



How multiple repetitions influence the processing of self-, famous and unknown names and faces: An ERP study

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ABSTRACT

Because we live in an extremely complex social environment, people require the ability to memorize hundreds or thousands of social stimuli. The aim of this study was to investigate the effect of multiple repetitions on the processing of names and faces varying in terms of pre-experimental familiarity. We measured both behavioral and electrophysiological responses to self-, famous and unknown names and faces in three phases of the experiment (in every phase, each type of stimuli was repeated a pre-determined number of times). We found that the negative brain potential in posterior scalp sites observed approximately 170 ms after the stimulus onset (N170) was insensitive to pre-experimental familiarity but showed slight enhancement with each repetition. The negative wave in the inferior-temporal regions observed at approximately 250 ms (N250) was affected by both pre-experimental (famous > unknown) and intra-experimental familiarity (the more repetitions, the larger N250). In addition, N170 and N250 for names were larger in the left inferior-temporal region, whereas right-hemispheric or bilateral patterns of activity for faces were observed. The subsequent presentations of famous and unknown names and faces were also associated with higher amplitudes of the positive waveform in the central-parietal sites analyzed in the 320–900 ms time-window (P300). In contrast, P300 remained unchanged after the subsequent presentations of self-name and self-face. Moreover, the P300 for unknown faces grew more quickly than for unknown names. The latter suggests that the process of learning faces is more effective than learning names, possibly because faces carry more semantic information.

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1. Introduction

Human beings live in an extremely complex social environment, and to function efficiently, they need to encode and retrieve hundreds or thousands of different names and faces on a regular basis. Classical models of face recognition (Bruce and Young, 1986; Burton et al., 1990) generally posit the following stages of this process: structural encoding; face recognition units (FRUs); person identity nodes (PINs); and semantic information units (SIUs). Structural encoding follows an initial pictorial analysis and consists of capturing the essential structural features of a face. If a face is known to the subject, it activates the FRU – a structural representation of a familiar face stored in long-term memory (LTM). This information is stored in LTM as a generic representation that takes into account the variability of viewpoints and changeable facial features. It is suggested that familiarity decisions are made at the level of FRU or at the level of the connection between FRU and PIN (Bruce and Young, 1986). Next,

the corresponding PIN is activated, which is a multimodal representation of the face bearer. When the person is identified, biographical knowledge about him or her (for example occupation or nationality) may also be retrieved (Burton et al., 1990). This retrieval is thought to entail the activation of SIUs.

Valentine et al. (1995) proposed a model of name processing based on Bruce and Young's (1986) model of face recognition and Morton's (1969, 1979) model of word-recognition. They suggested that the stages of name recognition correspond to respective mechanisms present in face recognition. Instead of the structural encoding of a face, the first step in name processing (and generally word processing) is word form analysis. Next, name recognition units (NRUs), equivalent to FRUs, are activated if the presented name is familiar. The same PIN and SIU may be accessed by means of NRUs, as in the case of FRUs for faces (Valentine et al., 1995).

Event-related potential (ERP) studies carried out within the framework of person-recognition models have identified several correlates of face and name recognition. For instance, the occipito-temporal negative deflection occurring in the posterior-temporal scalp sites approximately 170 ms after the stimulus onset (N170) was shown to be sensitive to face inversion but is unaffected by the

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familiarity of a face (e.g., Bentin et al., 1996; Rossion et al., 2000; Eimer, 2000; Schweinberger et al., 2004) or the number of stimuli repetitions (Schweinberger et al., 2002a,b, 2007; Pfützte et al., 2002; but see: Itier and Taylor, 2004b; Kaufmann et al., 2008; Guillaume et al., 2009; Heisz et al., 2006). Therefore, it is now widely recognized that N170 represents the analysis of a face's structural information (e.g., Carbon et al., 2005; Herzmann et al., 2004; Schweinberger et al., 2002a; Bentin and Deouell, 2000; Eimer, 2000) or a name's word form analysis (Bentin et al., 1999), both of which occur before the process reaches identity-specific representations.

Unlike N170, a subsequent negative waveform in the inferior-temporal scalp sites observed approximately 250 ms after the stimulus onset (N250) seems to be sensitive to both the pre- and intra-experimental familiarity of social stimuli. N250 amplitude was found to be greater for familiar as compared to unfamiliar faces, especially in the right hemisphere (e.g., Pfützte et al., 2002; Schweinberger et al., 2002a). This wave has also been shown to occur in reaction to written familiar names, an effect present mainly in the left inferior-temporal region (Pickering and Schweinberger, 2003; Sommer et al., 1997). Moreover, N250 was not modulated by associative priming (i.e., processing of a stimulus is facilitated by a preceding semantically-related stimulus, e.g., Gorbachev's face facilitates the processing of Yeltsin's face), which supports the view that in person-recognition models, N250 could reflect the activation of pre-semantic stages, i.e., FRUs and NRUs (Schweinberger, 1996).

Finally, ERPs for familiar names and faces are typically characterized by increased central-parietal positivity, which starts approximately 300 ms after the stimulus presentation (Bentin and Deouell, 2000; Eimer, 2000; Paller et al., 2000). The amplitude of this waveform was shown to be modality independent because it shows similar amplitude for names and for faces (Schweinberger, 1996). Although this late central-parietal positivity is probably associated with the familiarity of any given stimulus, it has also been hypothesized to reflect the access to PIN and SIU nodes (Paller et al., 2000).

The majority of the previous studies in this field have focused on the processing of familiar names and faces (e.g., names or faces of celebrities). With this procedure, however, it is impossible to fully control the pre-experimental familiarity of such stimuli (Herzmann and Sommer, 2007). Therefore, researchers have started to investigate the recognition of names and faces which were learned experimentally. Apart from posing methodological issues, such studies seem to highlight the formation of NRUs or FRUs, which is intriguing in itself.

For example, in the first part of Tanaka et al.'s (2006) study, subjects were asked to memorize the face of an unknown person called "Joe" for male subjects or "Jane" for female subjects. In the second part of the experiment, subjects identified series of faces presented to them as either "Joe"/"Jane" or "not-Joe"/"not-Jane". Joe's/Jane's face was presented along with the subject's own face and a same-sex "Other's" face. The ERP analyses showed that the subject's own face produced an N250 in both the first and the second part of the study. Moreover, in the first part of the study, the ERPs for Joe's/Jane's face could not be differentiated from the ERPs for Other's faces. However, in the second part of the study, Joe's/Jane's face produced an N250 that was similar in magnitude to the one produced by the subject's own face. Based on these findings, it was suggested that N250 is sensitive to two types of familiarity: pre- and intra-experimental. As far as the late (400–600 ms) central-parietal positivity was concerned, it was found that Own and Joe/Jane conditions had greater amplitude than the Other condition. Moreover, a significant difference was found between the two former conditions (Joe > Own), and this difference seemed to be greater in the second half than in the first half of the study. These results suggest that the amplitude of late central-parietal waveform, apart from pre- and intra-experimental familiarity, is also sensitive to task-relevance.

In a study by Paller et al. (2000), subjects were memorizing 40 faces (all of them were unfamiliar; half were supplemented with

additional semantic information about the person and half were presented without any commentary). In the test phase, the task was to discriminate between old and new faces. Increased central-parietal positivity occurring between 300 and 600 ms was found for both types of learned stimuli, but was stronger for faces which had been presented with additional semantic information. These results support the view that the late central-parietal positivity might reflect the activation of PINs and SIUs.

Another experiment that is seemingly highly relevant in this context was performed by Kaufmann et al. (2008). First, subjects viewed video clips of unknown people (with or without verbal commentary providing semantic information about the people) and then performed a two-choice familiarity task (learned vs. novel). The test phase consisted of four trial blocks, with every face being repeated one time in each block. To disentangle face vs. image learning, in each block, a different image of the previously learned face was used. The study found an increased amplitude of N250 and increased central-parietal positivity in subsequent phases of the study. Moreover, the faces provided with semantic information were associated with a more positive amplitude between 700 and 900 ms after the stimulus onset than faces presented without any commentary. In general, this study supported the role of temporal N250 in the acquisition of new face representation and suggested that additional semantic information provided during the learning phase could facilitate the post-perceptual analysis of learned faces.

Finally, in a study by Herzmann and Sommer (2007), subjects were first familiarized with a set of unknown names and faces. A week later, they were asked to decide whether faces or names shown to them were 'new' or 'old'. It is noteworthy that a target face could have been either primed (the same stimulus presented) or unprimed (other stimulus presented). Subjects were instructed to ignore the primed stimuli. The analyses showed that priming significantly influenced RTs and triggered the early repetition effect (ERE/N250r) for learned but not for novel faces and names. These results suggest that the new representations of learned stimuli had been created in LTM. Moreover, the late repetition effect (LRE/N400), commonly associated with the activation of PINs and SIUs (e.g., Boehm and Paller, 2006), was observed for both learned faces and learned names. The authors suggested that, although no semantic information had been provided with these stimuli during the learning session, information about gender, mood, attractiveness or even idiosyncratic reminiscences regarding familiar persons (e.g., "This person looks like my friend!") might be derived directly from each unfamiliar face or name, thus giving rise to the LRE.

Because faces contain more semantic information than names (gender, attractiveness, age, race, mood vs. nationality and gender), it could be hypothesized that the formation of PINs and SIUs, but not NRU or FRU (pre-semantic stages), should be more effective for faces than for names. As mentioned earlier, N250 and late central-parietal positivity (P300; Tanaka et al., 2006; Guillaume et al., 2009) have been commonly associated with the activation of NRUs/FRUs and PINs/SIUs, respectively. Therefore, if the above hypothesis was true, the amplitude of N250 should increase similarly after the subsequent repetitions of unknown names and faces, whereas the amplitude of P300 should increase faster for unknown faces than for unknown names.

However, as mentioned earlier, some studies have reported that the P300 amplitude is similar for a name and for a face of a given person (e.g., Schweinberger, 1996) which suggests that subsequent repetitions would have a similar effect on P300 amplitude for names and for faces. We hypothesized that this inconsistency in predictions could be related to the pre-experimental familiarity of social stimuli. While seeing a name of a familiar person, subjects could easily retrieve the image of this person's face and vice versa. In contrast, in the case of an unknown name or an unknown face, the retrieval of past associations is not possible (there is no name-face association in LTM and the information 'within' a given stimulus is the only available). Therefore, if the efficiency of learning (or strengthening of the existing representations in the case of

familiar stimuli) is different for names vs. faces, this effect should be stronger for unknown stimuli than for familiar ones. Furthermore, if this phenomenon was related to the semantic information carried by the stimulus, it should appear at the level of semantic (PIN/SIU) but not pre-semantic (FRU/NRU) stages of person-recognition process.

In sum, the aim of this study was to investigate two hypotheses: (1) after multiple repetitions, the pace of the P300 increase, but not the N250 increase, should be greater for faces than for names; and (2) this effect should be stronger for unknown stimuli than for familiar stimuli. To gain a holistic perspective on these issues, we analyzed reaction times (RTs), accuracy rates, P100, N170, N250 and P300 in reaction to own, famous and unknown names and faces in three phases of the study (in every phase, each stimulus was repeated a pre-determined number of times).¹

2. Methods

2.1. Participants

Thirty right-handed volunteers (15 male and 15 female) between 22 and 38 years of age (mean = 27.4; SD = 3.7) participated in this study. None of them had ever changed their first or last name. Handedness was confirmed with the Edinburgh Inventory (Oldfield, 1971). The participants were either PhD students or employees of the Nencki Institute of Experimental Biology, Warsaw, Poland. They did not have any neurological dysfunctions and had normal or corrected-to-normal vision. None of the subjects had any previous experience with the task. Due to technical problems in data acquisition, three of the subjects were excluded from the study. Another five subjects were removed from the analyses because of insufficient (<15) number of EEG epochs (see the ERPs analysis section). As a result, a total of 22 subjects were included in the analyses (10 male and 12 female; mean age: 26.2, SD = 4.2).

The experimental protocol was approved by the Bioethics Committee of Warsaw Medical University, and informed consents were obtained from all subjects prior to the study. The subjects were paid PLN 100 (approximately \$30) for their participation.

2.2. Stimuli

All the stimuli (names and faces) were presented visually. They were displayed in central vision on a 19-inch NEC MultiSync LCD 1990Fx monitor. We used Presentation® software (Neurobehavioral Systems, Albany, CA, USA) for stimulus presentation and measurement of the subjects' responses.

The set of names consisted of 240 compounds of first and last names (further referred to as "names"), written in white block capitals (Arial, 30 pt) against a black background. The size of the stimuli ranged from 2° × 2° to 2° × 6°. They belonged to three categories: (1) the subject's own name (60 presentations), (2) names of famous people from various fields, e.g., politics, entertainment, sports (20 different names, each repeated 3 times, resulting in 60 presentations within this category), and (3) unknown names (40 different names, each repeated 3 times, resulting in 120 presentations within this category). Although there were three categories of names, the subjects performed a two-choice recognition task: familiar vs. unfamiliar, with self-name being treated as a familiar name. The number of presentations was adjusted to make each type of response equally probable (i.e., 120 familiar and 120 unfamiliar names). The mean length of the famous names was 13 letters (SD = 2.8), of unknown ones – 13 letters (SD = 2.5) and of the subjects'

own names – 14 letters (SD = 2.9). No significant differences in the length of stimuli were found between categories.

The set of face stimuli also consisted of 240 images. They were grey-scaled pictures of faces (extracted from the original background so that only the face, ears and hair were visible) displayed against a black background. The size of the stimuli ranged from 4° × 4° to 4° × 5°. In parallel with the name stimuli, the face stimuli belonged to three categories: (1) the subject's own face (60 presentations), (2) faces of famous people from various fields, e.g., politics, entertainment, sports (20 different faces, each face was repeated 3 times, resulting in 60 presentations within this category), and (3) unknown faces (40 different faces, each face repeated 3 times, resulting in 120 presentations within this category). The photographs of the subjects had been taken three weeks before the study (participants had not seen the pictures before the experiment), whereas the photographs of famous and unknown persons had been downloaded from the Internet. We normalized the luminance of all pictures by matching their color statistics to the same image (arbitrarily chosen from the stimuli set).

In both parts of the experiment, we used names and faces of the same famous people (e.g., Albert Einstein's name and the image of his face). In addition, the number of female and male names within the famous and unknown categories was equal. The order in which the two parts were carried out was counterbalanced: half of the subjects were assigned the name recognition task first while the other half were asked to start off with face recognition. The two parts were separated with a pause of 10 min. To prevent habituation, the order in which the stimuli were presented within each part was pseudo-randomized, so that no more than three names or faces of the same category were presented consecutively. The number of intervening stimuli between the subsequent presentations of a particular face/name was different for different names and faces (both across and within categories).

2.3. Experimental procedure

The participants were seated in an acoustically and electrically shielded dark room at a distance of 60 cm from the computer monitor. They were asked to indicate whether they knew the identity of the person whose name/face was presented to them or not. They were to respond as quickly and accurately as possible by pressing one of two buttons on a Cedrus response pad (RB-830, San Pedro, CA, USA). The participants used only the index and the third finger of the right hand to press the keys (the keys were not counterbalanced between the subjects).

Having read instructions displayed on the computer screen, the participants started the experiment by pressing a button. After the presentation of a fixation point (a white 'x' against a black background) for 200 ms and a blank screen for 100 ms, a target item (name or face) was displayed for 300 ms. Next, the participants were shown a blank screen for 1700 ms, in which time they were to give a response. The inter-trial interval (ITI) was 100, 200 or 300 ms, and as a consequence the interstimulus interval (ISI) was 2100, 2200 or 2300 ms, respectively. Various ITI/ISI were supposed to prevent situations in which a readiness potential influenced the electrophysiological responses related to cognitive processes. Each part of the experiment lasted about 9 min without the pause.

2.4. EEG recordings

EEG was continuously recorded from 62 scalp sites using a 136-channel amplifier (QuickAmp, Brain Products, Enschede, The Netherlands) and BrainVisionRecorder® software (Brain Products, Munich, Germany). Ag–AgCl electrodes were mounted on an elastic cap (ActiCAP, Munich, Germany) and positioned according to the extended 10–20 system. Electrode impedance was kept below 5 kΩ.

¹ Part of the data from this experiment has been used to investigate another research question – we compared P300 responses specifically to self-name and self-face without including the repetition factor, i.e., without separating the data into three phases (Tacikowski and Nowicka, 2010).

The EEG signal was recorded against an average of all channels calculated by the amplifier hardware. The sampling rate was 500 Hz.

2.5. Behavioral data analysis

Responses were scored as correct if the appropriate key was pressed within 150–2000 ms after the stimulus onset. Pressing the wrong key or pressing no key at all was treated as an incorrect response. To investigate how the repetition rate influenced the accuracy rate and the RTs, we divided the data into three subsequent phases: initial, intermediate and final, each representing one-third of the trials from each category.

As mentioned earlier, self-name and self-face were repeated 60 times throughout the whole study (20 times in each phase), whereas each famous or unknown name/face occurred only 3 times (once in each phase). In order to avoid any misinterpretations at the results level (i.e., differences between categories deriving not from the differences in familiarity, but varying repetition rates), we performed two separate ANOVAs, one for self-related stimuli and the other for famous and unknown ones. As a consequence, to analyze RTs and the accuracy rate for self-name and self-face we used two-way repeated-measures ANOVA, where the type of stimuli (two levels: names and faces) and repetition (three levels: initial, intermediate and final) were the factors. The ANOVA for famous and unknown stimuli, in turn, included the additional factor of familiarity (two levels: famous and unknown). RTs were averaged across correct trials only. All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity according to the [Greenhouse and Geisser \(1959\)](#) formula. T-tests with Bonferroni correction for multiple comparisons were applied on post-hoc analyses. The results are reported, with significance accepted at $p < 0.05$.

2.6. ERP analysis

Off-line analysis of the EEG was performed using BrainVisionAnalyzer® software (Brain Products, Gilching, Germany). The first step in the data preprocessing was the correction of ocular artifacts using Independent Component Analysis, i.e., ICA ([Bell and Sejnowski, 1995](#)). After the decomposition of each data set into maximally statistically independent components, based on the visual inspection of the component map (see: [Jung et al., 2001](#)), the components representing eye blinks were rejected. Ocular-artifact-free EEG data were obtained by back-projecting the remaining ICA components as a result of multiplying them using the reduced component mixing matrix. Butterworth zero phase filters were then implemented: high-pass – 0.5 Hz, 12 dB/oct; low-pass – 30 Hz, 12 dB/oct; and notch filter – 50 Hz. Next, the EEG was segmented to obtain epochs extending from 200 ms before to 1500 ms after the stimulus onset (baseline correction from –200 to 0 ms). In the automatic artifact rejection, the maximum permitted voltage step per sampling point was 50 μV . In turn, the maximum permitted absolute difference between two values in the segment was 300 μV . The minimum and maximum permitted amplitudes were –200 μV and 200 μV , respectively, and the lowest permitted activity was 0.5 μV . The average reference was used.

The ERPs for self-, famous and unknown names and faces in subsequent phases were computed for correct trials only (a special “macro” was run to select those epochs). The mean number of segments which passed the artifact rejection procedure and which represented correct responses from the subjects, was as follows (\pm refers to the standard deviation): self-name (initial: 19 ± 2 ; intermediate: 18 ± 1 ; final: 19 ± 1); famous names (initial: 18 ± 2 ; intermediate: 17 ± 2 ; final: 19 ± 2); unknown names (initial: 34 ± 4 ; intermediate: 38 ± 3 ; final: 36 ± 2); self-face (initial: 19 ± 1 ; intermediate: 18 ± 1 ; final: 19 ± 1); famous faces (initial: 17 ± 1 ; intermediate: 17 ± 2 ; final: 18 ± 2); and unknown faces (initial: 34 ± 4 ; intermediate: 37 ± 5 ; final: 34 ± 5). The minimal number of segments was as follows:

self-name (initial: 16; intermediate: 17; final: 19); famous names (initial: 15; intermediate: 15; final: 15); unknown names (initial: 22; intermediate: 26; final: 28); self-face (initial: 17; intermediate: 16; final: 17); famous faces (initial: 15; intermediate: 15; final: 15); and unknown faces (initial: 24; intermediate: 24; final: 20).

To analyze the P100, N170, N250 and P300, we used the mean amplitude values, which were calculated as the mean of all values at each time point within a certain interval. This method reportedly produces results that are less affected by potentially low signal-to-noise ratio than peak measures ([Luck, 2005](#)). Based on the visual inspection of grand-average ERPs and on the existing literature, we selected the following time-windows: P100 (80–130 ms after the stimulus onset), N170 (130–220 ms), N250 (220–320 ms) and P300 (320–900 ms). We analyzed the scalp regions in which the aforementioned ERP components were previously reported: P100 in the central-occipital region (pooled data from the O1, O2 and Oz electrodes), N170 and N250 in the left and right inferior-temporal electrodes (pooled data from the TP9/TP10, P7/P8 and PO7/PO8 electrodes) and P300 in the central-parietal region (pooled data from the C1, Cz, C2, P1, Pz, P2, CP1, CPz and CP2 electrodes) (see: [Herzmann et al., 2004](#); [Schweinberger et al., 2002b, 2006](#); [Tanaka et al., 2006](#); [Kaufmann et al., 2008](#)). There are two reasons why the collapsing data across nearby recording sites is appropriate in the present study: (1) it reduces the number of degrees of freedom in the repeated-measures ANOVA, which prevents the loss of statistical power ([Gevins et al., 1995, 1996](#)); and (2) it implicitly recognizes the limits of functional localization of scalp-recorded ERPs, e.g., many ERP components are generated by widespread populations of neurons, there are individual differences in head size and shape as well as brain's morphology between participants, etc. (adapted from: [Ullsperger et al., 2000](#)).

Mirroring the behavioral data analysis, we performed separate analyses for self- and other-related stimuli. As a result, the ANOVA for self-name and self-face contained two factors: the type of stimuli (two levels: names and faces) and repetition (three levels: initial, intermediate and final). To analyze ERPs for famous and unknown names and faces, we applied a three-way repeated-measures ANOVA, where the type of stimuli (two levels: names and faces), the familiarity (two levels: famous, unknown) and the repetition (three levels: initial, intermediate and final) were the factors. Importantly, the ANOVA for N170 and N250 contained an additional factor, the hemisphere, as it was measured in both the left and the right inferior-temporal regions. All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity according to the [Greenhouse and Geisser \(1959\)](#) formula. T-tests with Bonferroni correction for multiple comparisons were applied on post-hoc analyses. The results of post-hoc analyses are reported, with significance accepted at $p < 0.05$.

3. Results

3.1. Behavioral data

[Fig. 1A](#) demonstrates RTs to three types of names and faces in all three phases of the study. The ANOVA on RTs to self-related stimuli revealed only the main effect of repetition ($F_{2,42} = 42.64$; $p = 0.0001$; $\eta^2 = 0.67$). Post-hoc analyses showed that in the final phase of the study, participants recognized their own names and faces faster than in the initial and intermediate phases.

The ANOVA on RTs to famous and unknown stimuli showed the main effect of the type of stimuli ($F_{1,21} = 17.03$; $p = 0.0001$; $\eta^2 = 0.45$), familiarity ($F_{1,21} = 22.57$; $p = 0.0001$; $\eta^2 = 0.52$) and repetition ($F_{2,42} = 57.2$; $p = 0.0001$; $\eta^2 = 0.73$). No significant interactions were found. Post-hoc analyses demonstrated that: (1) faces were generally recognized quicker than names; (2) participants responded faster to famous than to unknown names and faces; and

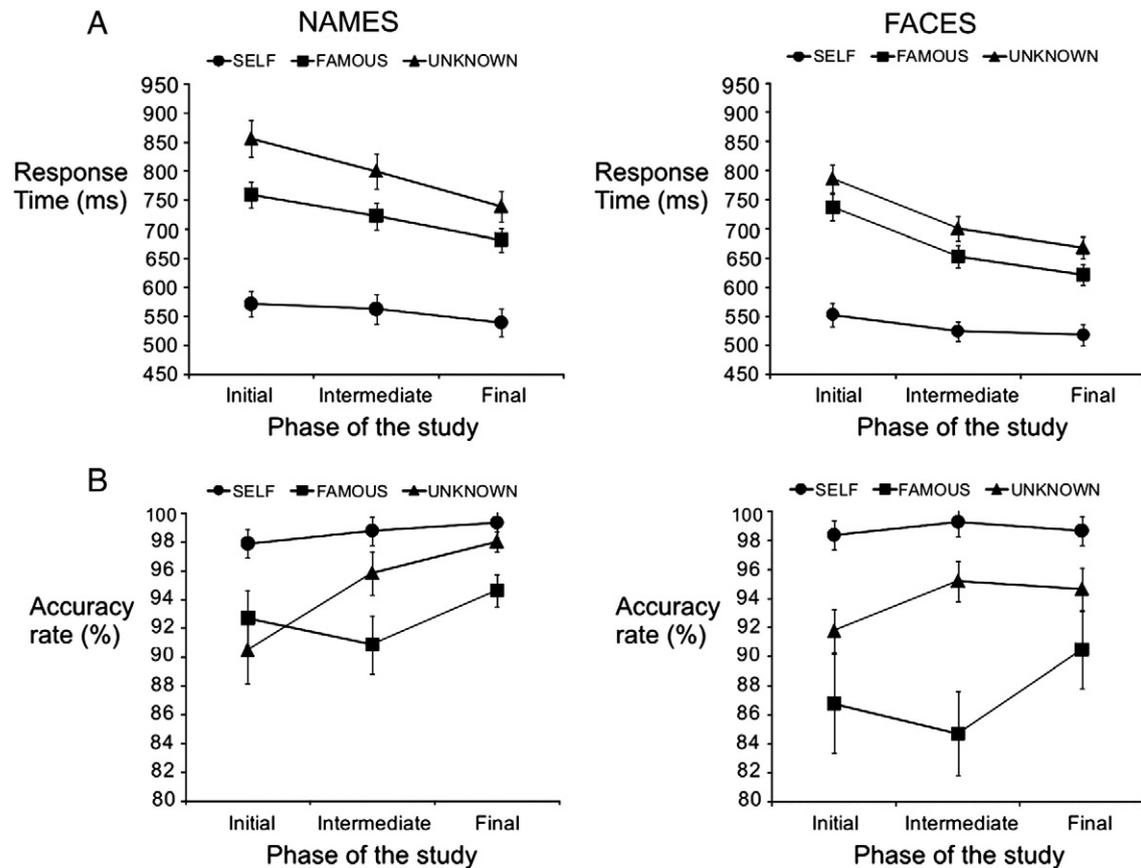


Fig. 1. Reaction times (A) and accuracy rates (B) in response to self-, famous and unknown names and faces in each phase of the study (the error bars represent the standard error of the mean – SEM). Statistical analysis confirmed that with each phase of the study, the subjects were generally responding faster and more accurately. This facilitation, however, was stronger for famous and unknown names and faces than for self-name and self-face.

(3) RTs were generally shorter as the number of repetitions was growing (initial > intermediate > final).

Fig. 1B illustrates the accuracy rate of responses to the three types of names and faces in the three phases of the study. The ANOVA on accuracy rates for self-related stimuli did not show any significant effects or interactions. In turn, the statistical analysis of the accuracy rate for famous and unknown names and faces revealed the main effect of familiarity ($F_{1,21} = 4.96$; $p = 0.04$; $\eta^2 = 0.19$) and repetition ($F_{2,42} = 14.04$; $p = 0.0001$; $\eta^2 = 0.42$), as well as a repetition \times familiarity interaction ($F_{2,42} = 6.97$; $p = 0.002$; $\eta^2 = 0.25$). Post-hoc analyses showed that unknown stimuli were recognized better than famous ones, but only in the intermediate and final phase (in the initial phase, this difference was not significant). Moreover, for famous stimuli, there was a significant increase in the recognition rate between the intermediate and final phase, whereas in the case of unknown stimuli such an increase occurred between the initial and intermediate/final phase.

3.2. Electrophysiological data

3.2.1. An overview of results

Our study demonstrated that faces were associated with larger P100 amplitude than names. We also found that names produced larger N170 response in the left inferior-temporal region, whereas faces elicited larger responses in the right inferior-temporal region. Moreover, the amplitude of N170 increased with each repetition. The amplitude of N250, in turn, was modulated by the number of repetitions (the more repetitions, the larger N250), pre-experimental familiarity (larger N250 for famous than for unknown stimuli) and by the hemispheric specialization (larger N250 for names, especially in the left inferior-temporal region). We did not find any significant

differences in the pace of N250 increase after multiple repetitions for self-, famous or unknown stimuli. As far as the analysis of P300 is concerned, we found that its amplitude was larger for famous than for unknown stimuli. Moreover, P300 was larger in the later phases than in the earlier phases of the study but only for famous and unknown social stimuli (i.e., the amplitude of P300 for self-related stimuli remained stable over the phases). We also found that after subsequent repetitions, the amplitude of P300 for unknown faces grew faster than for unknown names. A similar pattern occurred for famous stimuli, however, the effect was weaker (it constituted only a statistical trend). No such differences occurred for self-related stimuli. A detailed description of our ERP results is provided below.

3.2.2. P100

As mentioned in the [Methods](#) section, P100 was measured in the central-occipital region (pooled data from the O1, Oz and O2 electrodes). The ANOVA on the mean amplitudes for self-name and self-face showed significant modulations to the type of stimuli ($F_{1,21} = 40.74$; $p = 0.0001$; $\eta^2 = 0.66$). The main effect of the type of stimuli ($F_{1,21} = 39.78$; $p = 0.0001$; $\eta^2 = 0.66$) was also found for famous and unknown names and faces. Post-hoc analyses in both cases confirmed that the processing of faces was associated with significantly greater P100 amplitude than the processing of names (Fig. 2).

3.2.3. N170 for self-name and self-face

The amplitude of the N170 waveform was measured in the left and right inferior-temporal regions (TP10/TP9, P7/P8, and PO7/PO8). The main effect of the type of stimuli ($F_{1,21} = 10$; $p = 0.005$; $\eta^2 = 0.32$) and repetition ($F_{2,42} = 15.5$; $p = 0.0001$; $\eta^2 = 0.43$) was found, as well as a hemisphere \times type of stimuli interaction ($F_{1,21} = 26.57$; $p = 0.0001$; $\eta^2 = 0.56$). Post-hoc analyses revealed that the amplitude of N170 for

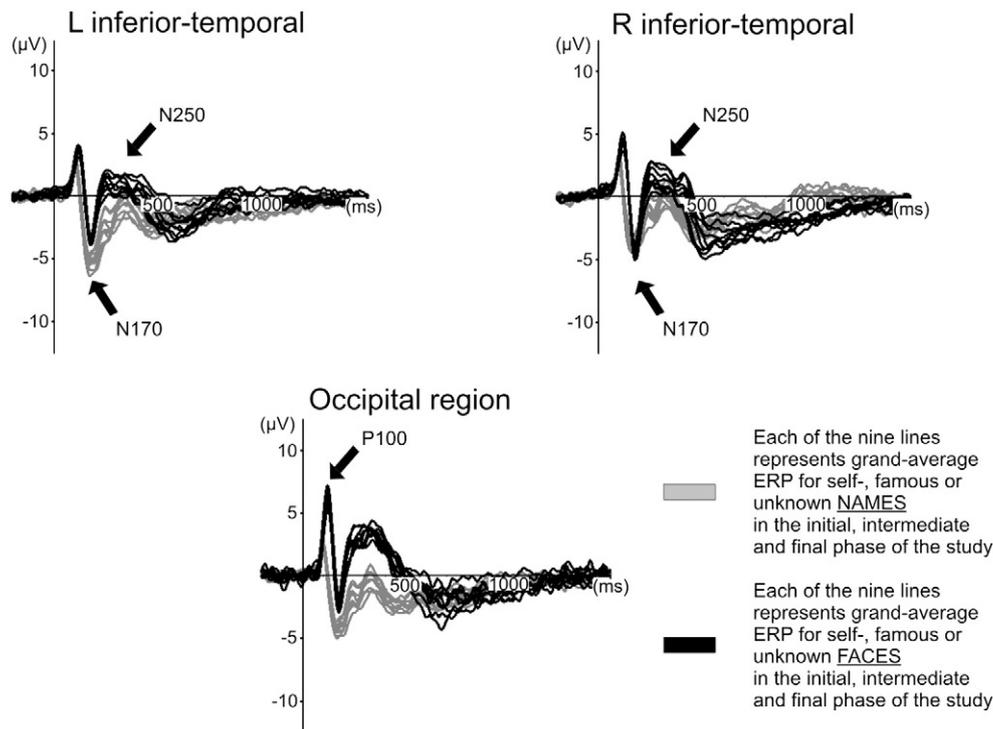


Fig. 2. Grand-average event-related potentials (ERPs) for self, famous and unknown names (grey lines) and faces (black lines) in all three phases of the study. The panels present pooled data from the central-occipital (O1, Oz, and O2), as well as left and right inferior-temporal regions (TP9/TP10, P7/P8, and PO7/PO8). As shown, the processing of names vs. faces differed in the early ERP components, such as P100 and N170. Regardless of the study phase or the familiarity of a stimulus, P100 in the central-occipital region was greater for faces than for names. As for the amplitude of N170, names and faces showed reverse patterns of activity depending on the hemisphere: in the left inferior-temporal region N170 for names was stronger than for faces, whereas in the right inferior-temporal region N170 for faces was stronger than for names. Finally, N250 was higher for names than for faces, especially in the left hemisphere. No inter-hemispheric differences in the N250 amplitude were found for faces.

both self-name and self-face was greater (more negative) in the final than in the initial phase of the study (final > initial). Moreover, self-name processing was associated with a stronger N170 response in the left than in the right inferior-temporal region. An opposite effect (more intense N170 in the right than in the left hemisphere) was found for self-face.

3.2.4. N170 for famous and unknown names and faces

The main effect of the type of stimuli ($F_{1,21} = 9.2$; $p = 0.006$; $\eta^2 = 0.3$) and repetition ($F_{2,42} = 17.35$; $p = 0.0001$; $\eta^2 = 0.45$) was found, along with a hemisphere \times type of stimuli interaction ($F_{1,21} = 8.32$; $p = 0.009$; $\eta^2 = 0.28$). Post-hoc analyses revealed that, regardless of the stimulus condition, the amplitude of N170 was generally greater in the final and intermediate phases of the study than in the initial one (final, intermediate > initial). Again, names were associated with greater N170 amplitude than faces in the left hemisphere, while in the right inferior-temporal region, the N170 for faces was greater than for names (see Fig. 2). The latter, however, reached only the level of a statistical trend ($p < 0.1$).

3.2.5. N250 for self-name and self-face

Fig. 3 demonstrates N250 for self-, famous and unknown names and faces in the three phases of the study. Analogously to the N170 waveform, this component was analyzed in the left and right inferior-temporal regions. The ANOVA on N250 mean amplitudes for self-name and self-face revealed the significant main effect of hemisphere ($F_{1,21} = 6.78$; $p = 0.017$; $\eta^2 = 0.24$), type of stimuli ($F_{1,21} = 31.63$; $p = 0.0001$; $\eta^2 = 0.6$) and repetition ($F_{2,42} = 10.3$; $p = 0.0001$; $\eta^2 = 0.33$). No significant interactions were found. Post-hoc comparisons demonstrated that N250 was greater (more negative): (1) in the left than in the right inferior-temporal region; (2) for self-name than for

self-face; and (3) in the final than in the initial and intermediate phases (final > initial, intermediate). Fig. 5C (the upper panel) illustrates these results.

3.2.6. N250 for famous and unknown names and faces

The ANOVA on N250 for famous and unknown stimuli revealed the significant main effect of hemisphere ($F_{1,21} = 11.77$; $p = 0.003$; $\eta^2 = 0.36$), type of stimuli ($F_{1,21} = 46.86$; $p = 0.0001$; $\eta^2 = 0.69$), repetition ($F_{2,42} = 34.32$; $p = 0.0001$; $\eta^2 = 0.62$) and familiarity ($F_{1,21} = 13.52$; $p = 0.001$; $\eta^2 = 0.39$), as well as a hemisphere \times type of stimuli interaction ($F_{1,21} = 8.95$; $p = 0.007$; $\eta^2 = 0.3$). The amplitude of N250 was greater: (1) in the left than in the right inferior-temporal region; (2) for names than for faces, especially in the left hemisphere; and (3) in the later than in the earlier phases (final > intermediate > initial). In addition, famous names and faces were associated with a stronger N250 response than unknown ones (see Fig. 3).

A separate ANOVA on N250 amplitudes for unknown names and faces revealed the main effect of the type of stimuli ($F_{2,42} = 21.77$; $p = 0.0001$; $\eta^2 = 0.51$), repetition ($F_{2,42} = 21.77$; $p = 0.0001$; $\eta^2 = 0.51$) and hemisphere ($F_{2,42} = 21.77$; $p = 0.0001$; $\eta^2 = 0.51$), as well as a type of stimuli \times hemisphere interaction ($F_{1,21} = 5.64$; $p = 0.027$; $\eta^2 = 0.21$). Post-hoc analyses showed that (1) N250 for unknown names was larger than for unknown faces, especially in the left hemisphere; and (2) N250 in the later phases was greater than in the earlier ones. Fig. 5A (the upper panel) illustrates these results.

An analogous pattern of results was present for famous names and faces (see Fig. 5B, the upper panel). We found the main effect of type of stimuli ($F_{2,42} = 42$; $p = 0.0001$; $\eta^2 = 0.67$), repetition ($F_{2,42} = 20.8$; $p = 0.0001$; $\eta^2 = 0.5$) and hemisphere ($F_{2,42} = 12.6$; $p = 0.01$; $\eta^2 = 0.38$), as well as a type of stimuli \times hemisphere interaction ($F_{1,21} = 11.6$; $p = 0.01$; $\eta^2 = 0.36$). Post-hoc results were identical to

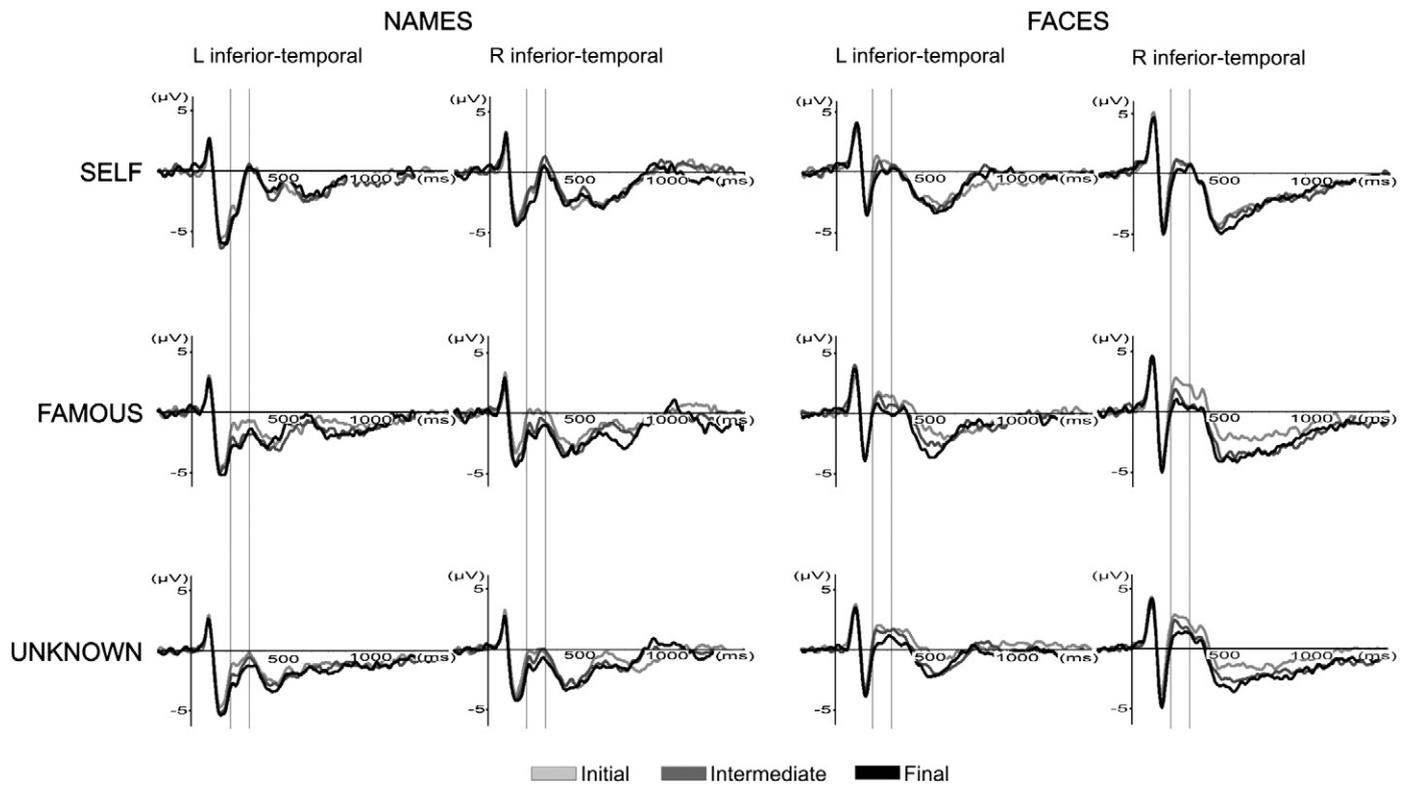


Fig. 3. Grand-average ERPs for all types of stimuli (self-name, self-face, famous names and faces, unknown names and faces) in three subsequent phases of the experiment: initial (light grey line); intermediate (dark grey line); and final (black line). The panels present pooled data from left and right inferior-temporal regions (TP9/TP10, P7/P8, and PO7/PO8). Vertical lines indicate the time interval in which the N250 waveform was evaluated (220–320 ms after the stimulus onset). Statistical analysis revealed that the amplitude of N250 was modulated by: (1) stimulus familiarity, i.e., N250 was higher for famous than for unknown names and faces; and (2) repetition, i.e., N250 was higher in the later phases of the study than in the earlier ones.

those observed for unknown stimuli: (1) N250 for famous names was larger than for famous faces, especially in the left hemisphere; and (2) N250 in the later phases was greater than in the earlier ones.

3.2.7. P300 for self-name and self-face

Fig. 4 presents the P300 waveform in the central-parietal region in all three phases of the study. The ANOVA for self-name and self-face did not reveal any significant differences across the types of stimuli (self-name vs. self-face), or the phases of the study (initial vs. intermediate vs. final). Fig. 5C (the lower panel) illustrates these results.

3.2.8. P300 for famous and unknown names and faces

The ANOVA on P300 amplitudes for famous and unknown stimuli showed significant main effects of repetition ($F_{2,42} = 38.24$; $p = 0.0001$; $\eta^2 = 0.65$) and familiarity ($F_{1,21} = 22.52$; $p = 0.0001$; $\eta^2 = 0.52$). Post-hoc comparisons revealed that its amplitude was more positive for famous than for unknown stimuli. Moreover, P300 increased significantly over study phases (final > intermediate > initial).

A separate ANOVA on P300 amplitudes for unknown names and faces showed the main effect of repetition ($F_{2,42} = 21.77$; $p = 0.0001$; $\eta^2 = 0.51$) and a type of stimuli \times repetition interaction ($F_{2,42} = 7.32$; $p = 0.002$; $\eta^2 = 0.26$). Post-hoc analyses showed that P300 for unknown faces was higher than for unknown names, but only in the intermediate phase of the study (see Fig. 5A the lower panel).

As shown in Fig. 5B (the lower panel), P300 for famous names and faces showed a similar pattern of results as those observed for the unknown stimuli. The ANOVA on P300 responses to famous stimuli showed the main effect of repetition ($F_{2,42} = 36.2$; $p = 0.0001$; $\eta^2 = 0.63$) and a type of stimuli \times repetition interaction ($F_{2,42} = 3.34$; $p = 0.045$; $\eta^2 = 0.14$). Post-hoc analysis showed a statistical trend

($p < 0.1$) for higher P300 amplitude for famous faces than for famous names in the intermediate phase of the study.

4. Discussion

The aim of this study was to investigate the effect of multiple repetitions on the processing of self-, famous and unknown names and faces. We were especially interested in the patterns of N250 and P300 modulations after repetitions of names vs. faces. Subjects were engaged in a person-recognition task and we measured both behavioral and electrophysiological responses in three phases of the study (in each phase, the same stimulus was repeated a pre-determined number of times).

In terms of behavioral results, we found that RTs were decreasing and the accuracy rate was increasing as subjects progressed through each phase of the study (only in the case of self-related stimuli there was no facilitation in the accuracy of responses). This result is consistent with many studies investigating repetition priming (e.g., Schweinberger et al., 2002b; Herzmann and Sommer, 2007) and learning processes (e.g., Kaufmann et al., 2008; Tanaka et al., 2006), suggesting that the speed and accuracy of behavioral responses depend partially on intra-experimental familiarity (i.e., the number of repetitions). The most probable explanation for the lack of effect for self-related stimuli is that their level of recognition was 'at a ceiling' right from the initial phase of the study.

In addition, we found that RTs to famous names and faces were shorter than to unknown ones. This finding is also in line with the existing literature (e.g., Herzmann et al., 2004; Pfützte et al., 2002; Schweinberger et al., 1995; but see: Herzmann and Sommer, 2007) and suggests that in addition to varying with the number of repetitions within the experiment, the speed of face or name identification changes with the level of pre-experimental familiarity.

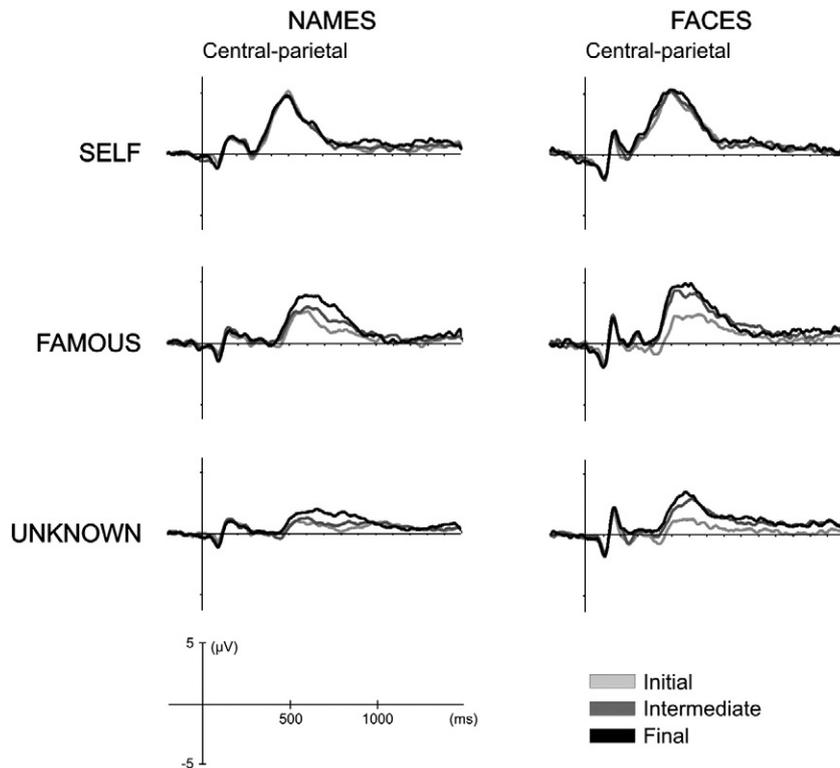


Fig. 4. Grand-average ERPs for all types of stimuli (self-name, self-face, famous names and faces, unknown names and faces) in the three phases of the experiment: initial (light grey line); intermediate (dark grey line); and final (black line). The study investigated P300 in the central-parietal region (i.e., pooled data from C1, Cz, C2, P1, Pz, P2, CP1, CPz and CP2 electrodes). In the case of self-related stimuli, the amplitude appeared to be unchanged between phases and was insensitive to differences between the types of stimuli (names vs. faces). In contrast, for famous and unknown names and faces, the amplitude of P300 increased with each phase of the study. Moreover, statistical results confirmed that P300 was higher for famous than for unknown stimuli.

It is noteworthy that in our study, RTs to faces were generally shorter than to names. A similar effect was demonstrated by Herzmann and Sommer (2007). Together, these results suggest that familiarity judgments for names require more effort and are less automatic than for faces. In order to recognize a name, one needs to read it, whereas faces can be recognized by a short glance. It appears that face recognition is more automatic than name recognition. Nevertheless, we did not observe any differences between RTs to self-name and self-face, which suggests that the level of automatization is similar for these two types of stimuli.

As far as electrophysiological results are concerned, we found that the amplitude of P100 in the central-occipital region was higher for faces than for names. However, P100 was insensitive to stimuli familiarity or repetition. Similar results were reported, for example, by Pfützte et al. (2002). It has been generally agreed that the amplitude of P100 is sensitive to perceptual features of visual stimuli, such as brightness, contrast, size and visual acuity (e.g., Allison et al., 1999; Pfützte et al., 2002). However, some other studies reported face-sensitive effects at the level of P100 (e.g., Eimer, 1998, 2000; Itier and Taylor, 2004a). Nevertheless, these findings are rather inconsistent and appear to reflect perceptual differences between faces and other complex visual stimuli (for review see: Rossion and Jacques, 2008). Therefore, the most probable explanation for our results is that faces induced a greater P100 response than names due to their size (faces: $4^\circ \times 5^\circ$ vs. names: $2^\circ \times 6^\circ$) and intensity.

An analysis of the N170 amplitude revealed that it was insensitive to differences in the pre-experimental familiarity of social stimuli. This result is consistent with previous studies (e.g., Tanaka et al., 2006; Schweinberger et al., 2002b) and supports the assumption that N170 indexes structural encoding (faces) or word form analysis (names), rather than individual person-related representations (see the Introduction section). In addition, we found differential left and right

inferior-temporal activity in response to names and faces, i.e., in the left hemisphere, names (regardless of their type) were associated with greater N170 than faces, and in the right hemisphere, the opposite tendency was found (see Fig. 2). A study by Pfützte et al. (2002), which also used names and faces as stimuli, showed a similar pattern. Moreover, increased N170 for faces in the right hemisphere is in line with previous investigations (Schweinberger and Sommer, 1991; Bentin et al., 1996; for review see: Rossion and Jacques, 2008) and corresponds with the dominant role of the right hemisphere in the processing of faces at pre-semantic levels. Increased amplitude of N170 for names in the left hemisphere was, in turn, reported by Schweinberger et al. (2006), and seems to be in line with the usual dominance of the left side of the brain in language processing. The differential lateralization of N170 seems to correspond with the commonly assumed hemispheric specialization for names and faces (Newcombe et al., 1989). However, there are studies showing bilateral or even left-sided N170 dominance for faces (e.g., Harris et al., 2005; Jemel et al., 2005; Righart and de Gelder, 2006). A recent investigation by Proverbio et al. (2010) proposed a possible reason for the discrepancy, as their results revealed a much stronger face-specific N170 over the right hemisphere in men, and a bilateral response in women. It seems that names and faces engage topographically different processes, though the level of this specialization might depend on individual differences, such as the level of brain lateralization. This interpretation might explain why the N170 right-hemisphere dominance for famous and unknown faces constituted only a statistical trend in our study ($p < 0.1$).

In addition, we found that the amplitude of N170 for names and faces was modulated by multiple repetitions, i.e., more repetitions elicited stronger N170 responses. Previous results are highly inconsistent regarding this issue. Some studies have shown that N170 increases with repetitions (e.g., Kaufmann et al., 2008), while others have revealed no changes (Schweinberger et al., 2002a,b, 2007; Pfützte

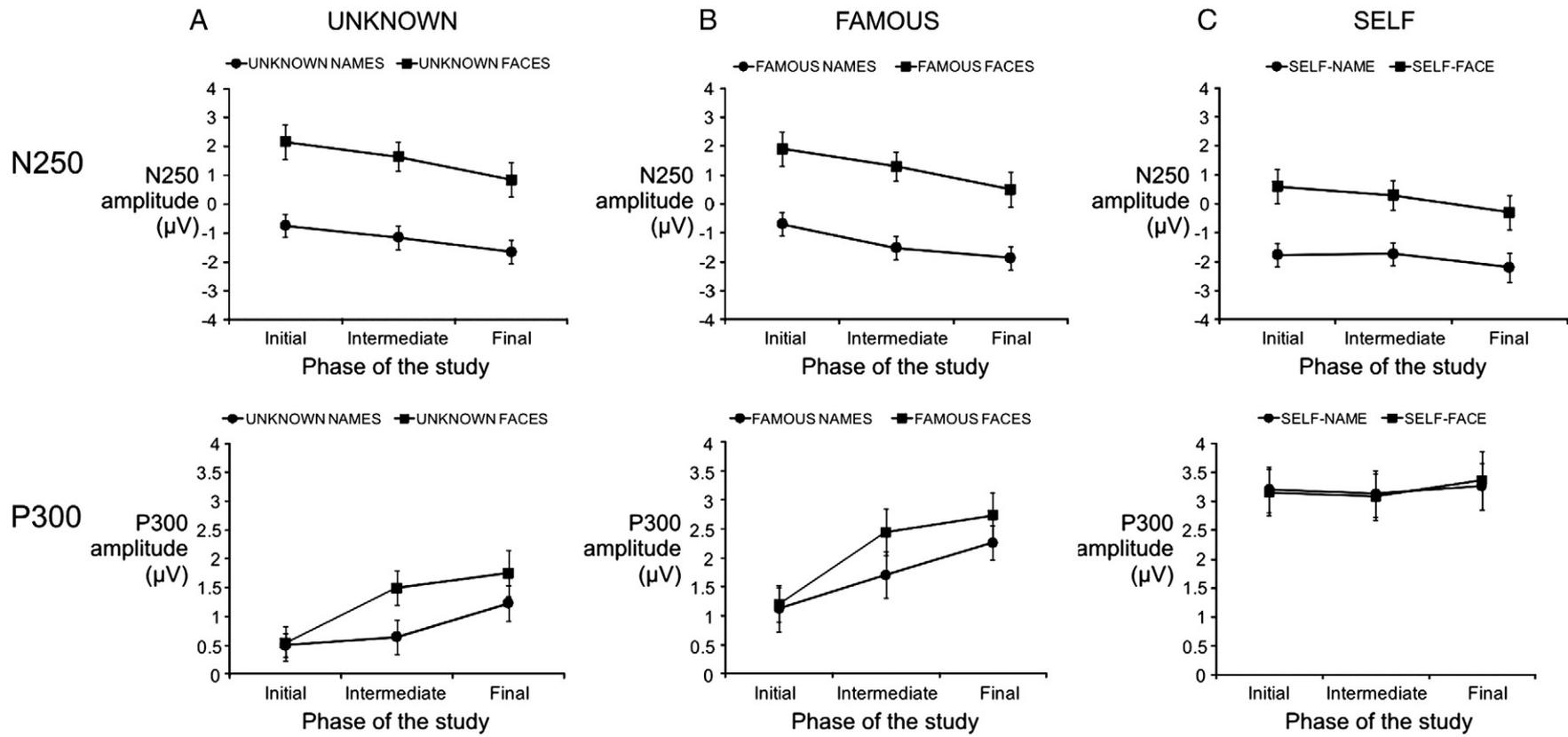


Fig. 5. Mean amplitude values (the error bars represent the SEM) of N250 and P300 in response to: (A) unknown; (B) famous; and (C) subjects' own names (circle marker) and faces (square marker) in the initial, intermediate and final phases of the study. As shown, N250 was generally higher for names than for faces, but no interaction between the type of stimuli and repetition was found. In contrast, an interaction between the type of stimuli and repetition was observed for P300: in the initial phase both unknown names and unknown faces were associated with an almost identical P300 response, but in the intermediate phase, P300 for unknown faces was significantly higher than for unknown names. An analogous pattern of results occurred for famous stimuli, but was a statistical trend ($p < 0.1$). These results suggest that faces might be learned more efficiently than names, and this facilitation seems to take place specifically at the level of semantic-related processing. The fact that this effect was weaker for famous than for unknown stimuli could be explained by the availability of name–face associations for the former stored in long-term memory. In contrast, for unknown stimuli, the available information may be restricted to that found 'within' the stimulus.

et al., 2002). Itier and Taylor (2004b), Guillaume et al. (2009) and Heisz et al. (2006) have demonstrated decreasing N170 for repeated faces. Kaufmann et al. (2008) suggested that these discrepancies may be linked to the images being repeated: repeating the same image of a given person's face could trigger repetition suppression and consequently N170 reduction, whereas repeating different images of a given face might generate repetition enhancement and increased N170. This interpretation, however, does not explain why we found increased N170 for the same image presentations in our study. At this point, the nature of the inconsistency is difficult to explain and requires more systematic investigation in the future.

With regard to the N250 amplitude, we found that it was higher for famous than for unknown stimuli. These results replicate some previous findings (e.g., Tanaka et al., 2006; Kaufmann et al., 2008) and support the assumption that N250 is sensitive to pre-experimental familiarity. It has been suggested that N250 reflects the access to FRUs and NRUs in the person-recognition models (e.g., Boehm and Paller, 2006) and our results seem to be in line with this assumption, as greater N250 for famous names and faces could reflect that FRUs and NRUs for these stimuli were better developed than for unknown stimuli.

Moreover, the amplitude of N250 for all types of names and faces was larger in the later than in the earlier phases of the study. For unknown stimuli, this effect could reflect the forming of new FRUs and NRUs. In the case of self- and famous names and faces, in turn, it could represent incorporating this particular form of a name or a face to the existing mental representation. Multiple repetitions of well-known stimuli may have increased activation levels or decreased thresholds within the already existing FRUs/NRUs (Bruce and Young, 1986). Alternatively, they may strengthen the links between FRUs/NRUs and PIN/SIU, which may result in accelerating the access to the semantic system for the subsequent presentations (Burton et al., 1990). More research is needed to support any of these possibilities.

The alternative interpretations of the N250 do not associate this wave solely with person-recognition processes. For example, Scott et al. (2006) proposed that N250 reflects a type of general expertise in the processing of within-category comparisons at the subordinate level. Our results, however, neither support nor refute this hypothesis, as only names and faces (and no non-person-related stimuli) were used in this experiment. The present findings are more conclusive with regard to another hypothesis stating that N250 is a face-selective ERP response (Schweinberger et al., 2004). Our results showing that N250 was greater for names than for faces do not appear to support this interpretation.

Furthermore, we found that the processing of names was associated with greater N250 amplitude in the left than in the right inferior-temporal scalp region. This is consistent with the results of studies using priming paradigms (e.g., Sommer et al., 1997; ; Pfützte et al., 2002; Pickering and Schweinberger, 2003; Schweinberger et al., 2006). As far as the N250 for faces is concerned, previous studies (e.g., Schweinberger et al., 2002a; Kaufmann et al., 2008; Pfützte et al., 2002) demonstrated larger modulations in the right than in the left inferior-temporal region. We did not find any inter-hemispheric differences in the amplitude of N250 for faces. Based on the study by Proverbio et al. (2010), it could be speculated that the level of N250 topographical specialization might be sensitive to individual differences in brain lateralization, as in the case of N170.

The results of the current study revealed that P300 amplitude was more positive for famous names and faces than for those that were unknown. This result is highly consistent with previous findings (e.g., Bentin and Deouell, 2000; Eimer, 2000; Paller et al., 2000) and supports the view that P300 amplitude is sensitive to the pre-experimental familiarity of names and faces, and perhaps other (i.e., not person-related) stimuli as well.

Moreover, we found that P300 amplitude for unknown and famous stimuli increased with each phase of the study. This result is in line

with previous research (e.g., Kaufmann et al., 2008). For unknown stimuli, this effect could reflect the formation of new PINs and SIUs. Although no additional semantic information was provided with these stimuli, information about gender, mood, attractiveness and other semantic information might be derived directly from an unfamiliar stimulus, thus giving rise to the PIN and SIU, and consequently larger P300. The increasing amplitude of P300 for the subsequent presentations of famous names and faces, in turn, could reflect the further strengthening of the existing PINs and SIUs, perhaps by spreading the activation in the semantic networks.

It is noteworthy that the pace of the repetition-related N250 and P300 increase seemed to be similar for unknown and famous social stimuli (no significant familiarity \times repetition interaction was found). This is quite surprising given the differences in pre-experimental familiarity between these two categories. This effect suggests that the formation of new perceptual (FRU/NRU) or semantic (PIN/SIU) representations could be as fast and as efficient as the strengthening of the existing ones.

In addition, P300 for self-name and self-face remained virtually the same over subsequent phases of the study. It seems that since these stimuli were already very familiar (a ceiling effect), so P300 could not have been further enhanced. Indeed, as there were over 60 repetitions of self-name and self-face, it is surprising the P300 was not reduced due to habituation to these stimuli. This might be due to the high adaptational value of these stimuli (cf. Tacikowski and Nowicka, 2010). However, as described earlier, we found that N170, N250 and RTs to self-related stimuli were influenced by multiple repetitions. This difference between P300 and other ERP and behavioral measures suggests that the general facilitation in the processing of self-name and self-face took place at the level of structural encoding/word form analysis, FRUs or NRUs activation (e.g., reflecting the incorporation of a new form of self-name or self-face to the existing mental representation), or action preparation, but not at the level of acquiring new semantic information about the subject (which seems to have been already at maximum). These results are in line with the predictions of the person-recognition models (Bruce and Young, 1986; Valentine et al., 1995) and their neural correlates (for review see: Boehm and Paller, 2006).

Figs. 4 and 5 suggest that self-related stimuli were associated with higher P300 than other-related ones. Interestingly, this difference seemed to decrease over the subsequent phases of the study, with the P300 amplitude for famous names and faces increasing and the P300 for self-name and self-face remaining almost unchanged. Due to the uneven numbers of repetitions across self- and other-related stimuli, we did not evaluate this effect statistically. Nevertheless, it might be speculated that this pattern of results corresponds to the one demonstrated by Herzmann et al. (2004), who showed that personally familiar faces produced stronger LRE than famous ones. Based on the present results, it is hard to determine whether the difference observed in the present study was due to: (1) higher emotional value of self-related stimuli; (2) their higher familiarity; or (3) their higher frequency of occurrence within the study. This issue requires further research.

With regard to the hypotheses that we outlined in the Introduction, we found no differences in the pace of repetition-related N250 increases for names or faces (see Fig. 5). In contrast, the amplitude of P300 for unknown faces seemed to grow faster than for unknown names (see Fig. 5A the lower panel). An analogous pattern of results occurred for famous stimuli (see Fig. 5B the lower panel), though the effect was only a statistical trend. Importantly, the P300 amplitude was almost identical for unknown names and faces in the initial phase which speaks against the possibility that this effect was due to physical differences between those stimuli. Indeed, if that was the case, the pattern would be stable across the phases. In addition, we did not find any differences between P300 for self-name and self-face, which also suggests that the effect was not only due to physical

differences between names and faces. Alternatively, these results could be explained by the fact that faces contain more semantic information about their bearers than names (gender, age, race, mood, direction of gaze, attractiveness, etc. vs. gender and nationality), and as suggested by Herzmann and Sommer (2007), this type of information could underlie a whole series of cognitive and emotional processes, which could be then used to form new or strengthen the existing PIN and SIU nodes. Our study suggests that the pace of this forming/strengthening could be faster for faces than for names and that this effect occurs at the level of semantic, not pre-semantic, stages of person-recognition processes. Moreover, the differences between names and faces seem to be more pronounced for unknown stimuli than for familiar ones which could be explained by the availability of name–face associations for the latter. The amount of semantic information ‘within’ the stimulus seems to be more crucial for unknown than for familiar stimuli, as in case of the unknown ones this information is the only available.

Finally, it is important to note that we cannot determine whether the observed behavioral and ERP effects were due to implicit (i.e., priming) or explicit (i.e., memory recognition) processes. In the familiarity task that we used, implicit and explicit memory processes could have been intermixed because familiarity decisions on the category level (familiar vs. unfamiliar) had to be made although participants were not asked to individuate and recognize individual faces/names. Over the course of three repetitions, simply the affiliation of individual faces/names to one of these categories could have been learned. Therefore, it is difficult to interpret our results solely with respect to repetition priming or recognition memory.

Another possible limitation is the fixed S–R assignment, as all participants responded with their right hand and the response key assignment was not counterbalanced across the subjects. The unilateral response could have influenced the lateralization of the ERPs, especially P300 which is measured during response preparation and execution. Nevertheless, the names vs. faces comparisons do not seem to be affected by this issue, as subjects pressed the same key for unknown names as for unknown faces, the same key for famous names as for famous faces, etc. It is also noteworthy that we used a relatively long time-window to evaluate P300 (i.e., from 320 to 900 ms after the stimulus onset). The reason for choosing such a long interval was that the latency of P300 varied significantly between conditions, and we wanted to perform comparable analyses for all the categories of names and faces.

In summary, we found the typical behavioral repetition effect: shorter RTs and higher accuracy rate for the later vs. earlier presentations of all types of names and faces. However, the magnitude of these effects was the weakest for self-name and self-face, which might be due to the fact that subjects' responses to these stimuli were ‘at ceiling’ from the initial phase of the study. As far as the electrophysiological results are concerned, we found that faces, probably due to their greater size and intensity, produced higher P100 amplitude than names. The amplitude of N170, in turn, was modulated by the hemispheric specialization, as names were associated with larger N170 in the left inferior-temporal scalp region, whereas faces showed the opposite tendency. In addition, the amplitude of N170 was sensitive to the repetition factor, which suggests that this wave, apart from structural encoding or word form analysis, could also reflect other cognitive processes. The amplitude of N250 also showed hemispheric specialization and it was greater for famous than for unknown names and faces. Moreover, the amplitude of this wave increased with repetition, but the pace of this increase was similar for names and faces. In contrast, the amplitude of P300 for unknown faces increased faster than for unknown names. A similar though weaker tendency was observed for famous stimuli. P300 for self-related stimuli, in turn, was insensitive to multiple repetitions. These findings suggest that the effectiveness of forming new or strengthening the existing representations is greater for faces than for

names, and this effect seems to be related to the amount of semantic information carried by these stimuli. The weaker effect for familiar names and faces could be interpreted in terms of the availability of name–face associations for these stimuli. Altogether, these results are an important contribution to the present state of knowledge about person-recognition processes and might encourage future research in this respect.

References

- Allison, T., Puce, A., Spencer, A.A., McCarthy, G., 1999. Electrophysiological studies of human face perception. I: potentials generated in occipitotemporal cortex by face and non-face stimuli. *Cereb. Cortex* 9, 415–430.
- Bell, A.J., Sejnowski, T.J., 1995. An information-maximization approach to blind separation and blind deconvolution. *Neural Comput.* 7, 1129–1159.
- Bentin, S., Deouell, L.Y., 2000. Structural encoding and identification in face processing: ERP evidence for separate mechanisms. *Cogn. Neuropsychol.* 17, 35–54.
- Bentin, S., Allison, T., Puce, A., Perez, E., McCarthy, G., 1996. Electrophysiological studies of face perception in humans. *J. Cogn. Neurosci.* 8, 551–565.
- Bentin, S., Mouchetant-Rostaing, Y., Giard, M.H., Echallier, J.F., Pernier, J., 1999. ERP manifestations of processing printed words at different psycholinguistic levels: time course and scalp distribution. *J. Cogn. Neurosci.* 11, 235–260.
- Boehm, S.G., Paller, K.A., 2006. Do I know you? Insights into memory for faces from brain potentials. *Clin. EEG Neurosci.* 37, 322–329.
- Bruce, V., Young, A., 1986. Understanding face recognition. *Br. J. Psychol.* 77, 305–327.
- Burton, A.M., Bruce, V., Johnson, R.A., 1990. Understanding face recognition with an interactive activation model. *Br. J. Psychol.* 81, 361–380.
- Carbon, C.C., Kaufmann, S.R., Schweinberger, J.M., Leder, H., 2005. The Thatcher illusion seen by the brain: an event-related brain potentials study. *Brain Res. Cogn. Brain Res.* 24, 544–555.
- Eimer, M., 1998. Does the face-specific N170 component reflect the activity of a specialized eye processor? *NeuroReport* 9, 2945–2948.
- Eimer, M., 2000. Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clin. Neurophysiol.* 111, 694–705.
- Gevens, A., Cutillo, B., Smith, M.E., 1995. Regional modulation of high resolution evoked potentials during verbal and non-verbal matching tasks. *Electroencephalogr. Clin. Neurophysiol.* 94, 129–147.
- Gevens, A., Smith, M.E., Le, J., Leong, H., Bennet, J., Martin, M., McEvoy, L., Du, R., Whitfield, S., 1996. High resolution evoked potential imaging of the cortical dynamics of human working memory. *Electroencephalogr. Clin. Neurophysiol.* 98, 327–348.
- Greenhouse, S., Geisser, S., 1959. On methods in the analysis of profile data. *Psychometrika* 24, 95–112.
- Guillaume, C., Guillery-Girard, B., Chaby, L., Lebreton, K., Hugueville, L., Eustache, F., Fiori, N., 2009. The time course of repetition effects for familiar faces and objects: an ERP study. *Brain Res.* 1248, 149–161.
- Harris, A.M., Duchaine, C.C., Nakayama, K., 2005. Normal and abnormal face selectivity of the M170 response in developmental prosopagnosics. *Neuropsychologia* 43, 2125–2136.
- Heisz, J.J., Watter, S., Shedden, J.M., 2006. Automatic face identity encoding at the N170. *Vision Res.* 46, 4604–4614.
- Herzmann, G., Sommer, W., 2007. Memory-related ERP components for experimentally learned faces and names: characteristics and parallel-test reliabilities. *Psychophysiology* 44, 262–276.
- Herzmann, G., Schweinberger, S.R., Sommer, W., Jentsch, I., 2004. What's special about personally familiar faces? A multimodal approach. *Psychophysiology* 41, 688–701.
- Itier, R.J., Taylor, M.J., 2004a. Effects of repetition learning on upright, inverted and contrast-reversed face processing using ERPs. *Neuroimage* 21, 1518–1532.
- Itier, R.J., Taylor, M.J., 2004b. Effects of repetition and configural changes on the development of face recognition processes. *Dev. Sci.* 7, 469–487.
- Jemel, B., Pisani, M., Rouselle, L., Crommelinck, M., Bruyer, R., 2005. Exploring the functional architecture of person recognition system with event-related potentials in a within- and cross-domain self-priming of faces. *Neuropsychologia* 43, 2024–2040.
- Jung, T., Makeig, S., Westerfield, M., Townsend, J., Courchesne, E., Sejnowski, T., 2001. Analysis and visualization of single-trial event-related potentials. *Hum. Brain Mapp.* 14, 166–185.
- Kaufmann, J.M., Schweinberger, S.R., Burton, A.M., 2008. N250 ERP correlates of the acquisition of face representations across different images. *J. Cogn. Neurosci.* 21, 625–641.
- Luck, S.J., 2005. Ten simple rules for designing ERP experiments. In: Handy, T.C. (Ed.), *Event-related Potentials. A Methods Handbook*. The MIT Press, Cambridge, MA, pp. 209–227.
- Morton, J., 1969. Interaction of information in word recognition. *Psychol. Rev.* 76, 165–178.
- Morton, J., 1979. Facilitation in word recognition: experiments causing change in the logogen model. In: Kolers, P.A., Wrolstal, M., Bouma, H. (Eds.), *Processing of Visible Language*. Plenum Press, New York, pp. 259–268.
- Newcombe, F., Haan, E.H., Ross, J., Young, A.W., 1989. Face processing, laterality and contrast sensitivity. *Neuropsychologia* 27, 523–538.
- Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9, 97–114.

- Paller, K.A., Gonsalves, B., Grabowecky, M., Bozic, V.S., Yamada, S., 2000. Electrophysiological correlates of recollecting faces of known and unknown individuals. *Neuroimage* 11, 98–110.
- Pfütze, E.-M., Sommer, W., Schweinberger, S.R., 2002. Age-related slowing in face and name recognition: evidence from event-related brain potentials. *Psychol. Aging* 17, 140–160.
- Pfütze, E.-M., Sommer, W., Schweinberger, S.R., 2003. N200, N250r, and N400 event-related brain potentials reveal three loci of repetition priming for familiar names. *J. Exp. Psychol. Learn. Mem. Cogn.* 29, 1298–1311.
- Proverbio, A.M., Riva, F., Martin, E., Zani, A., 2010. Face coding is bilateral in the female brain. *PLoS ONE* 5, e11242.
- Righart, R., de Gelder, B., 2006. Context influences early perceptual analysis of faces – an electrophysiological study. *Cereb. Cortex* 16, 1249–1257.
- Rossion, B., Jacques, C., 2008. Does physical interstimulus variance account for early electrophysiological face sensitive responses in the human brain? Ten lessons on the N170. *Neuroimage* 39, 1959–1979.
- Rossion, B., Gauthier, I., Tarr, M.J., Despland, P., Bruyer, R., Linotte, S., Crommelinck, M., 2000. The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: an electrophysiological account of face-specific processes in the human brain. *NeuroReport* 11, 69–74.
- Schweinberger, S.R., Pfütze, E.-M., Sommer, W., 1995. Repetition priming and associative priming of face-recognition. Evidence from event-related potentials. *J. Exp. Psychol. Learn. Mem. Cogn.* 21, 722–736.
- Schweinberger, S.R., 1996. How Gorbachev primed Yeltsin: analyses of associative priming in person recognition by means of reaction times and event-related brain potentials. *J. Exp. Psychol. Learn. Mem. Cogn.* 22, 1383–1407.
- Schweinberger, S.R., Sommer, W., 1991. Contributions of stimulus encoding and memory search to right hemisphere superiority in face recognition: behavioural and electrophysiological evidence. *Neuropsychologia* 29, 389–413.
- Schweinberger, S.R., Pickering, E.C., Jentzsch, I., Burton, M., Kaufmann, J.M., 2002a. Event-related brain potential evidence for a response of inferior temporal cortex to familiar face repetitions. *Cogn. Brain Res.* 14, 398–409.
- Schweinberger, S.R., Pickering, E.C., Burton, M., Kaufmann, J.M., 2002b. Human brain potential correlates of repetition priming in face and name recognition. *Neuropsychologia* 40, 2057–2073.
- Schweinberger, S.R., Huddy, V., Burton, A.M., 2004. N250r: a face-selective brain response to stimulus repetitions. *NeuroReport* 15, 1501–1505.
- Schweinberger, S.R., Ramsay, A.L., Kaufmann, J.M., 2006. Hemispheric asymmetries in font-specific and abstractive priming of written personal names: evidence from event-related potentials. *Cogn. Brain Res.* 1117, 195–205.
- Schweinberger, S.R., Kaufmann, J.M., Moratti, S., Keil, A., Burton, A.M., 2007. Brain responses to repetitions of human and animal faces, inverted faces, and objects – an MEG study. *Brain Res.* 1184, 226–233.
- Scott, L.S., Tanaka, J.W., Sheinberg, D.L., Curran, T., 2006. A reevaluation of the electrophysiological correlates of expert object processing. *J. Cogn. Neurosci.* 18, 1453–1465.
- Sommer, W., Komoss, E., Schweinberger, S.R., 1997. Differential localization of brain systems subserving memory for names and faces in normal subjects with event-related potentials. *Electroencephalogr. Clin. Neurophysiol.* 102, 192–199.
- Tacikowski, P., Nowicka, A., 2010. Allocation of attention to self-name and self-face: an ERP study. *Biol. Psychol.* 84, 318–324.
- Tanaka, J.W., Curran, T., Porterfield, A.L., Collins, D., 2006. Activation of preexisting and acquired face representations: the N250 event-related potential as an index of face familiarity. *J. Cogn. Neurosci.* 18, 1488–1497.
- Ullsperger, M., Mecklinger, A., Müller, U., 2000. An electrophysiological test of directed forgetting: the role of retrieval inhibition. *J. Cogn. Neurosci.* 12, 924–940.
- Valentine, T., Moore, V., Brédart, S., 1995. Priming production of people's names. *Q. J. Exp. Psychol. A Hum. Exp. Psychol.* 48, 513–535.