different ERP components, one corresponding to an N2 component (180-280 ms post stimulus) and one referred to by the authors as N400 component (480-680 ms) (Zhang et al., 2006). This result allows us to conclude that the N400 component is sensitive not only to semantic mismatches, but also affective mismatches, suggesting that affective priming shares a similar mechanism with semantic priming (Amodio & Bartholow, 2011). ERPs have been used in several studies to track the time course and level of engagement of various processes associated with the social categorization of faces. Early research examined different ERP responses as a function of a person's gender (Mouchetant-Rostaing et al., 2000). Observations of early ERP effects for race indicate that the certain aspects of social categorization process occur very rapidly and that these processes are relatively automatic, implicit (Ito et al., 2007). For the last decades in the field of social neuroscience, a lot of data have been obtained on the localization of brain processes, as well as the components of ERP that arise when activating implicit attitudes, including intergroup ones. ERP components that are sensitive to the racial ingroup/outgroup status of the stimuli presented, have been extensively studied. Among them there are N100 (Ito & Urland, 2003), P200 (Dickter & Bartholow, 2007), N200 (Kubota & Ito, 2007), P300 (Willadsen-Jensen & Ito, 2008), which selectively give a greater neural response to stimuli representing objects of ingroup or outgroup categories. Otherwise, these increased amplitudes of neural responses, at least in a number of cases, are related to the belonging of objects to intergroup categories or to the events of alternating ingroup and outgroup objects. N100 and P200 increase in response to the presentation of the outgroup object. N200 with a typical peak latency of 250 ms is incremented in response to objects of the ingroup category (Kubota & Ito, 2007). The value of N170 in the task of the ethnic IAT is noted as an early correlate of intergroup implicit attitudes (Ibanez et al., 2010).

However, all these data were obtained using face images of representatives of racial, more rarely – ethnic groups, while in our experiment words were used – names of ingroups and outgroups. In a few studies, the joint neural effect of semantically interacting images and words was studied in the task of the ethnic IAT (Ibanez et al., 2010). The registration of ERPs modulated by the presentation of primes – words (for the case of ethnic intergroup attitudes) and subsequent target evaluation adjectives in the task of SEP for various SOA has not been systematically carried out.

The obtained behavioral data require neurocognitive support, which has already been partially provided by preceding studies using neural response recording through EEG and magnetoencephalography techniques during the performance of various cognitive tasks aimed at assessing racial and ethnic attitudes. These studies, in particular, identified such significant ERP components associated with the processing of racial and ethnic attitudes with associated perceptual and attentional processes as N100, N170, N200, N250, P300, N400. "We hope the combined use of ERP-EEG and both implicit and explicit behavioral measures will yield further insights into our understanding of this phenomenon by facilitating the investigation of more subtle forms of prejudice and of the cognitive processes recruited during social evaluation" (Manfredi et al., 2023, p. 14).

The correspondence between ERPs and behavioral measures of implicit attitudes was observed using the IAT procedure, but not with data from priming procedures, including SEP (e.g., Willadsen-Jensen et al., 2008, Ibanez et al., 2010). The research hypothesis stated in studies (Plotka et al., 2016, 2017) requires verification at the non-behavioral (neural) level.

ERPs can be considered to represent changes in the balance of excitatory and inhibitory synaptic input to the basal versus apical compartments of pyramidal cells, and best explained as the coincidence (synchrony) in time and space (apical vs. basal) of faster and slower ionic currents (Edwards et al., 2009).

Time–frequency analysis serves as a key method for studying event-related EEG signals, allowing monitoring fluctuations in neural oscillatory patterns that reflect synchronized/desinchronized activity across cortical networks. These oscillations – originating largely from postsynaptic potentials in pyramidal neurons – can be tracked simultaneously in time and frequency domains, revealing how specific brain regions dynamically engage during different cognitive or sensory events that is the main advantage of this method (Zhang et al., 2023).

Compared both ERP and TF methods have their own strong and weak sides, dealing with the same physiologically originating primary data but in different calculation methods. More advanced is TF method.

Thus, to study implicit attitudes the implicit measures (e.g., SEP and IAT) based on RT analysis are mainly used. The neurocognitive correlates of these behavioral measures, especially those based on SEP data, have been less extensively studied. Taking into consideration the scarcity of data on the mechanisms of activation of implicit intergroup attitudes and their neuronal correlates, there should be a need to confirm and further study of separate processing of ingroup and outgroup implicit and explicit attitudes with ERPs registration and Time-Frequency analysis. Thus, the importance of this study is beyond doubt.

The aim of research is to find the neural markers of ethnic implicit attitudes obtained by time-frequency analysis of data of the subliminal evaluative priming procedure in the pilot study. The present study explores the possibility of using electroencephalography time-frequency analysis as a tool to assess neural signals associated with measures of implicit ethnic attitudes in conjunction with the subliminal evaluative priming procedure.

Method

Participants

The study was performed with data from nine volunteer undergraduate students with the right leading hand from the psychology program of the Baltic International Academy, Riga aged from 24 to 32 years old. The formation of ethnic group is based on the self-determination of the participants, and all of them were native Russian speakers. There were no restrictions on the sex and education. The research was approved in accordance with the *Ethical Principles of Psychologists and Code of Conduct* (American Psychological Association [APA], 2017).

Measurements

The measurements were the modified procedure of subliminal evaluative priming (SEP) in a task of affective categorization (Plotka et al., 2016) with continuous EEG recording. The experiment was performed in a quiet room, and during recording, participants assumed a comfortable position in a chair.

Procedure of SEP in the Task of Affective Categorization

The implicit ethnic attitudes have been measured by the SEP experimental procedure.

The instruction appears on the monitor once before starting the procedure. The participants saw on the monitor their task: "To push "1" key as quickly as possible if the positive word appears, and "2" key if the negative appears".

Then follows a sequence of displays and their duration:

• The fixation point (black cross in the middle of a white screen) – 1000 ms;

• Randomly presented Prime stimuli ("Russian" or "Latvian"), as well as empty screen: "baseline" – 17 ms. Participants did not see anything on the monitor due to the short (subliminal) exposure time. Prime stimuli activate an unconscious evaluative response that may influence the subsequent target;

• Backward mask: black lattice in the middle of a white screen, coincides with randomly presented intervals of stimulus onset asynchrony (SOA): 200 ms or 300 ms;

• Target stimuli: a clearly visible affective positive words (love, joy, happiness, kindness) and negative words (evil, anger, disgust, contempt) (Schlosberg, 1952). Duration: Until response or time-limited. The participant categorizes the target ("positive" and "negative") via keypress.

Then the participant's reaction time (RT) is recorded. The RT is the time between the start of "Target" and the participant's pressing the corresponding key. The RT and the accuracy in categorizing the target words are dependent variables.

Inter-Trial Interval (ITI) (empty screen) (1000 ms) – provides a brief pause before the next trial (Wentura & Degner, 2010). It is the time between measuring the RT and starting the next trial. The ITI is critical for: "Resetting" the state of attention, minimizing the influence of the previous trial on the next one, preventing guessing of the stimulus presentation rhythm.

Black words (Arial font and size 50 pixels) were presented on a white screen. Stimulus words were presented on a 17" LCD resolution 1200x1024 monitor, and participants were seated approximately 100 cm away from it.

Apparatus. Stimulation software E-PRIME 2.0 Professional (Psychology Software Tools, https://pstnet.com) was used for stimulus presentation and response collection.

Procedure of EEG Recordings

EEG was recorded with a sample rate of 1000 Hz and cut-off frequencies of 0.1-50 Hz via 32 electrodes Ag/AgCl caps (MCScap, Medical Computer Systems Ltd) electrodes fixed to the scalp with electrolyte gel at electrode positions with impedances <5 kOhm using the 10-10 electrodes system, A1A2 electrodes as recording reference. NVX52 EEG amplifier with NeoRec software (Medical Computer Systems Ltd) was used.

EEG Data Processing and TF Data Processing

Data were analyzed using Matlab (The MathWorks, Inc., https://se.mathworks.com) based EEG software – EEGLAB (Delorme & Makeig, 2004) with some custom EEG data processing scripts.

Data prepossessing and further EEG analyses were performed with EEGLAB. 50 Hz noise in EEG signals was rejected using bandpass filters with a value of 50 Hz. Then, EEG signals with performance errors or remaining artifacts exceeding ± 120 µV in any channel were cleaned. The eye-blinked artifacts were rejected using the ICA procedure (EEGLAB tutorial, https://eeglab.org/tutorials/).

Data processing and statistics was performed in EEGLAB with a EEGLAB STUDY pipeline. Time Frequency (TF) method used in this experiment data analysis steps, with following values of the calculation – cycles 3 0.8, nfreqs of 100, and ntimesout of 200. Event Related Potential (ERP) calculated with baseline from -500 to 0 ms and time range from -500 to 1500 ms.

For analysis we used C3 electrode that are connected with motor actions performance as well as integrative decisions manifestation through motor acts – keyboard key's press and therefore allows us to make a tiny connection with behavioral data calculated variables of the SEP such as R, RR and RRR.

Results and Discussion

SEP Variables

Initial Information for Each Participant: The number of valid observations, the mean (*M*) and the standard deviation (*SD*) of RT for fixed prime ("Latvian" or "Russian"), baseline, target valency ("positive" or "negative") and SOA (200 ms and 300 ms). When processing data, the number of measurements can decrease: usually, measurements that do not fall within a "reasonable" range of values are discarded (in our study: 200 ms ≤ RT ≤ 1500 ms). The results of incorrect performance of the participant's task may also be discarded. The percentage of incorrect answers given by participants in the classification tasks does not exceed 3.13%. The initial number of observations was 6784, and after filtering the data, 6564 observations remained. A total of 3.24% of observations were deleted.

SEP Procedures with Fixed SOAs. To interpret the measures of implicit attitudes, the assumption of Fazio et al. (1986, p. 231) is used, from which it follows that if the subject has a positive attitude toward object, the reaction to positive target words will be faster, and for negative target words – slower than in the absence of prime. Also, when a negative attitude is formed, the reaction to negative target words will be fast, and to the positive ones – slow. We use the opposite statement. If the reaction to the positive target words is fast and to the negative target words is slow, then the attitude toward object is positive. We assume that this is true to fact.

Effect Sizes. We used the effect size Cohen's *d* to detect the implicit effects (Cohen, 1988, p.67). Interpreting the absolute values of Cohen's *d* effect sizes: 0.20 – the effect size is small, 0.50 – the effect size is medium, 0.80 – the effect size is large.

Facilitation Variables

Facilitation variable values R = R(*Prime, Target Valency*) are defined as follows (e.g., Rudman, 2011):

$$R = M(Baseline, Target\ Valency) - M(Prime, Target\ Valency)$$

If the mean *RT* of a participant with the prime stimulus is shorter than without the prime stimulus, then the participant's task is facilitated and R > 0.

If the participant's mean RT with the prime stimulus is longer than without the prime stimulus, then the participant's task is inhibited and R < 0.

For instance, fast reaction to positive words relatively to the basic rate R = R(*Prime, Target Positive*) > 0 indicates participant's positive attitude. Slow response to the positive words relatively to the basic rate R = R(*Prime, Target Positive*) < 0 indicates non-positive attitude.

Fast reaction to negative words relatively to the basic rate R = R(*Prime, Target Negative*) > 0 indicates negative attitude. Slow response to the negative words relatively to the basic rate R = R(*Prime, Target Negative*) < 0 indicates non-negative attitude (Rudman, 2011).

The absolute value of the facilitation variable R characterizes the strength of facilitation or inhibition in units of time (for example, in milliseconds).

According to Rudman (2011), the term "facilitation score" is used to encompass both response facilitation and inhibition.

R(*Latvian, Target Positive*) > 0	Facilitation of solving the task of classifying positive target stimuli in the presence of "Latvian" prime.
R(*Latvian, Target Negative*) > 0	Facilitation of solving the task of classifying negative target stimuli in the presence of "Latvian" prime.
R(*Russian, Target Positive*) > 0	Facilitation of solving the task of classifying positive target stimuli in the presence of "Russian" prime.
R(*Russian, Target Negative*) > 0	Facilitation of solving the task of classifying negative target stimuli in the presence of "Russian" prime.

Figure 1 shows the participants' individual effects of facilitation or inhibition in the task of the classification of positive and negative target words in the presence of prime stimuli, revealed using Cohen's *d*(*R*) effect size. Facilitation effects are observed at *d*(*R*) > 0.2, while inhibition effects are observed at *d*(*R*) < -0.2 (outside the grey strip; s. Figures 1, 3). These effects depend on the participants and are more pronounced at SOA = 300 ms.

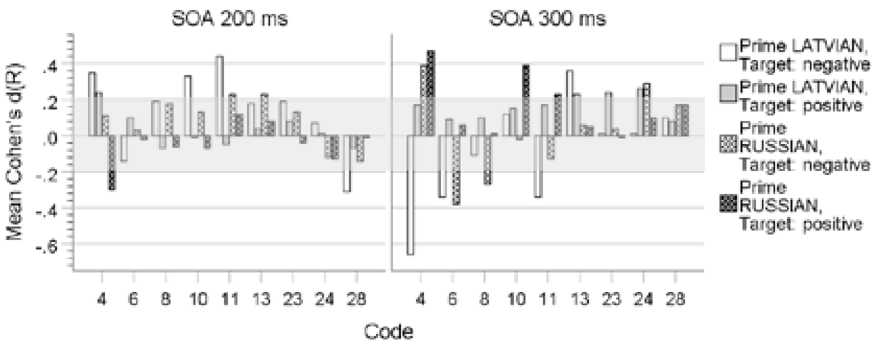

Fig. 1. Participations' Facilitation Variables: The Effect Sizes Cohen's d(R)

Table 1

Facilitation or Inhibition of the Task of Affective Classification of Target Stimuli in the Presence of the Prime Using One Sample t-test (N = 9, Test Value = 0)

SOA, ms	Prime	Target stimuli:	*d*(*R*)	*M*	*SD*	*t*	*df*	*p*-value (2-tailed)	The Effect
200	*Latvian*	*negative*	0.14	22.3	46.0	1.46	8	.18	not found
200	*Latvian*	*positive*	0.030	3.78	14.2	0.80	8	.45	not found
200	*Russian*	*negative*	0.087	16.8	27.1	1.86	8	.10	not found
200	*Russian*	*positive*	-0.048	-7.00	19.9	-1.06	8	.32	not found
300	*Latvian*	*negative*	-0.094	-17.7	60.7	-0.87	8	.41	not found
300	*Latvian*	*positive*	0.17	28.9	11.7	7.40	8	**.000**	**facilitation**
300	*Russian*	*negative*	0.017	-0.78	44.6	-0.052	8	.96	not found
300	*Russian*	*positive*	0.16	27.8	27.3	3.05	8	**.016**	facilitation

Table 1 shows both the mean values of Cohen's *d*(*R*) effect sizes and the results of comparing the means of variable *R* with zero c using the One Sample t-test, showing the presence of a priming effect (Rudman, 2011). For the entire sample, the facilitation effect is observed at SOA = 300 ms with positive target stimuli, both for the "Russian" prime and the "Latvian" prime.

The mean values of facilitation and inhibition effects for the entire sample are shown in Figures 2–3. For a given sample, they depend on the valency of target stimuli, primes, and SOA.

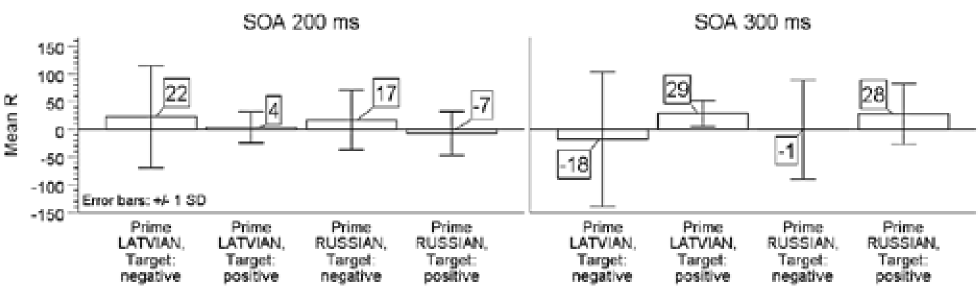

Fig. 2. The Means of Facilitation Scores

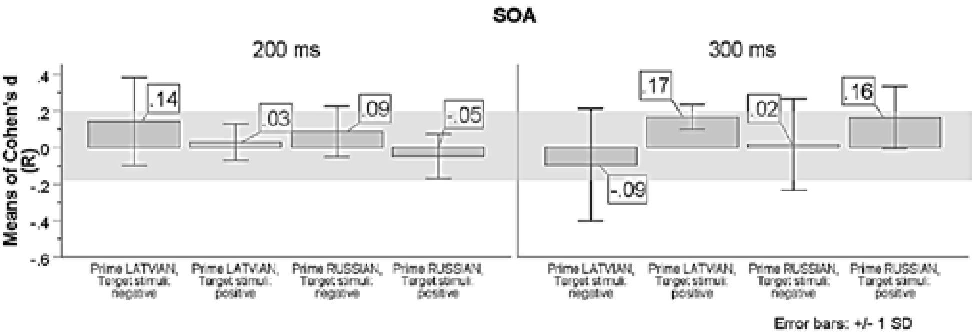

Fig. 3. Facilitation Scores: The Means of the Effect Sizes Cohen's d(R)

Attitude Variable *RR*

Each value of the *attitude variable RR = RR(Prime)* at fixed primes is defined as the difference between the mean values of the facilitation variables:

RR = RR(Prime) = R(Prime, Target Positive) – R(Prime, Target Negative).

If *RR(Prime)* >0, then the attitude is positive (in relation to prime).

If *RR(Prime)* < 0, then the attitude is negative.

When *RR(Prime)* = 0*,* the attitude is non-positive and non-negative (Plotka et al., 2016, 2023): it is possible that it is either ambivalent or unformed (s. Figures 4-6).

The absolute value *RR* characterizes the strength of the attitude in milliseconds.

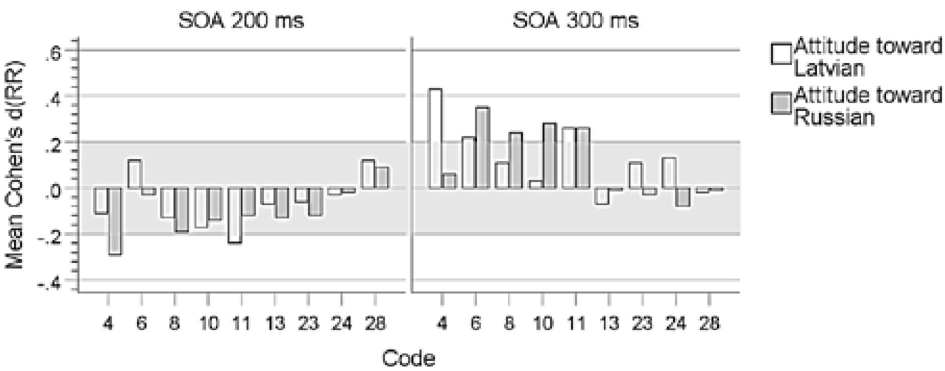

Fig. 4. Participations' Attitude Variable RR: The Effect Sizes Cohen's d(RR)

Figure 4 illustrates the in-group and out-group ethnic attitudes of participants, represented by Cohen's *d*(*RR*) effect sizes. When *d* > 0.2, the attitude is positive, and when *d* < -0.2, the attitude is negative (outside the gray strip, s. Figure 4). Attitudes are more pronounced at SOA = 300 ms.

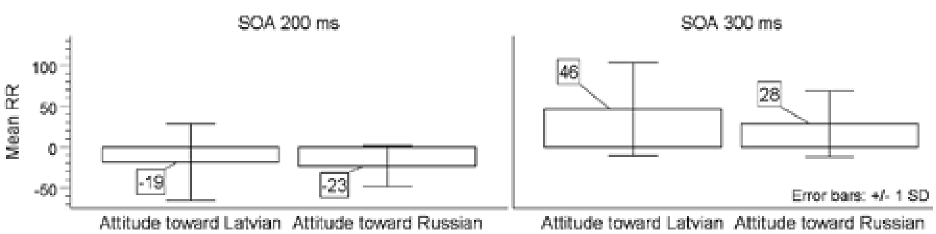

Fig. 5. The Means of Attitude Variable RR

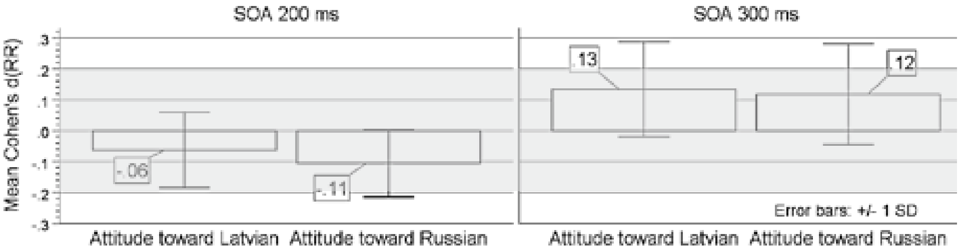

Fig. 6. The Means of Attitude Variable RR: The Effect Sizes Cohen's d(RR)

The second way to find the attitude is to compare the mean value of the *RR* variable with zero. Table 2 shows both the mean values of Cohen's *d*(*RR*) effect sizes and the results of comparing the means of variable *RR* with zero c using the One Sample t-test. Table 2 shows that at SOA = 200 ms, there is a negative ingroup attitude toward Russians. At SOA = 300 ms, there is a positive outgroup attitude toward Latvians (s. Figures 5–6).

Table 2

The Ethnic Attitures at Different SOA: One Sample t-test (N = 9, Test Value = 0)

SOA, ms	Prime	*d*(*RR*)	*M*	*SD*	t	df	*p*-value (2-tailed)	Attitude
200	*Latvian*	-0.063	-18.6	47.0	-1.18	8	.27	
200	*Russian*	-0.11	-23.3	25.3	-2.77	8	**.024**	negative
300	*Latvian*	0.13	46.4	57.2	2.44	8	**.041**	positive
300	*Russian*	0.12	28.4	40.4	2.11	8	.068	

Implicit Preference Variable RRR

Implicit preference variable, RRR, which is constructed on the basis of the third contrast according to Rudman (2011) and is the difference of the second order:

RRR = RRR(*Russian*) – RRR(*Latvian*).

If RRR > 0, there is an implicit preference for "Russian". If RRR < 0, there is an implicit preference for "Latvian".

The participants with codes 4 and 24 at SOA = 300 ms show the implicit preference of Latvians (Figure 7).

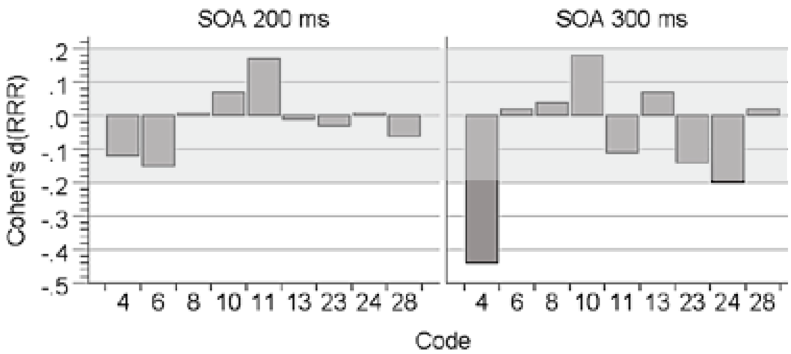

Fig. 7. Participations' Implicit Preference Variable, RRR: The Effect Sizes Cohen's d(RRR)

No implicit preferences were found in the entire sample (Table 3, Figures 8–9).

Table 3

The Implicit Preferences at Different SOA: One Sample t-test (N = 9, Test Value = 0)

SOA, ms	*d*(*RRR*)	*M*	*SD*	*t*	*df*	*p*-value 2-tailed
200	-0.012	-4.89	35.9	-0.41	8	0.69
300	-0.061	-17.7	57.7	-0.92	8	0.39

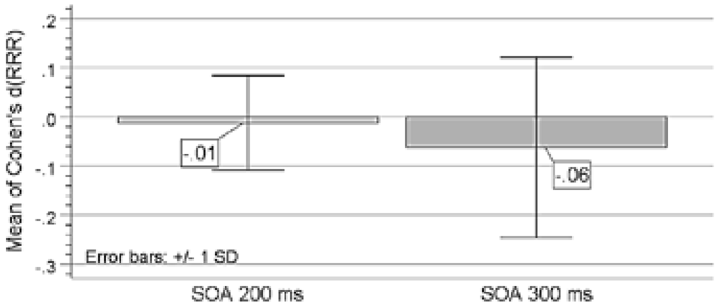

Fig. 8. The Means of Implicit Preference Variable RRR: the Effect Sizes Cohen's d(RRR)

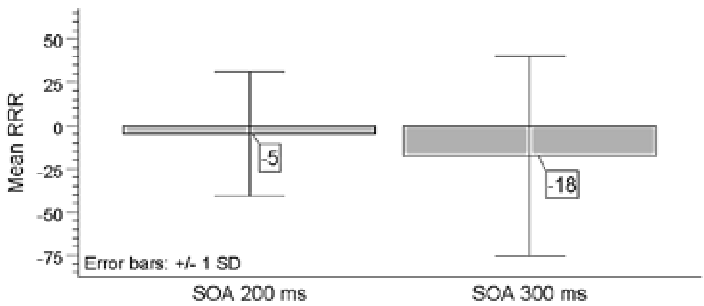

Fig. 9. The Means of Implicit Preference Variable RRR

EEG Results

TF and ERP analyses were performed for the selected electrode C3. Both quantitative and qualitative analyses were performed for the results obtained.

EEG recorded data were combined according to SEP experimental conditions: SOA (200 or 300 ms), primes (baseline, “Latvian”, “Russian”), target words – positive or negative.

Using the EEGLAB Study function at the level of primary responses of ERP and TF, statistical analysis was performed using „exact” statistical threshold parameters or p-values for the entire sample.

For the calculated variables R, RR and RRR, TF data were presented in qualitative form for the entire sample.

Group Analysis Using ERP Method

With different primes and SOAs, no statistically significant differences between ERPs for positive and negative target stimuli were found.

Some statistically significant ERP differences were observed for both SOAs for the “Latvian” prime. At the 200 ms SOA, statistically significant ERP differences were observed in the time interval between 50 and 200 ms, suggesting a potential relationship with stimulus processing. For both SOAs, statistically significant ERP differences were found within 1000 ms after the participant's response (Figure 11).

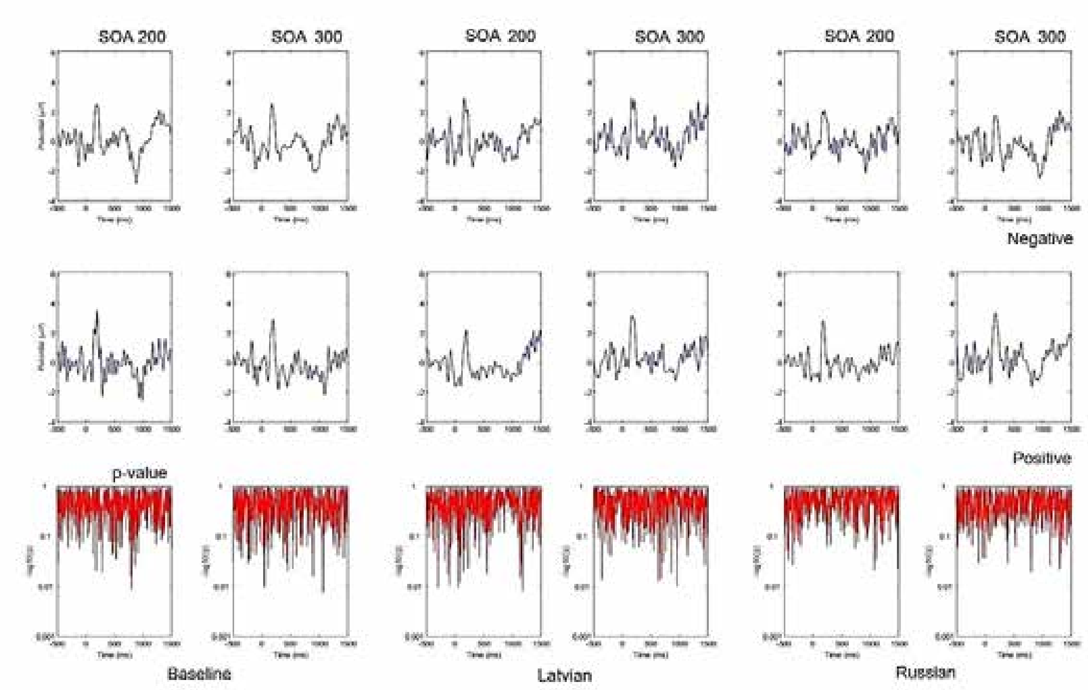

Fig. 10. C3 Electrode, ERP Plots of Different Stimulus Events (Baseline, Primes "Latvian" or "Russian", Positive and Negative Target Words) with p-Values; x-Axis: Time (ms), y-Axis: Amplitude (mkV)

A spike with a duration of approximately 200 ms (N200) was observed across all experimental conditions for both SOAs (Figures 10–11), potentially reflecting processing of the stimulus stream.

Figure 11 illustrates the procedures for calculating ERP data for variables R, RR, and RRR.

When using the prime "Russian", some ERP disturbances for variables R and RR are observed following the test subject's key press (post-response) in the 800–1200 ms time window (Figure 11).

One possible explanation for the absence of a 200 ms ERP spike across all experimental conditions might lie in the specific calculation procedures applied to the SEP variables (R, RR, RRR) patterns.

The early response window (around 250 ms), characterized by increased gamma activity in visual processing areas, has been interpreted as reflecting a mechanism that supports the integration of individual perceptual features into coherent object representations (Tallon-Baudry & Bertrand, 1999). Increased gamma power may be linked to stronger activation of sensory networks during stimulus encoding, which can positively influence memory formation (Hanslmayr et al., 2009). In turn, stronger memory activation may enhance the semantic network associated with implicit attitudes, while reduced gamma activity may indicate the opposite effect.

Group Analysis Using TF Method

In the first step, each event data TF was calculated (Figure 12). Differences in EEG frequencies over time were observed at all experimental variables or event levels.

Baseline negative events under SOA 300 ms showed beta and low gamma wave power decreasing or inhibition during negative stimulus presentation and key press moments, which was different from baseline positive events in the TF patterns.

Another interesting pattern was discovered with SOA 200 ms and positive target stimuli: at the primes "Russian" and "Latvian," gamma wave activation in the post- response period was more pronounced than at baseline.

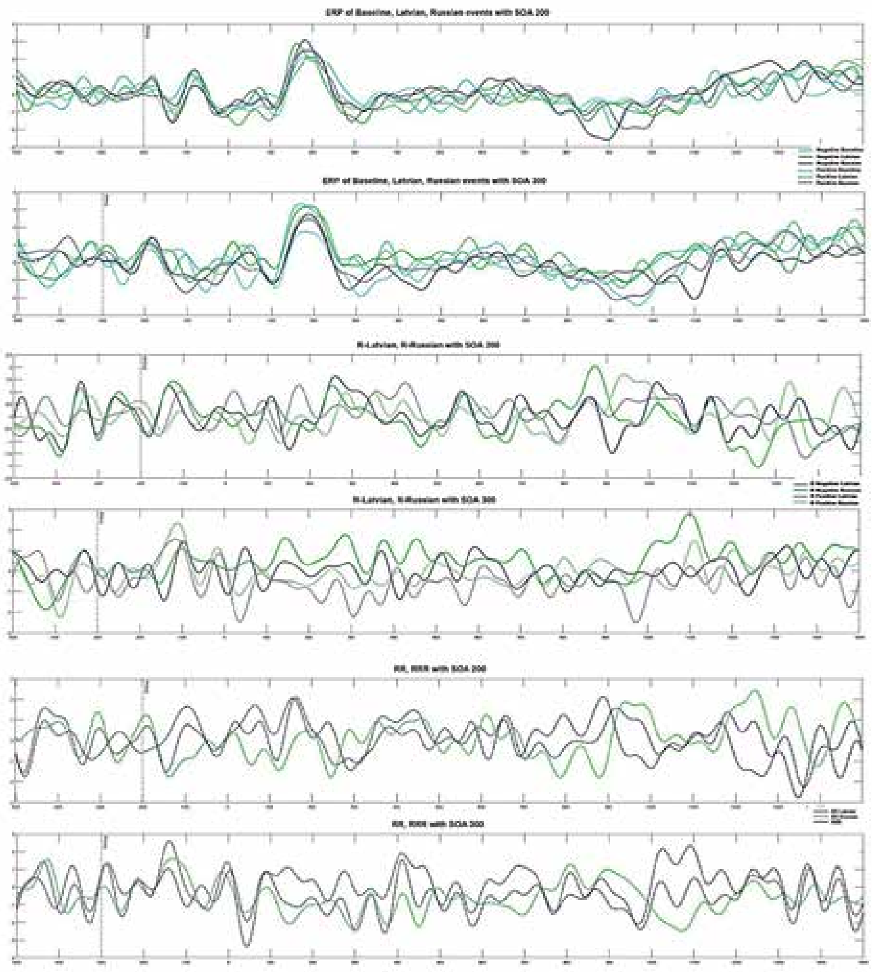

Fig. 11. C3 Electrode, ERP Plots, the R, RR, RRR Plots of Different Stimulus Events (Baseline, Primes "Latvian" or "Russian", Positive and Negative Target Words); x-Axis: Time (ms), y-Axis: Amplitude (mkV)

At the 200 ms and 300 ms SOA and prime "Latvian", gamma wave activation in the post-response period for a positive target stimulus differed more than baseline gamma wave activation for a negative target stimulus. This is consistent with the results obtained from behavioral implicit data for our pilot study.

The high differences in beta and gamma waves (15–48 Hz) in the post-response time period (800–1200 ms), especially in outgroup cases "Latvian" positive vs "Latvian" negative at SOA 200 ms ($p < .05$) were observed. At negative target stimuli, beta and gamma waves showed differences between SOA 300 ms and SOA 200 ms.

At prime "Latvian" and positive target stimuli, a tendency of differences in signal power at different SOAs was observed. This trend consists of desynchronization of theta waves (3-4 Hz) at SOA 300 ms in the time window up to about 500 ms and at 7 Hz in the time range between 550 and 1000 ms. In contrast, synchronization was observed in the low beta wave between 550 and 650 ms. Gamma wave desynchronization was observed at SOA 300 between 200 and 300 ms.

When processing negative target stimuli with prime "Latvian", more pronounced differences in signal strength were observed than in other cases considered, especially in the response time range (approximately 700 ms).

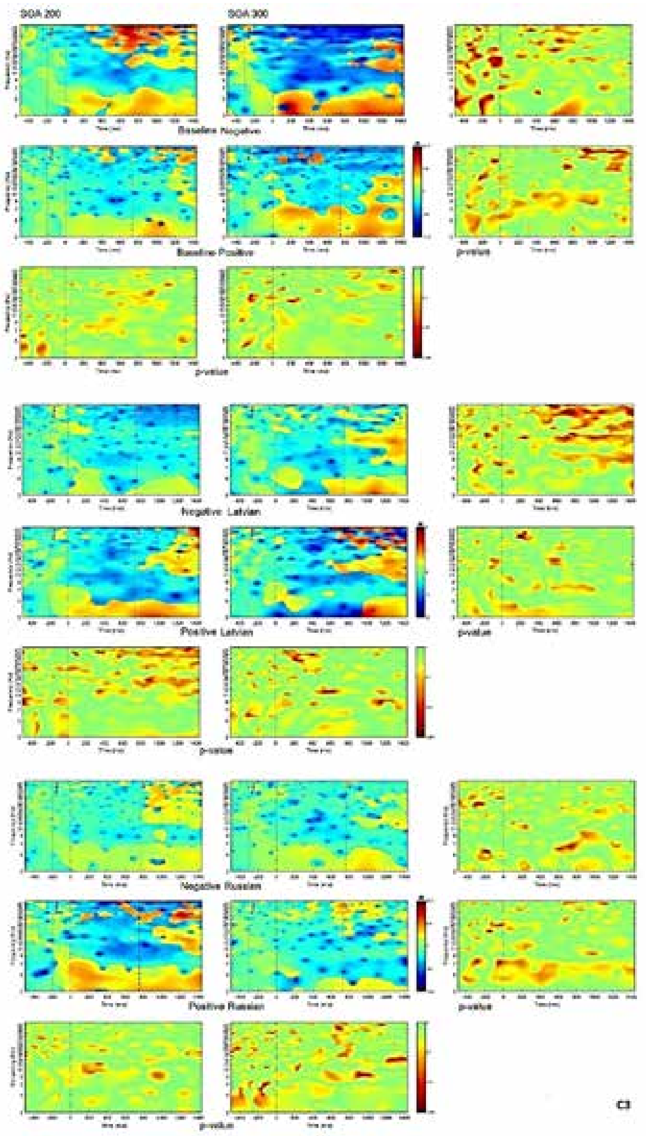

Fig. 12. C3 Electrode, TF Plots of Different Stimulus Events (Baseline, Primes "Latvian" or "Russian", Positive and Negative Target Words) with p-Values; x-Axis: Time (ms), y-Axis: Frequency (Hz)

In the time window from 400 to 600 ms, a region of differences between the two synchronization conditions was identified in the frequency ranges, including the alpha, beta, and gamma wave ranges, which was observed until the end of the signal recording time.

Noteworthy is the drop in signal strength, especially in the range up to 600 ms, in the theta wave region at SOA 300 ms compared to SOA 200 ms in at the prime "Russian" and positive target words. At prime "Russian" and negative target words, the focus of similar differences in neural activity shifts to the upper theta and lower alpha regions beyond 600 ms.

Group Analysis TF Matrix for R, RR and RRR Calculation

In the second step, the TF matrix data were processed according to the definitions of the variables R, RR and RRR.

Figure 13 illustrates the process of calculating R, RR and RRR. The qualitative data, represented by the image of these variables obtained with the TF, shows that in the case of the 200 ms SOA, the signal power at the positive target stimulus is lower than at the negative stimulus. This suggests that the negative target stimulus affects the RR values and, consequently, the RRR values.

The main effects were observed in beta and gamma waves at post-response time after 800 ms. Theta-delta wave synchronization was also observed at time intervals ranging from 400 to 800 ms at the prime “Latvian” and negative target stimulus in the TF patterns of R, RR and as a result in RRR.

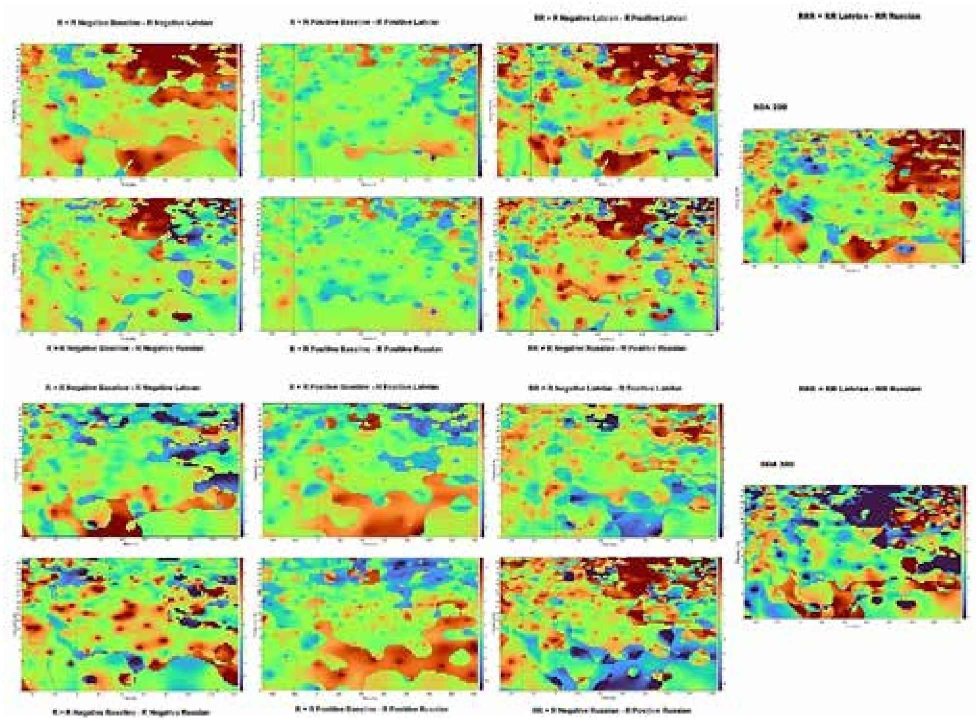

Fig. 13. C3 Electrode, TF Plots of R, RR, RRR Cases of Different Stimulus Events (Baseline, Primes “Latvian” or “Russian”, Positive and Negative Target Words); x-Axis: Time (ms), y-Axis: Frequency (Hz)

At SOA 300 ms, theta and delta waves synchronizations at both primes and positive target stimulus in the R-pattern were observed. But this is not expressed in RR and RRR patterns plots.

The main differences in the RRR pattern at different SOAs seem to be gamma waves with desynchronization at SOA 300 ms in the 400-800 ms time interval and synchronization at SOA 200 ms in the time interval after 800 ms. Similar synchronization of theta waves was observed in time intervals around 400-600 ms.

A comparative analysis of neural activity, calculated to obtain TF matrices in the case of RRR, revealed differences in neural responses to positive and negative target stimuli as well as to different primes. One notable feature was the emergence of lower gamma activity in the early response window (around 250 ms). Gamma desynchronization was observed in the case of the “Latvian” prime paired with a positive target stimulus at SOA 300 ms, while the “Russian” prime paired with a positive target stimulus showed gamma synchronization in the same time window.

Negative target stimuli paired with the “Latvian” prime exhibited gamma synchronization at SOA 300 ms, whereas those paired with the “Russian” prime did not show statistically significant changes in gamma power at this SOA.

In the experiment with this design, the processing of target words began at intervals after the presentation of the prime, to which the identified components of TF and ERP can correspond at the neural level. They can arise after 200 and 300 ms, as a stable neural response to the appearance of specific stimuli. It manifests itself in the peak amplitude variation of a neural signal in a specific brain area, which is recorded by means of EEG. Since the presentation of the prime, this peak neural response can coincide with the moment of presentation of the target word. In this case, subsequent cognitive processing of the target stimulus may be affected by this response.

This assumption is important for interpreting the obtained TF results. Gamma desynchronization for the "Latvian"–positive stimulus combination at SOA 300 ms, along with synchronization at SOA 200 ms, may suggest stronger activation of implicit attitudes in the latter case. Similarly, gamma synchronization for the "Russian"–positive stimulus combination at SOA 300 ms, combined with a lack of significant gamma power changes in response to negative stimuli across SOAs, may reflect a greater role of implicit associative processes in semantic memory at SOA 300 ms.

These findings are consistent with previous behavioral data, which showed activation of an ingroup "pro-Russian" implicit attitude at SOA 300 ms and an outgroup "pro-Latvian" attitude at SOA 200 ms (Plotka et al., 2016). Thus, the data provide evidence for the presence of neural markers of implicit ethnic attitudes in the lower gamma range, within a time window of approximately 250 ms at SOAs of 200–300 ms. However, further research is needed to draw definitive conclusions.

Study limitation was a small number of participants and only one ethnic group. The analysis was restricted to qualitative assessment of time-frequency and event-related potential patterns in SEP components (R, RR, RRR).

We anticipate future investigations integrating both qualitative and quantitative analyses of SEP-related TF variables (R, RR, RRR). The experimental design may incorporate ethnically stratified participant groups and subgroups under various SOAs showing priming effects.

The results seem to show that at SOA 200 ms and SOA 300 ms, different frequency patterns were present in the time-frequency data. This may indicate a preference for an ethnic group in the case of outgroup-congruent stimuli at SOA 300 ms, differing from the corresponding patterns at SOA 200 ms, which are associated with the influence of stimuli congruent with an alternative outgroup. The obtained results align with previous studies (e.g., Plotka et al., 2016; Amodio & Cikara, 2021; Amodio & Bartholow, 2011; Kubota & Ito, 2007).

Conclusion

Researchers in implicit social cognition and social neuroscience have highlighted the importance of investigating relationships between behavioral implicit measures and non-behavioral measures obtained through EEG methodology (Williams & Themanson, 2011; Healy et al., 2015; Perry, 2022; Huang et al., 2025).

The correspondence between ERPs and behavioral measures of implicit attitudes has primarily been examined using IAT procedures, but not with data from subliminal priming experimental paradigms (e.g., Willadsen-Jensen et al., 2008; Ibanez et al., 2010). The hypothesis proposed in previous studies (Plotka et al., 2016, 2017) requires verification at the non-behavioral (neural) level.

The current pilot study achieved its aim of exploring the potential utility of electroencephalography time-frequency analysis for assessing neural signals associated with measures of implicit ethnic attitudes in combination with subliminal evaluative priming procedures.

Our findings suggest the feasibility of using TF patterns of SEP variables (facilitation, attitudes, implicit preference) for both qualitative and, potentially, quantitative analysis. The study also demonstrates the possibility of integrating behavioral and non-behavioral data within a unified research framework.

The employed electroencephalography methods appear promising for investigating implicit ethnic attitudes. The results reveal distinctive neurophysiological responses to specially designed stimulus combinations used for measuring implicit ethnic attitudes.

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