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How society modulates our behavior: Effects on error processing of masked emotional cues contextualized in social status

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ABSTRACT

In the present study, we investigate whether subliminal complex social cues have an impact on error-monitoring processes. For this purpose, we presented two social status ranks (high and low) with three possible emotional expressions (happy, neutral, angry), using a backward masking paradigm. Participants were instructed to perform a flanker task while recording Event-Related brain Potentials. Results showed larger amplitudes for the Error-Related Negativity index after the presentation of high relative to low social ranks, only for neutral expressions. Neither the angry nor the happy faces induced significant differences in social rank processing. This indicates that subliminal high social ranks, specifically with neutral expressions, increase error processing by boosting attentional control to perform the ongoing task. Our findings extend current knowledge on the automaticity of social and emotional processing and its influence on performance monitoring mechanisms.

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1. Introduction

The automatic detection of social and emotional cues, such as hierarchical positions (Koski et al., 2015; Mattan et al., 2017) or facial expressions (Hinojosa et al., 2015) is crucial to successfully navigate in the social world. Indeed, we meet people daily and these cues affect us even when we are not aware of them. This automatic detection, in turn, may have an impact on how we monitor our behavior to constantly adapt it to different social contexts. Then, in the present work, we explore the unconscious effects of social status and facial expressions on performance monitoring mechanisms.

People can infer status from the perception of ranked cues such as military symbols, cars or faces (Chiao et al., 2004, 2009; Zink et al., 2008). In this regard, the use of high temporal resolution techniques has provided many clear results regarding the influence of social ranks on attention. For instance, high-status relative to low status faces elicited larger amplitudes of early automatic (Arviv et al., 2015; Feng et al., 2015; Santamaría-García et al., 2015) and late ERPs components (Breton et al., 2014, 2019; Feng et al., 2015; Furley et al., 2016; Gyurovski et al., 2017). These solid findings reflect more attention and motivation cognitive resources for higher hierarchies. In contrast, there is a lack of studies exploring the effects of social hierarchies on performance monitoring mechanisms, despite their importance to trigger social adaptation behaviors. Results from studies using different tasks and neuroimaging techniques have pointed out that social and emotional stimuli have an impact on monitoring processes (for a review see Koban & Pourtois, 2014). However, the specific effects of social hierarchies are almost unexplored (but see A. Boksem et al., 2012).

Emotional expressions are probably the most important social cue that humans automatically detect even in the absence of conscious awareness (Kiss & Eimer, 2008; Liddell et al., 2005; Smith et al., 2013). Negative masked expressions such as fearful faces have shown to impact the cognitive system to a greater extent than non-fearful ones (Pegna et al., 2011, 2008). But also, angry and happy masked faces have an impact on cognition (Nomura et al., 2004; Sabatini et al., 2009; Suslow et al., 2010). In fact, results of studies have shown that masked emotional faces affect cognitive processes such as spatial attention (Carlson & Reinke, 2010) or social and emotional judgments (Lu et al., 2011). Furthermore, facial expressions are a potent source of information affecting our internal performance monitoring processes (M. A. Boksem et al., 2011; Suzuki et al., 2020). For example, a study by Boksem and colleagues (2011) found larger amplitudes of an electrophysiological marker of

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error processing, namely the Error-Related Negativity (ERN), after the presentation of disgusting faces in comparison to neutral faces. The authors, therefore, concluded that social disapproval enhances the salience of our own errors.

Importantly, most studies have typically used isolated faces, but contextual information – including verbal, auditory and visual body or scene cues, as well as previous knowledge – substantially modify facial processing (for reviews see Brooks & Freeman, 2017; Wieser & Brosch, 2012). That is, in everyday life, people's faces are perceived and automatically integrated within a social context (Aviezer, Bentin, Dudarev & Hassin, 2011). Different types of social information, such as emotion, race, sex, attire or hair cues are commonly processed in interactive fashion. For example, Freeman et al. (2011) presented a range of faces varying along a white-black continuum together with high-status (shirt and tie) or low-status attire (t-shirt). The likelihood of categorization as a white face was increased by the high-status attire, whereas low-status attire produced a tendency to categorize the face as black (Freeman et al., 2011). Considering this, in the present study we combine different social status and facial expression using a subliminal presentation and explore how they affect error monitoring processes.

Errors generally signal the need for increasing cognitive control as part of a network that constantly monitors our performance (Cavanagh et al., 2009). In ERPs research, the main neural generator of signaling errors was first discovered in speeded choice reaction time tasks, when a prominent response-locked waveform appeared as a difference between error and correct trials (Falkenstein et al., 1995). The Error-Related Negativity (ERN) is a negative deflection generated by the anterior cingulate cortex (ACC) and the adjacent supplementary motor area (SMA), peaking around 50–100 ms post-error response (for a review see Gehring et al., 2012). Regarding its functional significance, one of the most well-established theories suggests that the ERN reflects the automatic detection of cognitive conflict between the internal representation of an erroneous (i.e., produced) and a correct (intended) response (Yeung et al., 2004). More recent findings suggest that the ERN reflects an increase in attentional control, supported by enhanced activation of the medial prefrontal cortex, typically observed in situations demanding monitoring of ongoing actions (Van Noordt et al., 2015). There is also data suggesting that the ERN amplitude is directly related to subjective error awareness, and thus, it depends on individual differences in error reporting and confidence (Shalgi & Deouell, 2012, 2013). Further, the affective-signaling hypothesis integrates findings from control monitoring and emotion research and gives a novel view regarding the functional significance of ERN. According to this hypothesis, conflicts elicit a negative affective reaction that is registered by the monitoring system in the ACC. Then, this negative affect triggers adaptation of attention and performance to a given context in the dorsolateral prefrontal cortex (DLPFC). Thus, the ERN would reflect an affective response to errors, a special case of conflicts. In this regard, the expected finding is that negative emotions boost cognitive resources devoted to error processing (for a review see Dignath et al., 2020). Nevertheless, results of emotional manipulations on error processing are sometimes ambiguous, and it has been shown that positive emotions can also enhance the ERN amplitude (Larson et al., 2006). Another error processing index is the Error Positivity (Pe), a positive deflection occurring at about 250 to 350 ms post-error response, which is thought to reflect the strength of accumulated evidence that an error has occurred (Steinhauser & Yeung, 2010). Additionally, the Pe has been associated with later conscious processes such as compensatory adjustments, emotional appraisal and overall error awareness (Shalgi & Deouell, 2012, 2013).

In this experiment we used a backward masking paradigm to present high – and low-status figures with different emotional expressions (happy, angry and neutral), and participants performed a flanker task inducing error responses. We expect that the masked presentation of external social and emotional cues would modulate, both alone and in combination, internal performance monitoring processes. As evidences suggest that high-status figures increase attention, we predict that this would consequently boost error-monitoring processes, showing larger amplitudes for both ERN and Pe by high relative to low-status figures. On the other hand, the affective-signaling hypothesis points out that errors trigger negative affect and predicts that negative emotions even increase error processing to a greater extent. Accordingly, we expect larger amplitudes of ERN and Pe by angry in comparison to happy and neutral faces. Given the lack of previous studies combining social cues, predictions about the interaction effects of social status and face expressions are necessarily exploratory and speculative. Even so, we predict that emotional expressions would modulate the effects of social ranks on error monitoring. That is, angry faces would reinforce the effects of high-status figures, showing greater ERN and Pe amplitudes in comparison to low-status ones. As neutral faces would not show an emotional effect, high-status relative to low-status figures would yield larger ERN and Pe amplitudes. Finally, if happy masked expressions elicit a positive affect, they would reduce the ERN and Pe and both high and low-status figures would show similar effects.

2. Methods

2.1. Participants

Forty-four native Caucasian participants (26 females, 18 males) ranging from ages 18 to 29 years (M = 23.5, SD = 2.03) were initially included in this study. Then, data for four participants were discarded (4 females) due to technical artifacts and incompletion of the task. They all had normal or corrected-to-normal vision and had no documented history of neural or psychiatric disorders. The handedness percentage score was 58.65%, ranging from −4 to 100%, according to the Edinburgh Handedness Inventory (Oldfield, 1971). The study was carried out according to the Declaration of Helsinki and approved by the ethics committee of the Center for Human Evolution and Behavior, UCM-ISCIII, Madrid, Spain. Prior to the experiment, subjects signed their informed consent, and were reimbursed at the end of the study.

2.2. Stimuli and task

Subliminal stimuli consisted of six images that were the orthogonal combination of three emotional expressions (happy, angry and neutral) and the military uniform of a soldier (low-status rank) or of a general (high-status rank). The faces were superimposed to the military uniforms in a naturalistic combination using Adobe Photoshop®. Face stimuli comprised colored images of the frontal view of one Caucasian individual from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist et al., 1998) which has been validated (Goeleven et al., 2008). Size and position of faces and uniforms were matched in all subliminal images. Contrast of these images was equalized and reduced to maintain these stimuli subliminal (Figure 1). Their mean luminance values slightly varied because the different insignias in their attires corresponded to the symbolic cues denoting status. For the high status the mean value was 22.46 cd/m2 (SD = 40.84) and for the low status 29.42 cd/m2 (SD = 40.84) within a range from 0 to 255 (RGB scale). The mask consisted of a neutral face (for similar procedures, see Costen et al., 1994) surrounded by a pattern of randomly generated colored ovals, shown just after the subliminal stimulus (backward masking). Interestingly, the backward masking, in comparison to other techniques, has been the only one that has demonstrated non-conscious affective processing for both happy and angry faces (Almeida et al., 2013). The neutral face mask was spatially offset by 0.3º of visual angle relative to the subliminal stimulus, in order to avoid "morphing" effects that may occur when overlaying a neutral face over a subliminal emotional face (e.g., perception of movement in the face) (see Liddell et al., 2005).

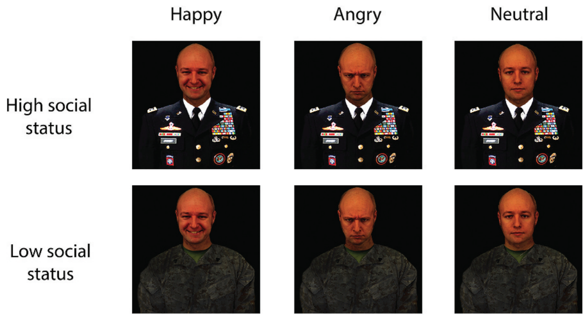

Figure 1. Examples of the subliminal stimuli; Social rank (low and high) by three Emotional expressions (happy, neutral and angry).

Participants completed an adapted version of the Eriksen Flanker task (Eimer, 2011), widely used in cognitive control research including error processing (i.e. Cavanagh & Allen, 2008; Cavanagh et al., 2009). The task consisted of different strings of five letters and the center letter could be either congruent (e.g., MMMMM or NNNNN, TTTTT or I I I I I, etc.) or incongruent (MMNMM or NNMNN, TTITT or II TII, etc.) with the flankers. Participants were instructed to press, as fast and accurate as possible, one of two buttons of the response box depending on whether the center letter of the string was one of either two visually similar letters, regardless of the flankers. In addition, they were instructed to look continuously at the center of the screen and to refrain from blinking as much as possible.

To confirm that the participants were not aware of the masked faces and uniforms, they performed a visibility task immediately after the ERP recording session. The visibility task consisted in 36 trials that were identical to the trial sequence in the main experiment, except that there was no flanker task. Instead, the subjects had to respond verbally after the presentation of the mask whether they had detected anything apart from the mask (subjective measure of visibility, Ramsøy & Overgaard, 2004). Although participants were deliberately looking for a subliminal stimulus prior to the mask, none of them reported to see the prime even once. The full experimental session lasted for about 50 minutes.

2.3. Procedure

All stimuli (subliminal primes, mask and letters strings) were presented white-on-black at the center of an LCD screen (60 Hz refresh) and controlled by Presentation®

Software (Neurobehavioral Systems). Participant's eyes were 65 cm from the screen, yielding viewing angles of 4.4º x 5.9º for the subliminal faces and of 13.3º x 13.3º for the whole subliminal images. During the flanker task, each combination of flankers and the center letter was specific, for reasons of visual similarity. The letters array extended 4.85º of visual angle horizontally and 0.88 º vertically.

Participants were seated in a sound-attenuated, electrically shielded room. Each trial began with a fixation cross with a random duration of 750, 1000, 1250 or 1500 ms drawn from a regular distribution. Thereafter, the subliminal stimulus (16 ms) was presented followed by the backward mask (200 ms). Immediately after, a letter string appeared for 100 ms followed by a blank screen lasting for a maximum of 2000 ms that allowed participants to respond. Participants were told that the appearance of the mask (the neutral face surrounded by the colored ovals) was merely an indication of the advent of trial's onset. A feedback on how fast or slow they were performing appeared in the screen every 24 trials, to give them a small break and motivate them to continue (the experimental procedure of the task is shown in Figure 2).

The full experimental session consisted of a training phase of 4 trials and a series of 40 blocks of 48 trials each in the experimental phase. In each block, a letter (e.g., F or E) would be assigned to the left – or right-hand response buttons and in the subsequent block, the target-hand mapping was reversed to increase response conflict. The pairs of letters to be discriminated varied across the blocks. In total, the experimental phase was composed of 1920 trials (60% of them were congruent). Trials and sets were presented in random order. In each of the forty 48-trials sets, the subliminal primes were repeated 8 times.

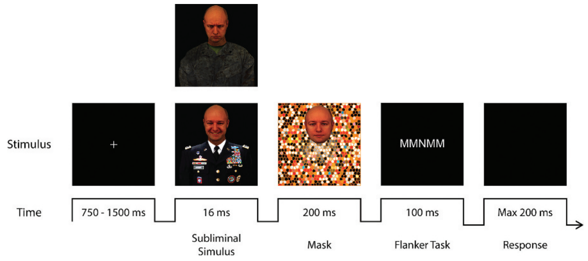

Figure 2. Experimental procedure depicting the subliminal presentation of social and emotional stimuli and the subsequent the flanker task.

2.4. EEG recording and preprocessing

Electroencephalographic (EEG) activity was recorded from 59 Ag/AgCl electrodes embedded in an electrode cap (Easy Cap®). Electrodes were placed according to the extended 10–20 configuration. All scalp electrodes were referenced online to the right mastoid – M2 – and re-referenced offline to the average of the left and right mastoids. Bipolar vertical and horizontal electrooculograms – EOG – were recorded for monitoring eye-related activity. Electrode impedances were kept below 5 kΩ. An online bandpass filter of 0.01–100 Hz was applied. Recordings were continuously digitalized at a sampling rate of 250 Hz for the entire session. The continuous recording was divided into 700-ms epochs time-locked to the response, with a baseline of 100 ms. Trials for which participants responded out-of-time (see behavioral analysis section) of did not respond were eliminated. Ocular artifacts were removed using Independent Component Analysis (ICA, Jung et al., 2000) as implemented in Brain Vision Analyzer® software. Following ICA-based correction, a semi-automatic artifact rejection was performed; first eliminating epochs exceeding ±100 µV, and second, discarding, by visual inspection, those still with artifacts. In the following we report the average number of trials per condition after artifact rejection (in parenthesis). To make it more clear, the 24 conditions are named with four letters where the first one indicates the Response factor (E for errors and C for correct responses), the second one indicates the Trial Type factor (C for congruent and I for incongruent), the third one indicates the Social rank factor (H for high and L for low) and the forth one indicates the Emotional expression factor (N for neutral, A for angry and H for happy): ECLN (20.02), EILN (28.67), ECLA (20.10), EILA (31,20), ECLH (21.67), EILH (30.75), ECHN (20.20), EIHN (30.2), ECHA (20.58), EIHA (29.62), ECHH (22.83), EIHH (29.12), CCLN (119.17), CILN (106.62), CCLA (117.32), CILA (104.72), CCLH (117.4), CILH (101.75), CCAN (118.15), CIHN (106.37), CCHA (116.95), CIHA (106.15), CCHH (116.37), CIHH (106.4). In total, there were 1642.33trials after artifact rejection; 1337,4 correct and 304,96 error responses. To maintain a good signal-to-noise ratio, a lower limit of 20 artifact-free trials per subject per condition was set. In this regard, evidences on the number of trials needed for a stable ERN and Pe signals, recommend a minimum of 14 trials (Larson et al., 2010).

2.5. Data analysis

Statistical contrasts were performed using the SPSS software package (Version 25; SPSS Inc, Chicago, US).

Repeated-measures ANOVAs were calculated on the number of responses, reaction times (RTs) and ERP data including as factors: Response (correct, error), Trial type (congruent, incongruent), Status rank (high, low), and Emotional expression (happy, neutral, angry) as within-subjects' factors. The Greenhouse-Geisser (GG) epsilon correction was applied to adjust the degrees of freedom of the F-ratios when necessary, and post-hoc comparisons to determine the significance of pair-wise contrasts were made using the Bonferroni procedure. Effect sizes were computed using the partial eta-square (η2 p) method.

Behavioral analysis

The number of responses (correct, errors) and RTs in the Flanker task were analyzed. ANOVAs were performed on each behavioral measure separately. In the case of RTs, outliers, defined as responses above 1500 ms or below 100 ms, were excluded from the analyses.

ERP analysis: Detection, spatiotemporal characterization and quantification of relevant response-related ERP components (ERN, Pe)

Data reduction preserving most part of the variance was necessary to further analyze our complex 2 X 2 × 2 × 3 (24 conditions) design, considering 59 EEG channels X 150 digitalized voltages or "time points" X 40 participants matrix. Thus, data reduction was carried out through two-step Principal Component Analysis (PCA). This is a factorial procedure that groups variables that tend to covary, forming a single "factor" that retains most of the variance of the individual variables that form it. The decision on the number of factors to be selected in the two-steps PCAs was based on the scree test (Cliff, 1987), and extracted factors were submitted to promax rotation (Dien, 2010) using SPSS 25 software.

Data reduction in the time domain: temporal PCA: Detection and quantification of response-related (ERN, Pe) ERP components was carried out through covariance-matrix-based tPCA, an approach that has been repeatedly recommended for these purposes (Dien, 2010; Dien et al., 2005). In brief, the tPCA computes the covariance between all ERP time points, which tends to be high between those involved in the same component and low between those belonging to different components. The solution is a set of factors made up of highly covarying time points, which ideally correspond to ERP components. The temporal factor score, that is, the tPCA-derived parameter of the respective temporal factors is linearly related to amplitude. The matrix submitted to tPCA was formed by time points as variables (i.e. 150 time points corresponding to the interval from 0 time-locked to the response to 600 ms at 250 Hz: see section 2.4) and participants X conditions X channels (i.e. 40 × 24 X 59 = 56,649) as cases. The five temporal factors (TFs) selected through the scree test can be seen in Figure 3.

Based on all the accumulated evidences of error processing, the resulting TFs, Factor 3 (peaking at 60 ms) and Factor 2 (peaking at about 268 ms) were associated with ERN and Pe in ERPs grand averages, respectively (see Figure 4).

Data reduction in the topography domain: Both the TF3 and the TF2 scores resulting from the previous tPCA were submitted to scalp map PCA (sPCA). This PCA provides a reliable division of the scalp into the different regions or scalp factors (SFs) in which each TF is distributed. Basically, each spatial factor (i.e., a frontal or

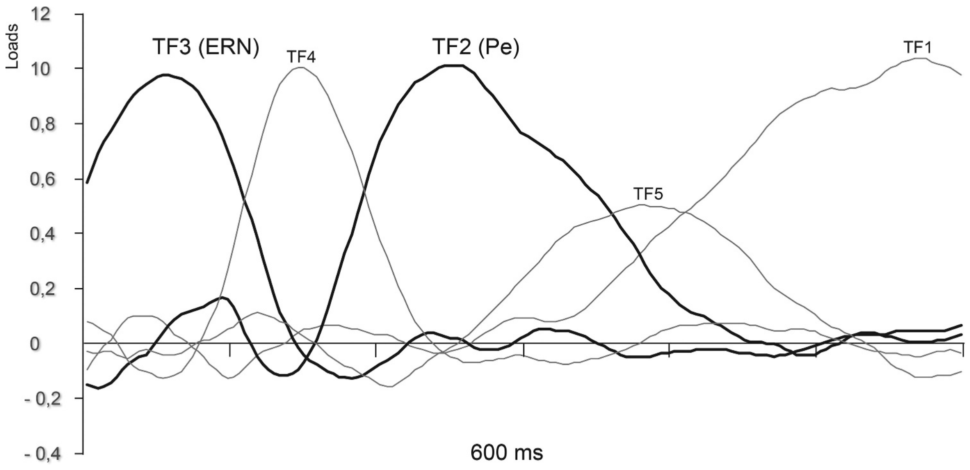

Figure 3. Temporal principal component analysis (tPCA): The Y axis shows the factor loadings after promax rotation and the X axis shows the 150 voltages points corresponding to the interval from 0 time-locked to the response to 600 ms at a sampling rate of 250 Hz. Temporal factors 3 (ERN) and 2 (Pe) are drawn in black.

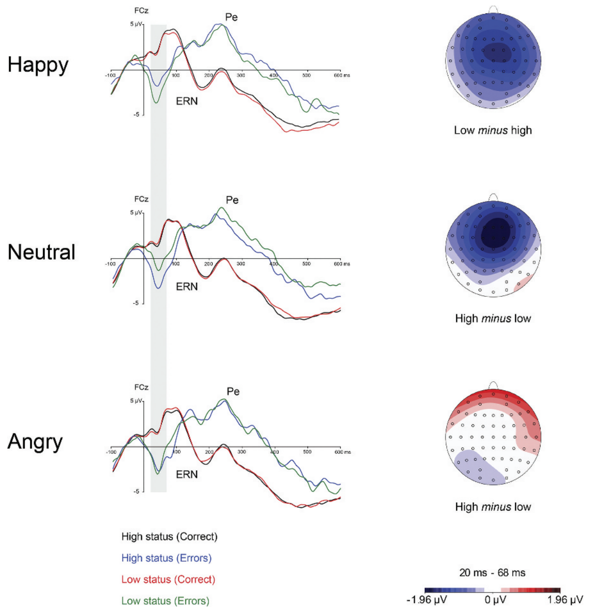

Figure 4. Grand Averages of ERN and Pe time-locked to the response. The figure shows the differences between the waveforms of the three Emotional expressions (happy, neutral and angry) and two Social ranks (high and low) in congruent trials for correct and error responses.

a posterior factor) is formed with the scalp points (i.e., electrode locations) in which the recordings tend to covary and, as a result, the shape of the sPCA-configured regions is functionally based. Each input matrix (one for ERN and one for Pe) consisted of 59 variables (i.e., EEG channels) and 960 cases (i.e., participants X conditions). By means of the scree test, three SFs (i.e., frontal, central and posterior) were selected for each of the two TF (ERN and Pe). Subsequently, SFs were submitted to promax rotation. Finally, repeated-measures ANOVAs were performed on ERN and Pe spatial factor scores, as described below.

3. Results

3.1. Behavioral data

Table 1. displays results from the repeated-measures ANOVA on the number of responses (correct, errors) and reaction times. Below, we only describe results of the main factors of interests (and its interactions).

Regarding the number of responses, the results showed significant main effects for: Response, with more correct (M = 122.08, SD = 21.54) than error (M = 25.41, SD = 10.47) responses, Social rank, with more responses (correct and errors) after high (M = 73.84, SD = 15.96) than low rank masked figures (M = 73.59, SD = 16.06) and Emotional expression, with more responses (correct and errors) after happy (M = 73.99, SD = 16.08) than after angry (M = 73.61, SD = 15.40) and neutral masked faces (M = 73.54, SD = 16.54). Although means are similar, differences are highly systematic along the sample and therefore the ANOVA analysis shows significant differences. On the other hand, we also observed several significant interactions. First, post-hoc contrast of the Response by Trial type interaction revealed more errors after incongruent relative to congruent trials ($p < 0.001$). Second, the interaction Trial type by Social rank showed more responses (correct and errors) after high relative to low rank ($p < 0.001$), only for congruent trials. Third, the Trial type by Emotional expression interaction showed more responses (correct and errors) after happy in comparison to both neutral ($p < 0.001$) and angry faces ($p < 0.001$), again only for congruent trials. Forth, the interaction of Social rank by Emotional expression factors showed that there were only more responses (correct and errors) after high relative to low for neutral masked faces ($p < 0.001$). Finally, this effect also interacted with Trial Type, revealing that it was observed only for congruent trials.

For RTs, the results yielded significant effects of Response and Trial type as main factors. As expected, participants were significantly faster in errors (M = 276.13 ms, SD = 88.75) relative to correct responses (M = 314.02 ms, SD = 58.82) and in congruent (M = 288.42 ms, SD = 77.70) relative to incongruent (M = 301.73 ms, SD = 69.86) trials. Results also showed a significant Response x Trial type interaction. Post-hoc comparisons revealed that only for correct responses, congruent trials yielded significantly slower RT than incongruent trials ($p < 0.001$). Neither Status rank nor Emotional expression, neither alone nor in interaction, were able to significantly affect RTs.

3.2. ERP data

Table 2 displays the results of all repeated-measures ANOVAs that contrast the magnitude of three Spatial Factors (SFs) per each Temporal Factor (TF) corresponding to the main ERPs components: ERN and Pe. In the following, we only describe results of the main factors of interests (and its interactions).

ERN: This component is defined by the difference between error and correct responses, and therefore a main effect of Response factor was found for all SFs, with greater amplitude for error than correct responses. Also, all three SFs showed a main effect of Trial Type with larger amplitudes for incongruent in comparison to congruent trials. Remarkably for the topographical distribution of the ERN, Frontal and Central SFs showed a significant interaction between two crucial variables of this experiment; namely, Social rank and Emotional

Table 1. Repeated measures ANOVA on the number of responses and RT from the flanker task. R = Response; T = Trial type; S = Social rank; EM = Emotional expression; df = degrees of freedom; n.s. = not significant, * p < 0.05, **p < 0.01, ***p < 0.001.

	R *(df = 1,39)*	T *(df = 1,39)*	S *(df = 1,39)*	EM *(df = 2,78)*	R x T *(df = 1,39)*	R x S *(df = 1,39)*	T x S *(df = 1,39)*	R x T x S *(df = 1,39)*	R x EM *(df = 2,78)*	T x EM *(df = 2,78)*	R x T x EM *(df = 2,78)*	S x EM *(df = 2,78)*	R x S x EM *(df = 2,78))*	T x S x EM *(df = 2,78)*	R x T x S x EM *(df = 2,78)*
Nº Responses	F = 486.71*** 2p = 0.92	F = 0.16, n.s	F = 10.30** 2p = 0.20	F = 8.41** 2p = 0.17	F = 150.95*** 2p = 0.79	F = 2.47, n.s	F = 11.01** 2p = 0.22	F = 0.70, n.s	F = 1.04, n.s	F = 13.24** 2p = 0.25	F = 1.40, n.s	F = 8.10** 2p = 0.17	F = 1.72, n.s	F = 12.44*** 2p = 0.24	F = 0.57, n.s
RT	F = 30.75*** 2p = 0.44	F = 24.47*** 2p = 0.38	F = 0.00, n.s	F = 0.33, n.s	F = 53.31*** 2p = 0.57	F = 0.00, n.s	F = 0.15, n.s	F = 1.32, n.s	F = 1.01, n.s	F = 0.51, n.s	F = 0.08, n.s	F = 0.22, n.s	F = 0.26, n.s	F = 1.10, n.s	F = 0.64, n.s

Expression. More specifically, post-hoc analysis in the frontal spatial factor revealed significantly larger amplitudes for high relative to low rank for neutral subliminal expressions. Importantly, these effects also interacted with Response and Trial type factors, and the results showed complex effects of social variables over the processing of errors only after congruent trials, as reflected by the ERN (see Figure 4). Indeed, the ERN was larger for high relative to low rank for neutral faces ($p < 0.01$), and, conversely, it was larger for low relative to high rank for happy faces, although this difference was supported by trend for significance. No differences were observed for angry emotional expressions in the processing of social ranks during errors.

Pe: Again, this component is defined by the difference between error and correct responses, thus, a main effect of Response was found for Central and Posterior spatial factors, with larger amplitudes for errors in comparison to correct responses. In addition, for both central and posterior SFs, post-hoc contrasts of the interaction Response by Trial type revealed larger amplitudes for congruent relative to incongruent error responses ($p < 0.01$). Importantly, although Figure 4 might suggest that the Pe could be different between social ranks in the neutral and happy conditions, we were not able to find statistically significant modulations of the Pe, neither by Social rank, Emotional expression, nor their interaction.

4. Discussion

This work aimed at extending current knowledge on how complex social stimuli may have an unconscious effect on high-level cognitive processes and behavior. Specifically, we investigate unconscious effects of social and emotional cues on error processing mechanisms. For this purpose, we presented subliminal figures with military uniforms denoting two status ranks (high and low) with three possible emotional expressions (happy, neutral, angry), and participants performed a letter flanker task. We focused on ERN and Pe ERPs components as electrophysiological indexes of error processing.

4.1. Behavioral data

As expected, findings showed more correct responses than errors and faster reaction times for the latter. We did not observe a significant difference in the number of responses between congruent and incongruent trials, but participants responded faster to the former, being this a general finding in cognitive conflict research (Holroyd & Coles, 2002). Regarding social rank effects, we observed more responses during congruent trials when a high-rank relative to a low rank was presented.

Table 2. Repeated measures ANOVAs for each SFs (frontal, Central and posterior) of the two TFs (ERN and Pe). TF = Temporal Factor; SF = Spatial Factor; R = Response; T = Trial type; S = Social rank; EM = Emotional expression; df, degrees of freedom; n.s., not significant, *p < 0.05, **p < 0.01, ***p < 0.001.

TF	SF	R (df = 1,39)	T (df = 1,39)	S (df = 1,39)	EM (df = 1,39)	R x T (df = 1,39)	R x S (df = 1,39)	T x S (df = 1,39)	R x T x S (df = 2,78)	R x EM (df = 2,78)	T x EM (df = 2,78)	R x T x EM (df = 2,78)	S x EM (df = 2,78)	R x S x EM (df = 2,78)	T x S x EM (df = 2,78)	R x T x S x EM (df = 2,78)
TF3 (ERN) (60 ms)	**Frontal**	F = 20.08*** 2p = 0.34	F = 4.59* 2p = 0.1	F = 0.25, n.s.	F = 0.90, n.s.	F = 1.74, n.s.	F = 0.01, n.s.	F = 1.54, n.s.	F = 0.85, n.s.	F = 0.16, n.s.	F = 0.803, n.s.	F = 0.18, n.s.	F = 4.95* 2p = 0.11	F = 1.34, n.s.	F = 2.35, n.s.	F = 3.47* 2p = 0.08
	Central	F = 43.63*** 2p = 0.52	F = 13.48** 2p = 0.25	F = 1.74, n.s.	F = 0.62, n.s.	F = 0.10, n.s.	F = 3.10, n.s.	F = 0.82, n.s.	F = 0.51, n.s.	F = 0.81, n.s.	F = 0.05, n.s.	F = 0.11, n.s.	F = 3.22* 2p = 0.07	F = 0.91, n.s.	F = 2.82, n.s.	F = 2.60, n.s.
	Posterior	F = 42.30*** 2p = 0.52	F = 5.48* 2p = 0.12	F = 0.13, n.s.	F = 0.37, n.s.	F = 15.70*** 2p = 0.28	F = 0.45, n.s.	F = 1.59, n.s.	F = 1.03, n.s.	F = 0.94, n.s.	F = 1.85, n.s.	F = 1.42, n.s.	F = 0.82, n.s.	F = 1.03, n.s.	F = 0.78, n.s.	F = 1.56, n.s.
TF2 (Pe) (268 ms)	**Frontal**	F = 2.62, n.s.	F = 4.39* 2p = 0.10	F = 1.16, n.s.	F = 0.08, n.s.	F = 1.04, n.s.	F = 0.54, n.s.	F = 0.06, n.s.	F = 0.94, n.s.	F = 0.16, n.s.	F = 0.08, n.s.	F = 0.26, n.s.	F = 2.64, n.s.	F = 0.62, n.s.	F = 0.12, n.s.	F = 0.89, n.s.
	Central	F = 69.93*** 2p = 0.64	F = 8.75** 2p = 0.18	F = 0.05, n.s.	F = 0.78, n.s.	F = 4.29* 2p = 0.09	F = 1.61, n.s.	F = 0.00, n.s.	F = 0.00, n.s.	F = 0.22, n.s.	F = 0.21, n.s.	F = 0.19, n.s.	F = 0.38, n.s.	F = 0.22, n.s.	F = 1.23, n.s.	F = 1.78, n.s.
	Posterior	F = 71.32*** 2p = 0.64	F = 0.06, n.s.	F = 3.34, n.s.	F = 1.43, n.s.	F = 14.00** 2p = 0.26	F = 0.09, n.s.	F = 0.84, n.s.	F = 1.42, n.s.	F = 2.83, n.s.	F = 2.76, n.s.	F = 1.76, n.s.	F = 1.96, n.s.	F = 0.57, n.s.	F = 0.61, n.s.	F = 0.09, n.s.

In the same line, social rank and emotional expression main factors interacted on the number of responses during congruent trials. That is, only masked neutral faces induced more responses when presented with a high-rank attire in comparison to a low one. These results fit well with our prediction that high social ranks generally increase attention (Balconi & Pagani, 2015; Klein et al., 2009) which, may enhance the monitoring of ongoing actions (Van Noordt et al., 2015), resulting in a better performance. On the other hand, emotional expression effects showed more responses for congruent trials when a happy face was presented relative to both angry and neutral faces. In support to this emotional effect, it has been shown that subliminal affective faces enhance target selection (Lu et al., 2011), probably due to an increase of attentional resources (Carlson & Reinke, 2010).

4.2. ERPs data

In line with behavioral effects on the number of responses, main electrophysiological results were observed only during congruent trials. Most studies only analyze incongruent trials, normally because both congruent and incongruent are considered equivalent while there is a reduced proportion of the former (Davies et al., 2001; Steinhauser & Kiesel, 2011). However, others analyze both congruent and incongruent separately, since they seem to be differentially affected by uncertainty and post-response conflict (Danielmeier et al., 2011). In fact, committing an error is easier during incongruent trials, while errors in congruent trials are more conspicuous. Supporting this idea, a number of studies have found larger ERN to congruent in comparison to incongruent trials (Forster & Pavone, 2008; Maier et al., 2008; Scheffers & Coles, 2000), and this difference has shown to be sensitive to certain social factors, like age (Nieuwenhuis et al., 2002). In our study, one possible explanation that subliminal social cues only affected congruent trials is that errors in these trials are more aversive and produce lower levels of uncertainty. A more plausible explanation, however, is that the effects are restrained enough as to be visible only when the error-related ERP modulations were larger. Further studies are necessary to settle this issue.

Regarding the error processing indexes explored here, we only observed significant modulations of ERN, as Pe was unaffected by the subliminal social cues. Then, complex social stimuli were not able to have an impact on higher-level error-monitoring processes, as indexed by the Pe component (Shalgi & Deouell, 2012, 2013). Contrary to our predictions, we did not find ERN effects neither by social rank nor by emotional expressions as main factors. These findings might be the consequence of both the subliminal presentation and the strength and relevance of the combination of complex social cues. In fact, results showed interaction effects of social rank and emotional expression on ERN. In line with behavioral results, only neutral faces elicited a differential processing for social rank information at the post-response stage. Furthermore, this effect extended to erroneous congruent trials. According to our expectations, high rank drove these effects, inducing a larger ERN amplitude as compared to low rank. As we mentioned previously, it is a well-known finding that high social hierarchies increase attention resources (e.g., Breton et al., 2014, 2019; Feng et al., 2015; Santamaría-García et al., 2015). In this regard, the ERN not only reflects the automatic detection of errors (Yeung et al., 2004), but an increase in attentional control of ongoing actions (Van Noordt et al., 2015). Then, high-status figures may increase error detection by boosting attention. Similarly, and according to the affective signaling hypothesis (Dignath et al., 2020), high-status figures may enhance the negative affect generated by errors, and this, in turn, may trigger increased attention and monitoring in the flanker task.

Of interest, the effect of social rank was only observed for neutral faces. A neutral expression is normally used in research as a baseline, a stimulus that does not elicit any kind of emotion. Nevertheless, behavioral and neuroimaging evidences suggest that we perceive traits of emotional expressions in neutral faces, and this leads to an emotional and neurocognitive response. For example, Carvajal et al. (2013) found that neutral faces evoke the activation of a complex brain network that includes areas of facial expression processing. Interestingly, they also observed that during a social task, neutral faces increased the cognitive load of executive control more than emotional faces. In the same vein, a recent study (Kouptsova et al., 2017) showed a greater orbitofrontal activation for neutral faces during a short presentation in comparison to a long one. This suggests that it is specifically at short stimulus duration when the task taxes executive control more for neutral than emotional faces. Our findings seem consistent with these studies. Neutral faces, due to their ambiguity, may require higher cognitive effort than angry and happy faces to ascertain their social significance, especially at a short subliminal presentation. Furthermore, when presented with high-rank figures, neutral faces would elicit even greater attention resources to perform the ongoing task and supervising errors.

On the other hand, masked angry and happy faces in combination with social rank figures would not increase enough the level of attention to have an impact on error monitoring. These results are contrary to some of our initial predictions. We expected that angry masked faces and high-status cues would drive the strongest effects on error monitoring. Conversely, results showed statistically comparable ERN amplitudes for high and low ranks presented with both angry and happy expressions. The scarce previous evidence showing an enhancement of ERN by negative faces, have used expressions of disgust (M. A. Boksem et al., 2011). It could happen that angry faces did not activate enough the error-monitoring system, because they mainly affect another brain network at short presentations (Nomura et al., 2004). Regarding happy expressions, our predictions fit with the results. If happy faces elicited a positive affect, the negative affect produced by errors may have been counteracted. As a consequence, the system would not process the two social ranks differently. However, these interpretations should be considered with caution. Only few studies have induced phasic affect with presentations of emotional stimuli prior to a flanker paradigm or similar. Some have found an increase of the ERN amplitude following negative pictures (Wiswede et al., 2009), and others observed the opposite; an enhancement of ERN amplitude by positive pictures (Larson et al., 2006). Then, it is not clear yet the ways by which emotional stimuli have an impact on error monitoring, and more research is needed to clarify this ambiguity of results. If we add to this ambiguity, the complexity of the social cues and the subliminal presentation used here, these unexpected findings are not that surprising.

It is important to highlight some limitations of the present work. The combination of social and emotional cues and all the variables of the flanker task gave rise to a large number of conditions. Although our sample size was considerably high, the fact of analyzing twenty-four conditions may have affected the statistical power. In this regard, a less complex design would have allowed to explore more basic aspects with higher confidence and more robust statistical results. On the other hand, error monitoring processes have been shown to be affected by subjective (Shalgi & Deouell, 2012, 2013). and clinical variables (Dignath et al., 2020). In our study, however, we did not consider any individual differences, and the heterogeneity of the sample may have also affected the statistical power. It seems of interest that future research explores this topic.

Notably, this study contributes substantially to the current knowledge on how the brain automatically computes and integrates complex social cues. Although the effects may be subtle and limited, our results establish that the unconscious processing of social and emotional cues affect error monitoring, especially when a high social status figure with a neutral face expression is presented. In turn, this study demonstrates the worth of using contextualized faces in social neuroscience research, adding ecological value to our findings. Indeed, we are constantly exposed to complex social stimuli and we have found this have an impact on how we monitor our own behavior, even in the absence of consciousness awareness.

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