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ARTICLE



Seeing is believing: Early perceptual brain processes are modified by social feedback

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ABSTRACT

Over 6 decades ago, experimental evidence from social psychology revealed that individuals could alter their responses in perceptual judgement tasks if they differed from the prevailing view emitted by a group of peers. Responses were thus modulated to agree with the opinion of the social group. An open question remains whether such changes actually reflect modified perception, or whether they are simply the result of a feigned agreement, indicating submissive acceptance. In this study, we addressed this topic by performing a perceptual task involving the assessment of ambiguous and distinct stimuli. Participants were asked to judge the colours of squares, before, and after receiving feedback for their response. In order to pinpoint the moment in time that social feedback affected neural processing, ERP components to ambiguous stimuli were compared before and after participants received supposed social feedback that agreed with, or disputed their response. The comparison revealed the presence of differences beginning already 100ms after stimulus presentation (on the P1 and N1 components) despite otherwise identical stimuli. The modulation of these early components, normally thought to be dependent on low-level visual features, demonstrate that social pressure tangibly modifies early perceptual brain processes.

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ERP; visual perception; P1; social feedback; uncertainty

Introduction

Almost 70 years ago, Solomon Asch (1951), in a series of simple perceptual judgment experiments, observed that individuals would sometimes alter their responses to conform to the prevailing view emitted by their peers. Some 20 years later, Moscovici, Lage, & Naffrechoux, (1969), using a blue/green colour perception task, showed that even a minority expressing a consistent opinion, can lead participants to modify their responses in the long run. What is particularly significant in this latter study is the authors' conclusion that response modification appears best accounted for as a change in perception than a simple verbal agreement. However, whether social influence has an actual effect on perceptual processes per se, or whether such changes in representation affect later, higher-level processes associated with perception in a top-down manner, remains to be clarified with the methods of neuroscience.

One way by which neuroscientific research may inform us whether conformity acts on later, more elaborate cognitive levels, or whether it influences an

individual's actual perception, is by investigating the effect of group opinion on neural processing of visual stimuli. Few studies have examined the impact of conformity on early levels of perceptual and attentional processes as opposed to later, post-perceptual (e.g., executive) effects (Berns et al., 2005; Stapel & Koomen, 1997; Trautmann-Lengsfeld & Herrmann, 2013), despite the suggestion already raised by Asch (1951) that social pressure could alter perception. The first investigation in this area was provided by Berns et al. (2005) using fMRI, who found evidence of alterations in perceptual processing (i.e., in occipito-parietal networks) when subjects were confronted with incorrect peer feedback regarding the degree of rotation of an abstract figure. However, the limited temporal resolution of hemodynamic measures does not allow their finding to be identified as an early or late process. Determining its temporal characteristics would prove highly revealing as this would indicate whether this activity arises rapidly, during the visual processing phase, or long after higher-order, top-down processing has begun (Henson & Rugg, 2003).

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 Supplementary data for this article can be accessed [here](#).

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Electroencephalography (EEG) and event-related potentials (ERP) can extricate the temporal unfolding of this socially induced effect, and was consequently used by Trautmann-Lengsfeld and Herrmann (2013) to investigate whether social context affected early perceptual processes (see also: Herrmann & Knight, 2001) or not. In their study, participants were shown visual stimuli side by side and were asked to select one of the two on the basis of a perceptual criterion. Simultaneously, an indication was provided alongside the stimuli, informing the participants of the response given by the supposed social group. The findings revealed that the P1 (a positive deflection occurring over posterior electrodes at around 100 ms in response to a visual stimulation) was smaller in amplitude when participants' response conformed with the group's incorrect response. This very interesting study therefore concluded that social influence acts on early levels of visual processing. However, the authors did not find any significant difference in P1 amplitude when participants adapted to the group's incorrect judgment compared to the condition where they refused to do so, thus mitigating the conclusions. Furthermore, the presentation of lateralised stimuli necessitated left vs. right-sided comparisons, which necessarily produces modulations of early ERP components sensitive to the direction of spatial attention (Luck, Heinze, Mangun, & Hillyard, 1990). Additionally, the simultaneous presentation of competing stimuli and the group's decision does not allow, strictly speaking, the study of revised judgments by participants, which could be better investigated using sequential stimulus presentations with indications of social feedback presented in between.

The purpose of the present study was thus to address the question of whether social influence impacts on early perceptual processes in situations of uncertainty induced by ambiguous stimuli. For this, we recorded EEG while examining the effects of social feedback while participants performed a visual discrimination task. We manipulated stimulus ambiguity, as previous studies have robustly demonstrated that social influence is most effective in situations of ambiguity and uncertainty (Cialdini & Goldstein, 2004). Inspired by a couple of studies that investigated the role of consensus in metacognition (Eskenazi et al., 2016; McCurdy et al., 2013), a novel experimental paradigm was created allowing us to measure event-related potentials (ERPs) in response to visual stimuli that were presented before and after social feedback, the latter being given by a face that either endorsed (i.e., displayed a happy face) or disputed (i.e., displayed a disgusted expression) the participant's judgment. Participants were asked to judge the colour of a square (the probe) that was either of a distinct blue or green colour (termed "distinct probe"), or was of a highly ambiguous bluish-green hue ("ambiguous

probe"). They were also asked to indicate the level of confidence of their judgment. Participants then received social feedback and the probe was presented once again for re-evaluation and judgment.

We hypothesised that participants would adapt their response to the opinion of the purported group when the stimulus was ambiguous and the social group disputed the participant's response. We focused on the visual P1 and N1 components locked to the presentation of the probe stimuli (coloured squares), before and after social feedback. These components are considered to be the earliest electrical marker of visual processing, and are influenced both by the low-level features of the stimuli (Johannes, Münte, Heinze, & Mangun, 1995), and by attentional processes (Luck et al., 1990). However, as low-level features were strictly controlled and no variations were operated on attention, any differences would only be attributable to an influence of social pressure. We predicted that if social influence acted directly on perceptual processes, changes should be observed on these early components, while changes on an explicit level would more likely be reflected on later components.

Materials and methods

Participants

Twenty-two students were recruited using posters placed at the University of Geneva (13 females, 9 males; mean age = 25.14, SD = 3.61). All the participants were right handed (mean laterality coefficient = 71.96, SD = 20.97 (Oldfield, 1971)), had normal or a corrected-to-normal vision and had no self-reported psychiatric or neurological disorder. The participants all reported that they were heterosexual and were not colour blind. They were paid 50 Swiss francs for their participation.

Stimuli and experimental procedure

Participants were presented with stimuli that displayed either an unequivocal, distinct colour (blue or green), or an ambiguous one (greenish-blue). They were asked to respond by indicating the colour that they thought was presented. Subsequently, they were given alleged social feedback, which they were told was the response of the majority of a sample population of women and men, tested beforehand. They were told that a happy face would indicate that their response was consistent with the majority, while a face expressing disgust would indicate that their response was in disagreement with the majority of other participants. They were then shown the identical probe once again and were asked

for a second judgment, either revising their initial response, or maintaining their decision.

The stimuli consisted of 32 coloured squares (probes) displaying different shades of blue and green, displayed on a white background. Eight distinct colours were clearly and unmistakably identifiable as green (hereafter distinct green), and 8 others as blue (hereafter distinct blue). The 16 remaining stimuli were made up of colours that were highly equivocal. These ambiguous probes were produced by changing the ratio of green, blue and red while maintaining overall luminance (minimum saturation: 28.17 cd/m²; maximum saturation: 30.73 cd/m²). As a result, for these 16 ambiguous, greenish-blue probes, 8 displayed a slightly greener hue (ambiguous green) and 8 a slightly bluer hue (ambiguous blue).

The faces used for social feedback in this experiment were 10 male and 10 female identities expressing happiness and disgust, taken from the Radboud Faces Database (Langner et al., 2010). All the stimuli measured 10 cm horizontally and 10 cm vertically and subtended a visual angle of 5.73° when seen from the participants' viewing distance of 100 cm.

Participants were given instructions regarding the task and gave their informed consent to participate in the study prior to electrode placement. The experiment began with a practice session. Once the task was fully understood, the experiment proper began.

The experiment was divided in three blocks of 160 trials, for a total of 480 trials. Each trial was composed of an initial evaluation of the probe, a social cue providing feedback, and a second (post-cue) presentation of the same probe for re-evaluation. Figure 1 illustrates the sequence of each trial in detail. These began with a fixation cross, presented for a random duration between 400 and 600 ms. A coloured square was then presented for 800 ms and was followed again by a fixation cross (between 400 and 600 ms). The letters V (which stands for "vert", or green in French) and B (blue) were then presented on the left and right of the fixation cross and participants were instructed to indicate the perceived colour of the stimulus as quickly as possible by means of a key press. If no response was given, the display disappeared after 3000 ms. The response options were indicated by two stickers placed on the computer mouse, representing letters V and B that participants pressed with their right forefinger and middle finger. Correspondence between response finger and colour was counterbalanced across subjects. After the response, a fixation cross appeared for 400–600 ms, this was followed by the self-confidence evaluation represented by a scale ranging from 1 (uncertain) to 5 (certain). The fixation cross then reappeared for 400–600 ms, followed by the social feedback cue for 1000 ms, represented as a face (male or female, 50% each), displaying an expression either of happiness

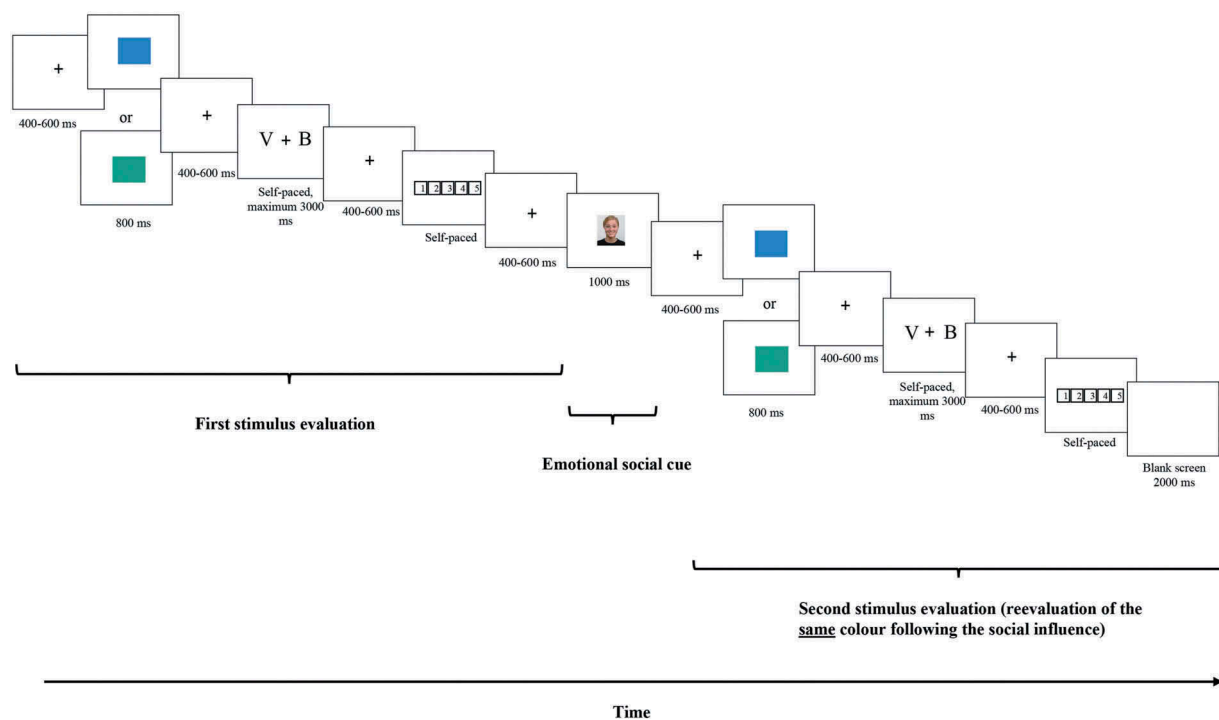


Figure 1. Example of an experimental trial. A distinct blue (top) and distinct green square (bottom) is illustrated, but only one probe was presented in each given trial. Here, the social cue is a happy face, thus indicating endorsement.

or of disgust. The participants were told that when the face expressed a happy emotion, their response corresponded to that given by the majority of former participants, whereas an expression of disgust indicated that their response differed from the majority. In actual fact, the expression was assigned randomly for each trial. In order to maximise credibility, probes composed of distinct colours (easily identifiable by participants) were always followed by a social cue indicating endorsement (i.e., a happy face).

After feedback, a fixation cross re-appeared for 400–600 ms, followed by the same probe again for 800 ms. A second judgement was then required, followed by a self-confidence rating, in the same manner as the first (see [Figure 1](#)). A blank screen (2000 ms) appeared at the end of this sequence, marking the end the trial. A total of 160 trials were presented in each of the three conditions (ambiguous endorsed, ambiguous disputed, distinct endorsed).

After the EEG experiment, participants were asked to evaluate the credibility of the social cue by indicating their level of belief on a 3-point scale (1: never believed in it; 2: believed in it sometimes; 3: always believed in it).

The study was accepted by the local ethics committee (University of Geneva) and was performed in agreement with the Declaration of Helsinki.

EEG acquisition

EEG was recorded using a 128-channels Biosemi Active-Two system (Amsterdam, Netherlands) with AG/AgCl electrodes positioned according to the extended 10–20 system. We used four additional flat electrodes, which were placed on the outer canthi of the eyes and above and under the right eye, in order to capture the eye movements and blinks. Each active electrode is represented with an impedance value, which we tried to keep below 20 k Ω for each participant. The EEG was continuously recorded with a sampling rate of 1024 Hz. Data was re-referenced off-line against the average reference.

EEG processing

Standard processing of EEG data was done offline using the software Brain Vision Analyzer V.2 (Brain Products, Gilching, Germany). The data was downsampled to 512 Hz. For the coloured square stimuli, epochs were computed from 200 ms prior to 800 ms after stimulus onset. Bad electrodes were removed and interpolated using a spherical spline (5.6% of the electrodes were interpolated in this way). A baseline correction was applied using the 200 ms prestimulus period. ERPs were obtained by averaging the trials for each

condition, on the data that was filtered with a low-cutoff at 0.1 Hz and a high-cutoff at 30 Hz. Ocular correction was performed on the EEG using the implemented standard algorithm (Gatton, Coles, & Donchin, 1983), in order to correct for eye movements and blinks. Trials with other artefacts were removed using a semi-automatic procedure following each stimulus presentation (amplitude allowed: $-100 \mu\text{V}$ to $+100 \mu\text{V}$). Accordingly, the mean number of segments retained per condition was 130 ± 22 trials (out of 160) for the ambiguous endorsed condition, 130 ± 22 trials (out of 160) for the ambiguous disputed condition and 127 ± 24 trials (out of 160) for the distinct endorsed condition. A total of 19% of the trials were removed.

Behavioural analysis

Trials in which participants revised their judgement after social feedback were counted as “revisions”. The mean number of revisions was calculated according to the ambiguity of the probe and the emotion of the social cue.

Statistical analyses of behavioural results were performed using repeated-measures ANOVAs. To examine the effect of the social cue on perceptual judgement, we carried out an ANOVA for repeated-measures, using the number of revisions as the dependent variable and “condition” (ambiguous endorsed vs ambiguous disputed vs distinct endorsed) as the within-subject factor.

Electrophysiological recordings and analysis

ERPs were computed for the distinct and ambiguous probes in the initial and post-cue presentations. Additional analyses were performed on the ERPs of the happy (endorsement) and disgusted (dispute) faces and are reported in the Supplemental material.

Early stages of processing were investigated by examining the P1 and N1 components in the different conditions, i.e., following the onset of the initial probe and following the onset of the post-cue probe. Peaks were determined using a semi-automatic peak detection method. The time windows of investigation were determined on the basis of the peaks observed in the grand averages across all conditions using a collapsed localizer (Luck, 2014). In this manner, P1 was measured over electrodes A14, A15, A16, A27, A28, A29 in the time window from 70 ms to 180 ms, and N1 was obtained from electrodes A9, A10, A11, B6, B7, and B8 in the time window from 160 ms to 240 ms (see [Figure 2](#) for electrode positions).

The EEG data were analysed using separate repeated-measures ANOVAs that aimed to identify the effect of

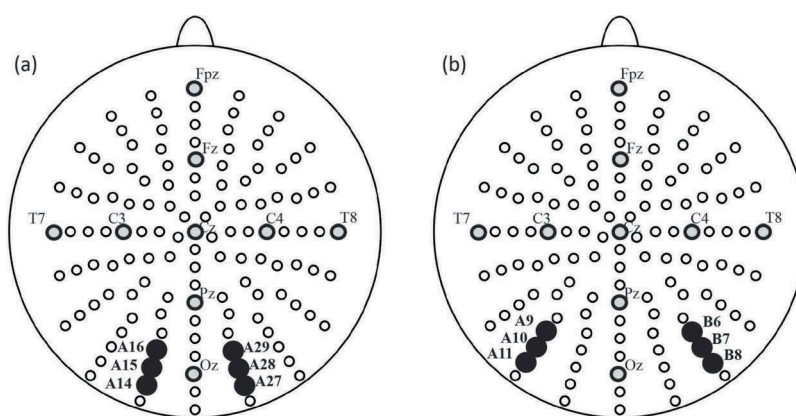


Figure 2. Electrodes retained for analysis. All channels are represented as open circles situated on a view of the scalp seen from above (nose on top, left side on the left). Electrodes used for analysis are indicated with full black circles. (a) the P1 component included electrodes A14, A15, A16 over the left and A27, A28, A29 over the right occipital regions (b) the N1 component included electrodes A9, A10, A11 on the left and B6, B7, B8 on the right.

social feedback on the early P1 and N1 components of the probes. For this, 2 (presentation: initial vs. post-cue) \times 2 (laterality: left vs. right) repeated-measures ANOVAs were performed on the mean latencies and amplitudes obtained over the electrodes within the regions of interest. In order to maintain credibility, our design deliberately excluded the condition in which distinct colours were “disputed” by the social group. Consequently, 3 conditions were presented: distinct stimuli that were endorsed by the alleged social group, ambiguous stimuli that were endorsed and ambiguous stimuli that were disputed. Separate ANOVAs were performed for each of the 3 conditions.

An effect of social cue was expected for the ambiguous disputed condition.

For clarity, only relevant comparisons are reported in the Results.

Results

Among the twenty-two subjects, one participant was excluded due to high number of artefacts. The following analyses (behavioural and EEG) were carried out on twenty-one subjects (nine men and twelve women).

Behavioural results

An ANOVA was performed on the number of revisions, using condition (ambiguous endorsed, ambiguous disputed and distinct endorsed) as a within-subject factor, which revealed a significant main effect of condition $F(2, 40) = 20.6$, $p < .10^{-4}$. Post-hoc comparisons carried out using Tukey tests revealed a significantly greater number of revisions for ambiguous disputed (26.3%) compared to ambiguous endorsed (4.7%) and distinct endorsed

probes (1.4%) ($p < .10^{-4}$ for ambiguous disputed vs ambiguous endorsed; $p < .10^{-5}$ for ambiguous disputed vs distinct endorsed). The number of revisions did not differ significantly between ambiguous endorsed and distinct endorsed conditions ($p > .05$) (Figure 3).

Results of the self-report questionnaire revealed that 70% of the participants always believed in the social cue, while 19% stated that they believed in it occasionally and 11% reported that they did not. Importantly, participants who reported not to have believed the social cue, still produced changes after their initial response to match the social feedback. Subjects reporting disbelief in the social feedback revised on average 6% of their judgments, compared to 9% for those who claimed an occasional belief and 12% for those who reported a full belief in the social feedback.

In summary, the behavioural results showed that the majority of participants considered the social feedback to be credible, and when challenged in their judgement regarding ambiguous probes, generated a significantly greater number of revisions than when these probes were endorsed.

Electrophysiological results

ERPs

P1 amplitude. A 2 (presentation: initial vs. post-cue) \times 2 (laterality: left vs. right) ANOVA performed on the P1 amplitudes for the ambiguous disputed condition showed a main effect of presentation ($F(1, 20) = 6.71$, $p = .018$) arising from the fact that the P1 was greater for the post-cue presentations of the ambiguous probes ($6.84 \pm 2.56 \mu\text{V}$) compared to the initial presentation ($6.34 \pm 2.55 \mu\text{V}$) (Figure 6). No such effect was found in the ANOVA for the distinct endorsed probes ($F(1,$

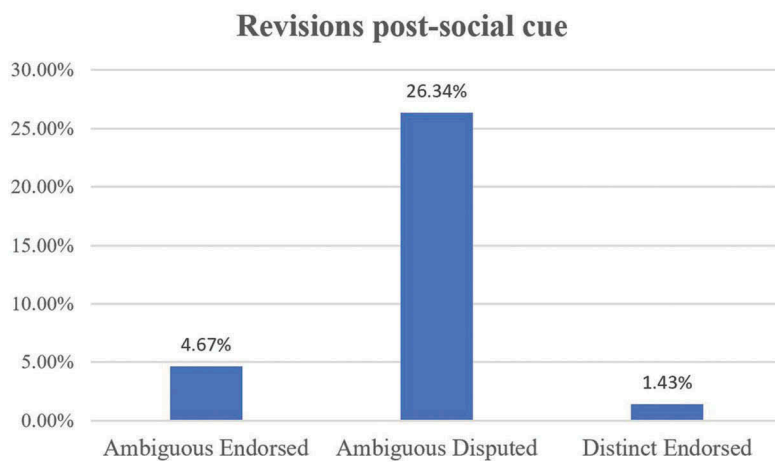


Figure 3. Behavioural results. Percentage of revisions (i.e., reversal of perceptual judgements) made by participants in the three experimental conditions (ambiguous stimuli that were subsequently endorsed, ambiguous stimuli that were subsequently disputed, and distinct stimuli that were subsequently endorsed).

20) = 0.01, $p = .92$) (Figure 4). The same ANOVA performed on the P1 amplitudes of the ambiguous endorsed probes showed a significant interaction between presentation and laterality ($F(1, 20) = 7.42$, $p = .013$), due to a difference in amplitude over the right hemisphere leads between initial and post-cue presentations (Figure 5).

P1 latency. The 2 (presentation) \times 2 (laterality) ANOVAs performed for each of the 3 conditions showed significant main effects of presentation. In the 3 ANOVAs, P1 was found to peak significantly later than for post-cue stimuli compared to the initial presentation. Table 1 shows the P1 mean latencies for each of the three conditions and Table 2 summarises the results of the 3 ANOVAs.

N1 amplitude. The 2 (presentation) \times 2 (laterality) ANOVAs performed on the N1 amplitudes in each of the 3 conditions revealed a significant main effect of presentation (ambiguous endorsed: $F(1, 20) = 20.36$, $p < .10^{-3}$; ambiguous disputed: $F(1, 20) = 31.77$, $p < .10^{-4}$, and distinct endorsed: $F(1, 20) = 48.14$, $p < .10^{-4}$) (Figures 4–6). The mean N1 amplitudes for probes presented after the social cue (see Table 2 for values) were significantly less negative than upon initial presentation (ambiguous = $-2.32 \mu\text{V}$, distinct = $-2.65 \mu\text{V}$).

N1 latency. No significant effects of latency were observed for the N1 latencies (Table 2).

Discussion

The aim of the present study was to explore the effect of social feedback on perceptual processes, and in particular to determine the temporal period on which such feedback impacts. This was produced by asking participants to categorise distinct or ambiguous colour stimuli before and after alleged social feedback that confirmed or disputed the participants' responses.

As expected, when faced with ambiguous stimuli, participants revised their judgments more often following social disagreement than following endorsement of their judgments (a negligible amount of revisions were made after endorsement of distinct hues). Confirming the validity of the feedback provided, when questioned after the procedure, the majority of the participants claimed to have believed the authenticity of the feedback.

ERPs measured in response to the ambiguous and distinct colour probes before and after social feedback revealed a number of differences arising very early on (within the first 120ms) as well as later in time (beyond 190ms), suggesting that social cues modulate brain activity during early stages of processing. Interestingly, the ERPs in response to the faces providing social feedback showed modulations that differed according to the ambiguity of the probes, further strengthening the idea that the cues were actively taken into account during the perceptual judgment task (see supplementary material).

Most importantly, an increase in P1 amplitude was found after the participants' judgements of ambiguous stimuli were disputed by the social group, while ambiguous probes that were endorsed only enhanced activity

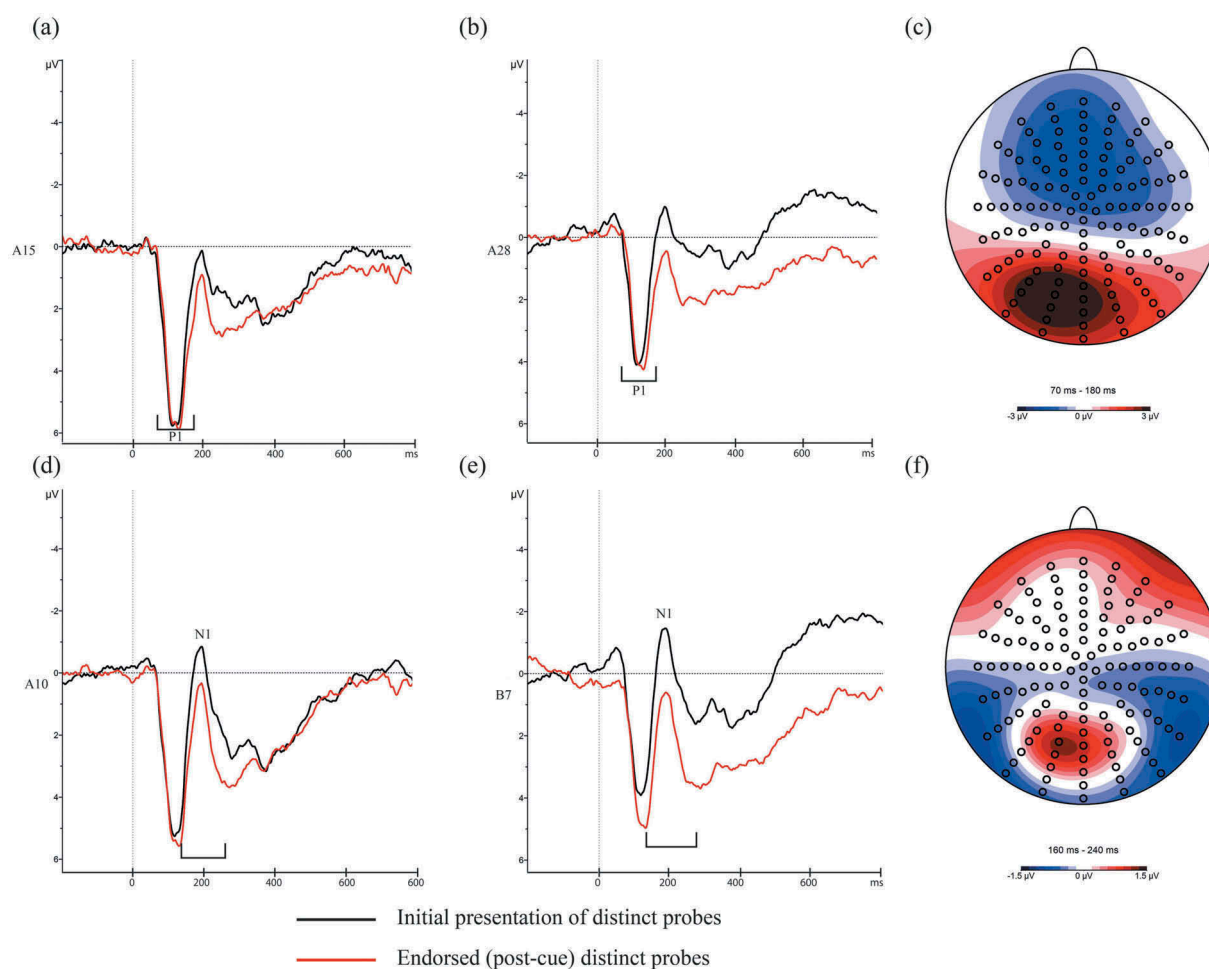


Figure 4. ERPs for distinct probes presented before (black trace) and after (red trace) social endorsement (i.e., presentation of a happy face). Traces are shown for two occipital electrodes (one left and one right) used to compute P1 (a, b) and N1 (d, e). (c) Topographical voltage map illustrating the P1 (time period between 70–180ms indicated with a black bracket in a and b). (f) Topographical voltage map illustrating the N1 (time period between 160–240ms indicated with a black bracket in d and e).

over the right electrodes in this period. Moreover, no effect was seen on distinct stimuli.

These findings suggest that social information modulates early perceptual processes. Indeed, the differences observed in the early electrophysiological response between the initial and post-cue presentations occurred even though the stimuli were identical. This indicates that feedback cues are able to act directly on the early visual ERPs, impinging on early processes that arise in the visual extrastriate regions (Di Russo, Martinez, Sereno, Pitzalis, & Hillyard, 2002). Since this effect cannot be driven by low-level features (as the stimuli are identical), it necessarily arises through top-down activation. One likely mechanism for this could be that top-down processes affects neural gain in the visual system by heightening its sensory capability. This mechanism in fact explains the enhancements observed in early ERP components that arise when

spatial attention is directed towards specific locations. Indeed, larger P1 amplitudes have been observed for stimuli presented at attended locations, reflecting a facilitation of early sensory processing (Luck et al., 1990).

Consequently, one may contend that the early modulations in our study derive essentially from a similar heightened sensory processing which could be due to a differential engagement of attentional processes for the ambiguous, challenged stimulus.

Alternatively, this effect could be the consequence of a greater mobilisation of attention linked to the increased relevance of the stimulus. Indeed, P1 modulations have been observed in response to highly relevant stimuli such as photographs of spiders, or to anticipatory spider-containing material in arachnophobics (Michalowski et al., 2009; Michalowski, Pané-Farré, Löw, & Hamm, 2015). Moreover, enhanced P1 responses have been found for

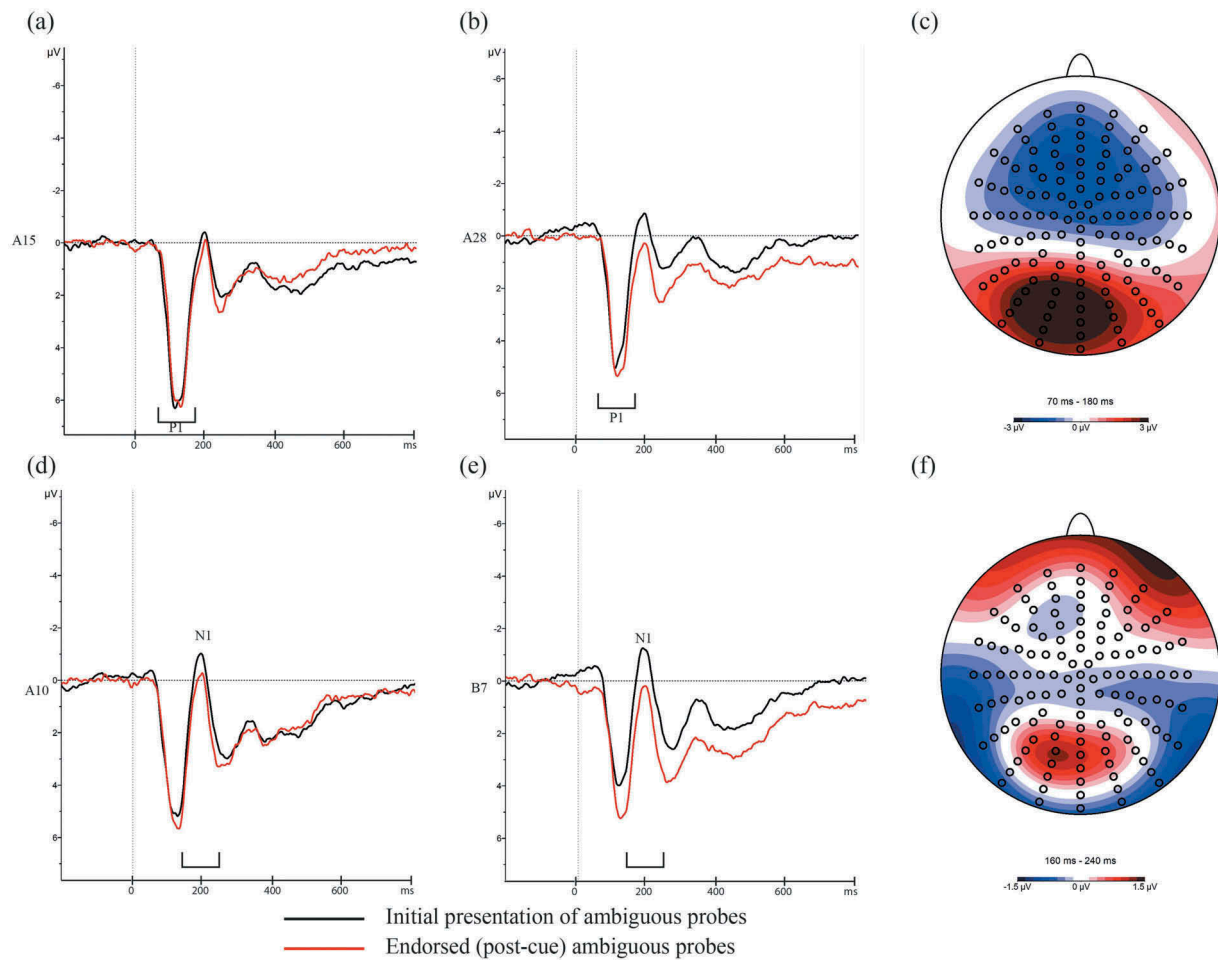


Figure 5. ERPs for ambiguous probes presented before (black trace) and after (red trace) social endorsement (i.e., presentation of a happy face). Traces are shown for two occipital electrodes (one left and one right) used to compute P1 (a, b) and N1 (d, e). (c) Topographical voltage map illustrating the P1 (time period between 70–180ms indicated with a black bracket in a and b). (f) Topographical voltage map illustrating the N1 (time period between 160–240ms indicated with a black bracket in d and e).

threatening cues more generally (Bublitzky & Schupp, 2012; Bublitzky, Flaisch, Stockburger, Schmäzle, & Schupp, 2010), and heightened N1 responses have been noted under conditions of anticipation of socially relevant feedback (Schindler, Wegrzyn, Steppacher, & Kissler, 2014).

Notwithstanding the underlying mechanism, the fact remains that an early effect was observed, which was caused by manipulation of alleged social information. It is therefore questionable whether early attentional processes are sensitive, and can be influenced by, higher-order social processes. This question was addressed in a study by Wykowska and colleagues (Wykowska, Wiese, Prosser, & Müller, 2014). The authors showed that the P1 was enhanced for stimuli appearing at a validly cued location when participants believed that the cue was provided by a human being rather than a machine. In our paradigm, the increased P1 for ambiguous stimuli appearing after, compared to before the social cue

therefore appear to reflect the effect of social information exerting a top-down influence on early visuospatial processes.

The current findings corroborate the only existing study to our knowledge, (Trautmann-Lengsfeld & Herrmann, 2013), to have investigated ERPs with a similar hypothesis in mind. However, two major differences exist between the latter investigation and the present study. First, our study included distinct colour probes, which served as a control condition in order to examine the impact of uncertainty under social pressure, whereas in the investigation by Trautmann-Lengsfeld & Herrmann, ambiguity was a constant. Even more importantly, our inclusion of sequential processing which contained both positive and negative feedback for ambiguous probes allowed for direct comparisons of the same stimulus before and after the social cue, thus consolidating the visibility of the cue's effect.

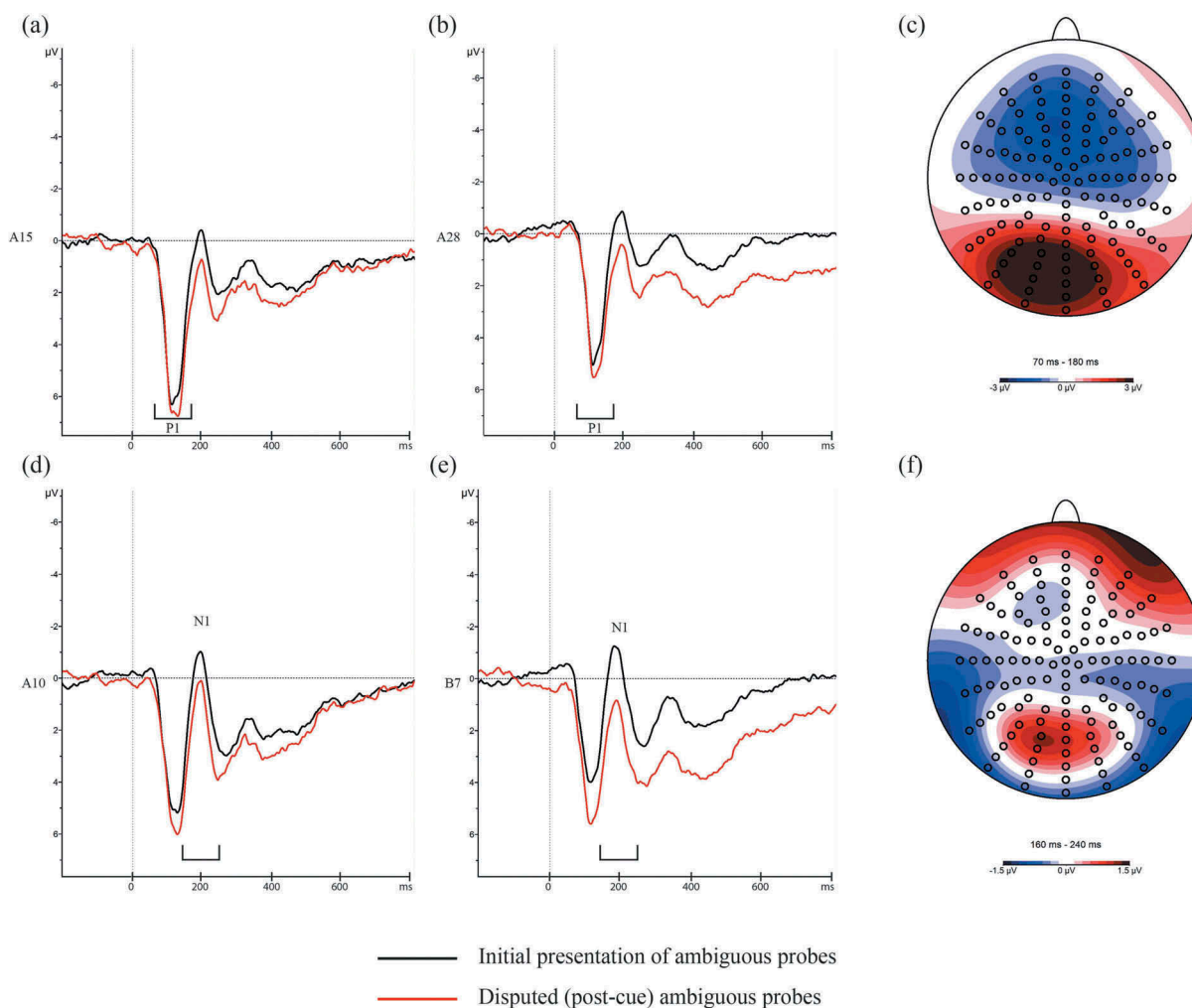


Figure 6. ERPs for ambiguous probes presented before (black trace) and after (red trace) social disagreement (i.e., presentation of a disgusted face). Traces are shown for two occipital electrodes (one left and one right) used to compute P1 (a, b) and N1 (d, e). (c) Topographical voltage map illustrating the P1 (time period between 70–180ms indicated with a black bracket in a and b). (f) Topographical voltage map illustrating the N1 (time period between 160–240ms indicated with a black bracket in d and e).

Table 1. Comparison of mean P1 amplitudes in μV (left) and latencies in milliseconds (right) between initial and post-cue presentations for the three conditions: ambiguous endorsed, ambiguous disputed and distinct endorsed.

	P1 mean amplitudes (μV)		P1 mean latencies (ms)	
	<i>Pre-cue probe</i>	<i>Post-cue probe</i>	<i>Pre-cue probe</i>	<i>Post-cue probe</i>
Ambiguous endorsed	6.35 ± 2.55	6.55 ± 2.40	118.02 ± 15.50	121.64 ± 16.72
Ambiguous disputed	6.35 ± 2.55	6.84 ± 2.55	118.02 ± 15.50	123.06 ± 17.33
Distinct endorsed	6.04 ± 2.60	6.06 ± 2.54	122.57 ± 18.61	126.33 ± 18.14

A difference also arose for ambiguous probes after social feedback at the N1 level. This overall amplitude enhancement for post-cue presentations of ambiguous probes was in fact also observed for distinct probes. This general enhancement of the post-cue N1 component for all stimuli could be seen as an effect of stimulus repetition, or as a global effect of social feedback that would be independent of its value (agreement or disagreement) and of the participant's perceptual certainty (apparently ambiguous

or distinct stimuli). Previous reports have evidenced changes in N1 for repeated presentations of visual stimuli (Groh-Bordin, Busch, Herrmann, & Zimmer, 2007; Olofsson & Polich, 2007), however these have been described as decreases in amplitude occurring with repetition and thus occur in the opposite direction to our findings. Non-specific effects of repetition therefore seem unlikely. The alternate possibility may therefore be that the N1 enhancement is associated with heightened attention towards the probes (Luck

Table 2. F and p values for the statistical comparison of the P1 (top row) and N1 (bottom row) amplitudes (left column) and latencies (right column) in response to the colour stimuli before and after presentation of social feedback. The results are shown for each of the 3 experimental conditions (ambiguous endorsed, ambiguous disputed and distinct endorsed).

PROBES: INITIAL vs POST-CUE	P1 Amplitude		P1 Latency	
	F(1, 20)	p-value	F(1, 20)	p-value
Initial and endorsed post-cue distinct probes presentation	0.011	0.919	9.031	0.007 *
Initial and endorsed post-cue ambiguous probes presentation	0.980	0.334	4.698	0.042 *
Initial and disputed post-cue ambiguous probes presentation	6.705	0.018 *	6.692	0.018 *
	N1 Amplitude		N1 Latency	
	F(1, 20)	p-value	F(1, 20)	p-value
Initial and endorsed post-cue distinct probes presentation	48.141	<10⁻⁵ *	2.023	0.170
Initial and endorsed post-cue ambiguous probes presentation	20.357	<10⁻³ *	0.017	0.896
Initial and disputed post-cue ambiguous probes presentation	31.766	<10⁻⁴ *	0.137	0.715

et al., 1990), and an increase in discriminative processes at the attended location (Hillyard, Vogel, & Luck, 1998; Luck & Hillyard, 1995). It is plausible that social feedback, independently of probe ambiguity, led to greater attention at the location of the stimulus (Hillyard & Anlo-Vento, 1998; Hopfinger & West, 2006; Johannes et al., 1995; Luck et al. 1990; Mangun & Hillyard, 1991) possibly in relation to some aspect of stimulus categorisation (Oliver, Cristino, Roberts, Pegna, & Leek, 2017; Pegna, Darque, Roberts, & Leek, 2017). Nevertheless, the presence of the enhanced N1 in all our experimental conditions do not allow us to conclude unequivocally to an effect of social feedback.

Conclusion

Taken together, our electrophysiological results support the hypothesis that social feedback can modulate early visual perception in situations of perceptual uncertainty, by acting on the early steps of visual processing that take place around 100ms after stimulus presentation. These effects are modulated according to whether social feedback endorses or disputes the participants' responses. Future studies will be necessary to ascertain the significance of the later ERP modulations that may well be linked to more complex functions such as stimulus monitoring.

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