Shared attention amplifies the neural processing of emotional faces

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Data availability

The dataset and analyses reported in this manuscript are available at Open Science Framework repository: **https://osf.io/xntj4/**

Abstract

Sharing an experience, without communicating, affects people's subjective perception of the experience, often by intensifying it. We investigated the neural mechanisms underlying shared attention by implementing an EEG study where participants attended to and rated the intensity of emotional faces, simultaneously or independently. Participants performed the task in three experimental conditions: 1) alone, 2) simultaneously next to each other in pairs, without receiving feedback of the other's responses (shared without feedback), and 3) simultaneously while receiving the feedback (shared with feedback). We focused on two face-sensitive ERP components: the amplitude of the N170 was greater in the shared with feedback condition compared to the alone condition, reflecting a top-down effect of shared attention on the structural encoding of faces; while the EPN was greater in both shared context conditions compared to the alone condition, reflecting an enhanced attention allocation in the processing of emotional content of faces, modulated by the social context. Taken together, these results suggest that shared attention amplifies the neural processing of faces, regardless of the valence of facial expressions.

Key words: shared attention, social cognition, N170, EPN, event-related potentials, face processing

Introduction

People live much of their lives with other people: they frequently spend time engaging in similar activities, sometimes even without any explicit communication between them. For example, people watch movies at the cinema, listen to music at concerts, and wait in line for theatre tickets, socially but silently. In the last decade, researchers have investigated whether having a simultaneous experience with another person, even without any verbal or non-verbal communication, may change people's perception, perhaps enhancing the lived experience (Richardson et al., 2012). Based on these considerations, it is possible to infer that people's perception is influenced by the physical presence of others, just by knowing that someone else is concurrently experiencing the same. This mechanism, known as joint or shared attention, represents a foundational skill in human social interaction and cognition.

Eye contact is an important precursor to initiating joint attention and shared attention mechanisms, as well as a crucial stimulus that people prioritize during processing of social information (for a review, see Hamilton, 2016). Establishing joint attention engages orienting mechanisms that allow the use of a directional gaze cue to shift spatial attention to the common object (for a review, see Frischen, 2007). Joint attention occurs when an individual (the initiator or gaze leader) gazes at an object, causing another individual (the responder or gaze follower) to orient his or her gaze to the same object. It requires that two individuals (A and B) are attending to the same object (C), based on one individual using the attentional cues of the second individual. Conversely, shared attention is a more complex form of communication, requiring that the two individuals have knowledge of the directions of the other individual's attention (Baron-Cohen, 1995; Emery, 2000), allowing the attendee to perceive the self and the other as a unified agent with a singular attentional focus. Indeed, shared attention emerges when the agent in the mental representation shifts from the first-person singular to the first-person plural, a transition that needs a neurocognitive system for the rapid detection of the eyes of another organism to exist (Baron-Cohen, 1995).

Shteyneberg (2015) explained that this shared attention mechanism does not require that co-attendants are engaged in dyadic eye gazing (i.e., look at each other) or triadic eye gazing (i.e., look at each other looking at the object), as is the case in classic joint action paradigm (Striano et al., 2006). More simply, shared attention exists when we have the perception of attending to some aspect of the world by merely being aware that we are attending to the same object, at the same time, as someone else. In social psychology, there is much evidence supporting the general idea that people may influence each other even without any explicit communication between them (e.g., Allport, 1985; Echterhoff, Higgins, & Levine, 2009; Hardin & Higgins, 1996; Triplett, 1898; Zajonc, 1965).

In more recent literature, it has been shown that sharing an experience may lead to stimuli being more psychologically prominent (Shteynberg, 2015), such as enhancing memory of stimuli (Eskenazi et al., 2013; He et al., 2011; Shteynberg, 2010), emphasizing goal pursuit (Carr & Walton, 2014; Shteynberg & Galinsky, 2011), increasing imitation of modeled behavior (Shteynberg & Apfelbaum, 2013), and also leading to the amplification of taste judgments (Boothby et al., 2014, 2016). In particular, Boothby and colleagues (Boothby et al., 2014) demonstrated that stimuli become more prominent when they are shared, perhaps because they receive greater cognitive resources during episodes of shared attention (Shteynberg & Apfelbaum, 2013), and consequently they may also be experienced as more intense. In their study, participants had to attend to and judge the quality of chocolate in two different conditions: in a shared-experience context, while the participant and an experimenter's confederate were doing the same task, or in an unshared-experience context, while the participant was tasting chocolate and the confederate was reading a book. Even if the chocolate was the same across the two conditions, the authors found that doing something together and simultaneously resulted in an enhanced evaluation of the pleasant experience. Interestingly, the authors demonstrated that having shared the experience made the experience better when it was a pleasant one – as when participants tasted good chocolate – and worse when the experience was less enjoyable – as when they ate unpleasantly bitter chocolate. Thus, this latter finding suggested that sharing experiences amplifies experiences, instead of improving them (unless they were pleasant to begin with). In particular, a pleasant experience became better, while an unpleasant experience became worse. In other words, doing something together does not change people's perception completely, but makes the experience itself more intense.

Furthermore, the aspect which seemed to play a pivotal role in this amplification was the timing of co-attention. Indeed, Shteynberg and colleagues (Shteynberg et al., 2014) found out that when participants were attending together to happy or sad images and videos with close others, this resulted in enhanced happiness or unhappiness, respectively. This phenomenon was found only when participants thought they performed the task synchronously (i.e., when they believed that their group was co-attending with them at the same time and not a minute before or after them).

Building further on this evidence, the present study was designed to investigate the neural mechanisms underlying the shared attention phenomenon while participants were attending to and judging the same stimuli (e.g., faces with different facial expressions) simultaneously or independently. Given that sharing attention and responding to perceptual inputs is an example of an unfolding sequence of processing stages, time-sensitive measurements during this unfolding interaction may be especially revealing. In particular, we aimed to investigate the effect of shared experience both in the early stage of structural encoding of faces and in the subsequent emotional face processing. Brain imaging studies have shown that natural selective attention to emotional picture content, such as faces with different emotional expressions, is accompanied by widespread activation of the occipital cortex – suggesting that we are tuned to process motivationally relevant stimuli (P.J: Lang et al., 1998). For this reason, by means of event-related potentials (ERPs), which provide information about stimulus encoding with a millisecond resolution, we monitored two important dissociable ERP components: the N170 and the Early Posterior Negativity (EPN) components.

N170 is the ERP component which precisely maps the structural encoding stage (Bentin et al., 1996), an occipitotemporal response characterized by a negative polarity with a peak latency at approximately 170ms, and with the largest amplitude to faces (Hinojosa et al., 2015). This component has been found to be sensitive to facial emotional expressions, mostly in tasks where faces were centrally presented, and the participants were instructed to direct their attention to facial expressions (Hinojosa et al., 2015; Leppänen et al., 2007; Wronka & Walentowska, 2011; for a review on the emotional and perceptual processes in facial expression recognition see also Calvo & Nummenmaa, 2016).

More recently, the N170 was found to also be sensitive to social information such as own-age or own-race biases, stereotyping, and social categorization (e.g., enhanced N170 to in-group faces; Amodio et al., 2014; Vizioli et al., 2010). This suggests that social information may impact even early stages of structural face encoding. Interestingly, some of the previous literature investigating the N170 component demonstrates that it is an appropriate index of feedforward perceptual processes and can be modulated in a top–down fashion (in N170 amplitude; Eimer, 2000a; Holmes et al., 2003; Sreenivasan et al., 2007; and latency; Gazzaley et al., 2005). These studies, investigating whether emotional expression effects depend on the type of task participants are engaged in, suggest that the modulation of ERP components due to emotional facial expression are also gated by attention (Eimer & Holmes, 2007; Holmes et al., 2003). This aspect contradicts the often assumed theory that affectively salient stimuli such as emotional facial expressions are detected pre-attentively, and attract attention automatically (for a review on the topic, see Palermo & Rhodes, 2007). However, a study by Rellecke and colleagues (2012) found that the N170 was not affected by the intentional state when processing emotional facial expressions, which contradicts some of the previous findings.

A second ERP component established as an index of emotion processing is the early posterior negativity (EPN), which appears to be modulated by the emotional content of stimuli from different categories. The EPN is a relative negative deflection at posterior electrodes, which becomes visible approximately 200-300 ms after the stimulus onset. The EPN has been linked to a boost of visual encoding due to enhanced attention allocation to emotional stimuli in comparison to neutral stimuli (Junghoefer Bradley et al., 2001; Schupp et al., 2006, 2007). Increased negativity for affective stimuli is expected, given selective processing of attentional allocation to motivationally relevant stimuli (Schupp et al., 2004). Modulation of the EPN amplitude was shown for pictures depicting emotionally relevant scenes and objects (Bayer & Schacht, 2014; Schupp et al., 2004, 2007) as well as for emotional facial expressions (Alonso-Recio et al., 2014; Eimer & Holmes, 2007; Rellecke et al., 2012). The effects of emotional stimulus content on attention have also been documented with a variety of other visual stimuli (e.g., words, and hand gestures; see Flaisch et al., 2009; Kissler et al., 2007). Further, its amplitude is increased for pleasant and unpleasant pictures high in emotional arousal, in contrast to neutral ones (Junghoefer et al., 2001; Schupp et al., 2003).

Despite previous studies demonstrating a top-down influence on the visual processing of emotional expressions during the first 350ms, the debate is still open, and results on the topic are controversial (e.g., studies in which emotional processing has been found independent of task demands; Aguado et al., 2019; Durston & Itier, 2021; Itier & Neath-Tavares, 2017; for a review see also Calvo & Nummenmaa, 2016).

In the present investigation, we implemented a dual-EEG study to investigate the neural consequences of shared attention on the processing of facial expressions of emotions, in pairs of participants that were required to attend to and judge the intensity of neutral, angry, and happy faces. We manipulated the social context in a within-subjects design such that participants both performed the task alone and together, simultaneously with another person. At the behavioural level, we aimed to replicate the amplification found in Boothby et al.'s study (2014); thus, we expected to find an interaction between the type of emotion and the level of shared attention. Specifically, we hypothesized that the mere presence of another person would increase the perceived intensity of positive and negative emotions, such as happy and angry facial expressions. We decided to include neutral facial expressions to have a baseline condition to rely on, but also to investigate whether shared attention would impact their perceived intensity, such that their neutrality would be amplified.

First, we expected that attending to emotional stimuli together with another person would make facial stimuli more prominent, causing a cascading effect on the early structural and emotional face processing. More specifically, we expected that both ERP components would increase in amplitude because of the motivated attentional state induced by the presence of another person. Moreover, we also wanted to investigate whether the level of shared attention could have a diverse effect on different type of emotion, as with the behavioural results; hence, we wanted to study whether there was an increase in N170 and EPN amplitudes for emotional facial expressions.

A second goal of the present investigation started from the idea that in a real face-to-face interaction, people usually receive immediate feedback from the other person; thus, we wanted to investigate whether receiving feedback of the other's response regarding their perceived intensity of faces has an impact both on participants' subjective perception and the early stages of structural and emotional face processing. We thus implemented a condition within the shared context in which participants received feedback of the other person's response at the end of each trial. In this way, we were able to compare three levels of shared attention – i.e., *alone, shared without feedback and shared with feedback* – to evaluate whether the presence of the feedback could modulate both stages of processing, reflecting a top-down effect on both structural encoding of faces and the processing of their emotional content.

Material and methods

Participants

Data were collected from 46 healthy volunteer students, recruited from the University of Copenhagen (KU) and the Technical University of Denmark (DTU). We aimed for ~40 participants (recruited in 20 pairs) of participants, based on the existing literature in the field (Mairon et al., 2020). Due to an excess of electrophysiological artefacts, especially eye movements, data from 6 participants were discarded from the analysis. All participants reported normal or corrected vision from lenses, and no history of neurological disorders. Forty participants (18 males, average age in years = 24, SD = 2.73; 5 left-handed) were included in the final sample. The experiment was approved by the Institutional Ethical Review Board at the Department of Psychology, University of Copenhagen (approval number: IP-IRB/02072018), and the ethical considerations were consistent with the Helsinki Declaration of ethical principles. All the data were anonymised.

We ensured that the participants did not know each other prior to the experiment since we aimed to control for the level of knowledge they had about the other person. We used a within-subjects design; thus, all participants participated in all the three conditions (i.e., alone, shared without feedback and shared with feedback).

Stimuli

The stimuli were coloured digital photographs selected from the Karolinska Directed Emotional Faces (KDEF) database. We selected 210 face images from the KDEF, of 3 different emotions (happiness, neutral and anger) for 70 individuals (35 males and 35 females). The images of the faces were chosen based on the ratings received in the validation study (Goeleven et al., 2008). Particularly, according to the highest proportion of correctly identified target stimuli with comparable participants' ratings of intensity and arousal within each facial emotion category (see Appendix 1 and 2 in Goeleven et al., 2008). After the face stimulus presentation, a question was presented below each face stimulus (see Experimental design and procedure).

The face stimuli were scaled using an image-processing software so that each face fit within a $2.9° \times 3.6°$ (width × height) rectangle, and the questions were presented across two lines at the centre of the screen in a 1.73° × 3.9° (width × height) virtual rectangle from a viewing distance of approximately 70 cm. The stimuli were presented on a 21" LCD monitor controlled by a computer running E-prime software. The faces were shown at the central fixation point, marked by a fixation cross before each presentation.

Experimental design and procedure

Each trial began with a fixation cross presented for 500-600ms at the centre of the screen, followed by a face stimulus duration of 1000ms. Then a question appeared below the face, asking participants to rate how intense the emotion of each facial expression was, by pressing a number on a 7-point scale (from 1 "not at all" on the far left to 7 "a lot" on the far right). The face stimulus remained at the centre of the screen until the participant's response (i.e., in the alone condition) or both participants' responses (i.e., the shared condition without and with feedback). In the shared with feedback condition, both participants received feedback of the other person's rating on their own screen following their own rating. The feedback screen was presented for 1 s. Each trial ended with a black screen (1000-1500ms, randomly jittered in steps of 100ms). Each participant completed three blocks of trials, with the shared with and without feedback blocks counterbalanced across participants (i.e., i.e., half of the dyads started with the shared with feedback, while the other half started with the shared without feedback condition), each one showing all the selected face stimuli, presented in a random order (210 trials for each condition block, thus 630 trials in total). The duration of each block was approximately 14 minutes (~ 42 minutes as a whole) (see Figure 1). Participants had a 1-minute break every 5 minutes.

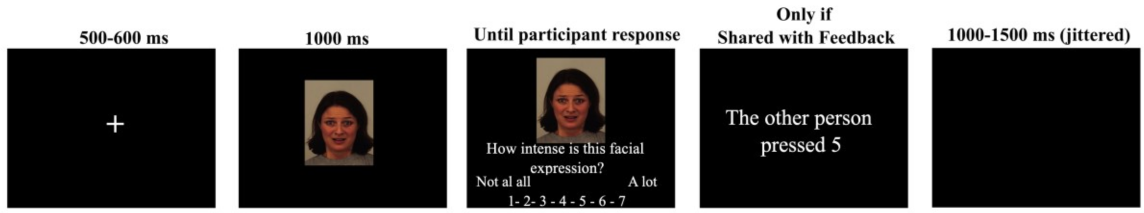

Figure 1. Schematic representation of experimental paradigm.

We used a within-subject design; thus, all participants performed the task in the three conditions (i.e., alone, shared without and with feedback). To ensure the correct succession of all the conditions, and to counterbalance the order of conditions, the participants of each pair arrived at different times. For the sake of simplicity of explanation, we will call the participants A and B following the order of their arrival. Participant A performed the experimental task alone (alone condition). When participant B arrived, they were acquainted with one another upon entering the lab through an ice-breaker task during which they asked and answered a series of questions about one another, increasing in terms of subjectively perceived intrusion level (e.g., "What is your name?", "How old are you?", "Which is your favourite book?", "What food do you really enjoy?", "What are some of your hobbies?", and "What is one of your biggest fears?"). We prepared this questionnaire by following Boothby and colleagues' study 1 (2016), with the aim to let the participants "break the ice" and get to know each other. In line with previous evidence, this aspect is crucial given that one of the minimal aspects to experience shared attention is creating a sense of "co-attending" to something together, which is more likely to occur when people are relationally close. This part lasted approximately 30 minutes, while setting up the EEG for participant B. Then, participants A and B performed the task together and simultaneously (shared with and without feedback, counterbalanced across dyads), seated side-by-side. When the shared condition ended, participant A left the laboratory, while participant B performed the experimental task in the alone condition (see Figure 2 for a schematic representation of the experimental phases). We asked participants to avoid communicating during task execution. While performing the task in the alone condition, participants were alone in the experimental room.

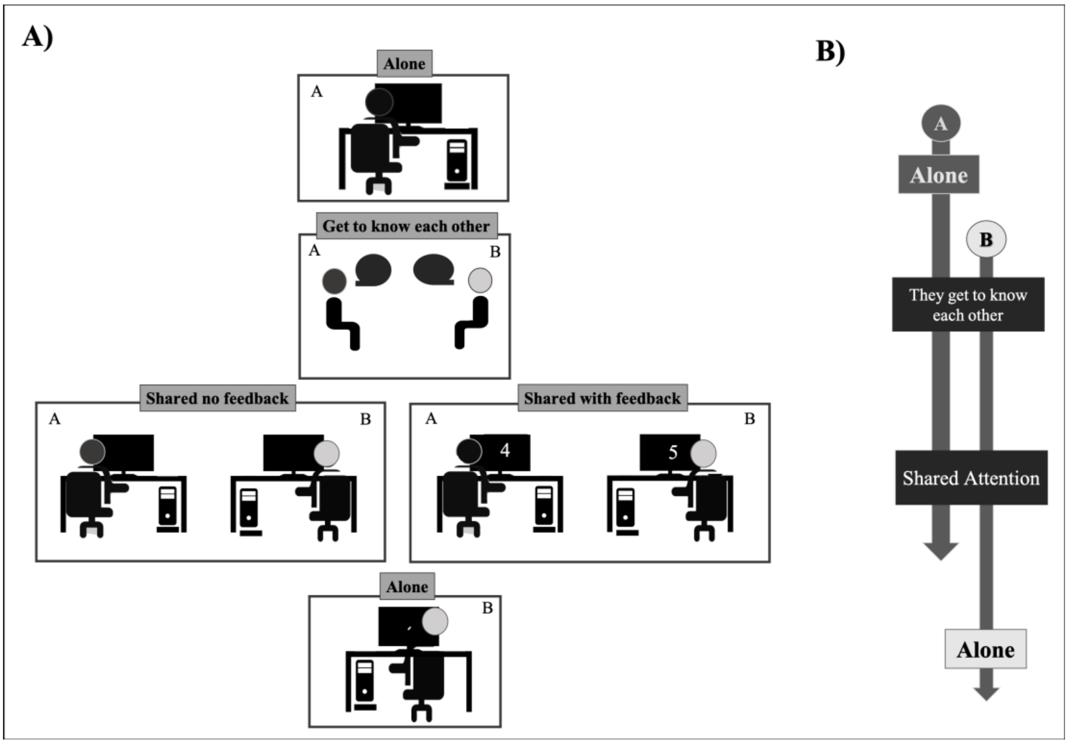

Figure 2. **A)** and **B)** Schematic representation of experimental procedures and phases: Participant A performed the experimental task alone (alone condition). At the end of participant A's experimental task, participant B arrived at the lab. They got to know each other through an ice-breaker task and sat facing one another for approximately 30 minutes. Then, participants A and B performed the task together and simultaneously (shared with and without feedback, counterbalanced across dyads), seated side-by-side at approximately 1 meter of distance. Finally, participant A left the laboratory at the end of the shared phase, whilst participant B performed the experimental task in the alone condition.

EEG/ERP recording

The EEG was recorded during the task (simultaneously from both participants during the shared conditions) using 64 active electrodes distributed on the scalp according to the extended 10/20 system, positioning an elastic using the ActiveTwo Biosemi System (Biosemi, Amsterdam, Netherlands), at a sampling frequency of 2048 kHz. As designed by BioSemi, the reference electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode. Vertical and horizontal electro-oculograms were recorded by attaching additional flat electrodes (Flat Active Electrode, BioSemi) below the left eye, and at the outer canthi of both eyes. Particularly, horizontal EOG (i.e., HEOG) was recorded bipolarly from two external electrodes positioned laterally to the left and right external canthi, while vertical eye EOG (i.e., VEOG) was recorded bipolarly from Fp1 and one external electrode placed below the left eye. The high viscosity of the gel used allowed the offset to be kept below 20 mV. The two EEG systems were synchronized using the daisy chain, provided through the hardware of the Biosemi system, enabling synchronized dual-EEG recordings. Offline EEG processing and analyses were conducted using MATLAB R2019b (MathWorks) and EEGLAB toolbox (Delorme & Makeig, 2004). EEG, HEOG, and VEOG signals were filtered (band-pass 0.1–30 Hz; 24 dB/octave) and downsampled to 256 Hz. The epochs were baseline-corrected based on the mean activity during the 200ms pre-stimulus period, for each electrode site. The EEG was re-referenced offline to the average reference and segmented into epochs lasting 1500ms (-500 to 1000ms). Trials contaminated by large horizontal eye movements, eye blinks, or other artifacts (exceeding ± 30 μV, ±60 μV, and ±80 μV, respectively) were automatically discarded from analysis, which accounted for the exclusion of an average of 6% of trials (see Study Details file at the OSF repository for information about the number of trials for each of the conditions after artefact rejection). Separate average waveforms for each condition were then generated, and time-locked to the presentation of the face stimuli for each experimental condition. To simplify the analysis and reduce the potential for Type I errors, the waveforms were averaged across channels into an a priori cluster of interest (COI) consisting of posterior electrodes (PO7/PO8, P7/ P8, P9/P10). For each experimental condition, the N170 and EPN activities were defined as the mean amplitude of each participant's grand average in the time windows 170-200ms and 230-350ms, respectively.

Statistical Analysis

In order to test our hypothesis – whether the different levels of shared attention and emotion modulated perceived intensity, and the N170 and EPN components – we employed a linear mixed-effect (LME) modeling approach. The LME models were applied separately to the behavioural data (perceived intensity), the N170, and the EPN. The fixed effects for all three models included the level of shared attention (i.e., alone, shared without feedback, shared with feedback), the type of emotion (i.e., neutral, angry, happy), and an interaction between shared attention and emotion (i.e., the full model's structure for both perceived intensity and ERPs measures in Wilkinson notation was: Dependent Variable ~ Level of shared attention * Type of emotion + (1 |ID)). The random effects' structure included participants as random intercepts, thus adjusting for individual differences in the dependent variable (i.e., perceived intensity, N170 amplitude, EPN amplitude).

We could not include a more complex random structure because the models failed to converge. Although the debate is still ongoing and controversial, some studies suggest that including only the random intercept may increase the possibility of Type-I error (Bates et al., 2015; Matuschek et al., 2017). Thus, we also implemented cluster permutation t-tests as additional analyses, to further test the robustness of our results. We applied a whole-scalp analysis across all 64 electrode sites in the 0-350ms time window, using a paired t-test cluster permutation approach (cluster $\alpha = .05$, 5000 within-participant random-permutations of the data) to control for the family-wise error rate (Groppe et al., 2011). We used Fieldtrip functions (Maris & Oostenveld, 2007), accessed via Brainstorm (Tadel et al., 2011). Given the noisiness of the EEG data, and to make all analyses consistent throughout the manuscript, we averaged across trials within each shared attention level and emotion type category for all dependent variables.

In the LME analyses, we first started from the full model (i.e., the one including all the interactions between the predictors), and identified the combination of predictors that best described the data using a step-wise approach based on the Akaike Information Criterion (AIC) model selection strategy (Wagenmakers & Farrell, 2004). AIC (Akaike, 1973) is a well-established data-driven procedure to select the best parameter's combination to fit the data, considering that under-fitting a model may not capture the true nature of the variability in the outcome variable, while an over-fitted model loses generality. It is a strategy to compare different models on a given outcome, and to select the model that best represents the true relationship with the given data. AIC is a measure for comparing mixed models based on the -2 (Restricted) log likelihood derived from Information Theory, which given a set of candidate models allows to derive the relative quality of each model, with the lowest AIC value indicating the best-fitting model (i.e., best trade-off between goodness of fit and parsimony in terms of the number of parameters) (Burnham et al., 2011). This strategy has been widely used in different research fields and with different types of data (e.g., ERPs: Hall et al., 2006; Schiano Lomoriello, Maffei, Brigadoi, & Sessa, 2021; behavioural: Boldrini, Schiano Lomoriello, Del Corno, Lingiardi, & Salcuni, 2020; Novick, Hussey, Teubner-Rhodes, Harbison, & Bunting, 2013).

In order for our results to be comparable to those within previous relevant literature, we have also reported the effect sizes. However, previous studies have mostly computed the classical analysis of variance (ANOVA) (Bruchmann et al., 2020; Hoffman et al., 2020; Mairon et al., 2020; Wang et al., 2019); hence, effect sizes for LME models are not directly comparable. Moreover, according to Nagakawa & Schielzeth (2012), there is no agreement on how to calculate effect sizes when LME models are implemented. Therefore, we have computed effect sizes based on the classical ANOVA approach.

The best fitting LME models were then used for further analyses. All analyses were done using the software R (2.13) using the lmer function from the lme4 package (Bates, Mächler, Bolker, & Walker, 2015). Significance levels for fixed and random effects were computed using the 'anova' function in the lmerTest package, which uses Satterthwaite's approximation for degrees of freedom. Post-hoc comparisons were computed using the PHIA package (Post-Hoc Interaction Analysis), corrected for multiple comparisons using the false discovery rate (*FDR;* Benjamini & Hochberg, 1995). Confidence intervals (i.e., CIs, set at 95%) are defined only for paired post-hoc comparisons and referred to difference of means (i.e., Mdiff; as suggested by Cumming, 2012).

The dataset and analyses reported in this manuscript are available at Open Science Framework repository: https://osf.io/xntj4/

Results

Participants' subjective ratings

From the LME model applied to the behavioral data, AIC model comparison showed that the model that best explained the data was the one including as fixed-effects the type of emotion (*AIC* 1030.8, *logL* = -510.332, *ΔAIC* = -318.2). The Δ*AIC* was computed as the difference in *AIC* between the best ranked model and the null model, representing a measure of the difference of the quality between the two models. Thus, we regressed participants' ratings on these sets of regressors (i.e., in Wilkinson notation: Ratings ~ Type of emotion + (1 | ID)), and computed significance levels for the fixed and random effects using the 'anova' function (lmerTest package), which returns a type III ANOVA table with significance levels. We found a main effect of the type of emotion ($F(2,320) = 278.07$, $p < .001$) (see also the LME results' summary in Table 1), showing a medium to large association between this variable and participants' responses ($\eta_p^2 = 0.67$). Following planned comparisons indicated that participants' ratings of intensity were lower for neutral than for happy (χ^2 (1, N = 40) = 293.81, $p < .001$; Mdiff = 2.07 [1.83, 2.30]) and angry facial expressions (χ^2 (1, N = 40) = 510.63, $p < .001$; Mdiff = 2.73 [2.49, 2.96]). Moreover, participants' ratings were also lower for happy than for angry facial expressions (χ^2 (1, N = 40) = 29.77, $p < .001$; Mdiff = .66 [0.42, 0.89]). (See Figure 3).

Table 1: Summary of the LME behavioral results.

		mean		
Predictors	*Estimates*	*CI*	*p*	*df*
(Intercept)	4.98	4.66 – 5.29	**<0.001**	123.08
Type of Emo [Happiness]	-0.66	-0.90 – -0.42	**<0.001**	82.05
Type of Emo [Neutral]	-2.73	-2.96 – -2.49	**<0.001**	82.05
Random Effects				
σ^2	0.87			
$\tau_{00\ sj}$	0.22			
N_{sj}	40			
Observations	360			
Marginal R^2 / Conditional R^2	0.553 / 0.643			

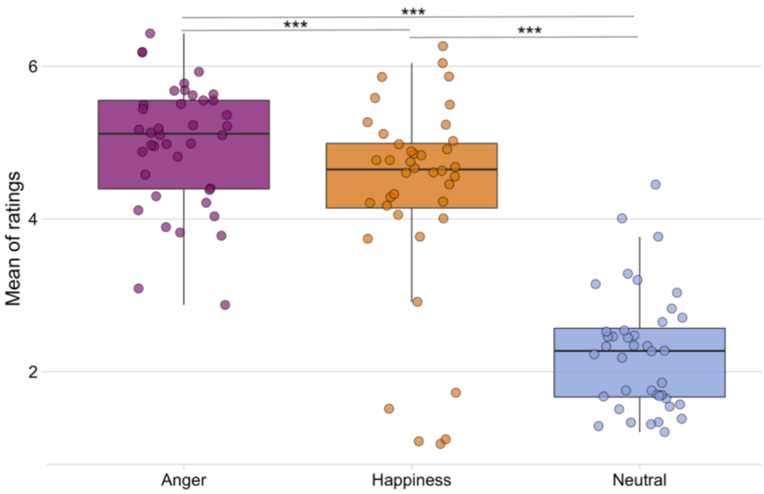

Figure 3. Boxplots depicting the mean of ratings across trials as a function of the emotion of facial expressions. Dots represent participants' mean responses. Asterisks indicate the level of significance (* p ≤.05, ** p ≤.01, *** p ≤.001), according to the planned comparisons.

ERP (N170 and EPN) results

Model comparison showed that the model that best explains the data observed for the N170 component was the one including as fixed-effects the type of emotion and levels of shared attention, and a random intercept to model repeated measurements across subjects (*AIC* = 1746.3, *logL* = -865.97, *ΔAIC* = -4.968). This result suggests that the N170 amplitude was explained by the level of shared attention and the type of emotion in an additive manner. Based on this, we discuss only the potential effect of the two factors included, one independent of the other. Thus, we regressed the N170 component on these sets of regressors (i.e., the best selected model in Wilkinson notation was: N170 amplitude ~ Level of shared attention + Type of emotion + (1 |ID)). The *F*-test revealed a significant main effect of the level of shared attention ($F(2,336) = 4.886$, $p = 0.008$) (see also the LME results' summary in Table 2), showing a small to medium association between this variable and the N170 amplitude (η_p^2 =0.26). Planned comparisons indicated that the N170 was significantly more pronounced in the shared with feedback condition compared to the alone one (χ^2 (1, N = 40) = 9.50, $p = 0.006$; Mdiff = -1.00 [-1.57, -0.45). No significant difference emerged between the shared without feedback compared to the shared with feedback and alone conditions. This pattern suggests that the structural processing of facial expressions is enhanced when we receive feedback of another person's perception. No differences emerged as a function of the type of emotion.

Table 2: Summary of the N170 model's results.

	N170			
Predictors	*Estimates*	*CI*	*p*	*df*
(Intercept)	-0.62	-1.82 – 0.58	0.301	29.65
Shared without feedback	-0.35	-0.99 – 0.28	0.276	336.00
Shared with feedback	-1.00	-1.63 – -0.36	**0.002**	336.00
Type of Emo [Happiness]	0.37	-0.27 – 1.00	0.257	336.00
Type of Emo [Neutral]	0.73	0.09 – 1.36	**0.024**	336.00
Random Effects				
σ^2	6.25			
$\tau_{00\ sbj}$	5.18			
ICC	0.45			
N_{sbj}	20			
Observations	360			
Marginal R^2 / Conditional R^2	0.022 / 0.465			

Model comparison showed that the model that best explains the data observed for the EPN component was the one including as fixed-effects the type of emotion and levels of shared attention, and a random intercept to model repeated measurements across subjects (AIC = 1648.5, $logL$ = -817.07 ΔAIC = -19.123). Similar to the N170 amplitude modulation, the EPN amplitude was explained by the level of shared attention and the type of emotion in an additive manner. We regressed the EPN component on these sets of regressors (i.e., the best selected model was: EPN amplitude ~ Level of shared attention + Type of emotion + (1 |ID) (in Wilkinson notation). In line with previous findings, we observed that the EPN amplitude was modulated by the type of emotion the participants were observing ($F(2,340) = 7.48$, p = < 0.001) (see also the LME results' summary in Table 3), revealing a medium to strong association between this variable and its amplitude

(η_p^2 =0.57). Particularly, the EPN was less pronounced for the neutral compared to the angry facial expressions (χ^2 (1, N = 40) = 14.31, p < .001; Mdiff = 1.07 [0.20, 1.43]). No differences emerged when processing happy compared to neutral facial expressions, while we found a less pronounced EPN for happy compared to angry facial expressions (χ^2 (1, N = 40) = 6.71, p = .014; Mdiff = 0.95 [0.04, 1.44]).

Moreover, the EPN was significantly modulated as a function of the shared attention (F(2,340) = 6.63, p = 0.0015), suggesting a medium association between this variable and the EPN amplitude (η_p^2 =0.57). Planned comparisons revealed that the EPN was significantly more pronounced in the shared with feedback condition compared to the alone one (χ^2 (1, N = 40) = 11.80, p = .0018; Mdiff = -0.97 [-1.30, -0.16]). A significant difference was also found between the shared without feedback compared to the alone condition (χ^2 (1, N = 40) = 7.65, p = .008; Mdiff = -0.78 [-1.45, -0.09]). This difference in amplitude reflects a modulation of the EPN by the social context. There was no significant difference between the shared with feedback compared to without feedback conditions (see Table 3 and 4).

Table 3: Summary of the EPN model's results.

			value	
Predictors	*Estimates*	*CI*	*p*	*df*
(Intercept)	2.72	1.84 – 3.59	**<0.001**	42.18
Shared without feedback	-0.79	-1.35 – -0.22	**0.006**	344.05
Shared with feedback	-0.98	-1.54 – -0.41	**0.001**	344.05
Type of Emo [Happiness]	0.74	0.17 – 1.30	**0.010**	344.05
Type of Emo [Neutral]	1.07	0.51 – 1.64	**<0.001**	344.05
Random Effects				
σ^2	4.84			
$\tau_{00\ sbj}$	2.27			
ICC	0.32			
N_{sbj}	20			

Observations	360
Marginal R^2 / Conditional R^2	0.051 / 0.354

Table 4: Means and standard deviations of both N170 and EPN components as a function of a 3 (Level of Shared Attention) x 3 (Type of Emo) design

N170	Level of shared attention					
	Alone		Shared no feedback		Shared with feedback	
Type of emotion	*M(μV)*	*SD*	*M(μV)*	*SD*	*M(μV)*	*SD*
Anger	-0.52	3.27	-1.10	3.47	-1.58	3.71
Happiness	-0.23	3.37	-0.66	3.41	-1.21	3.10
Neutral	-0.00	3.24	-0.05	3.50	-0.96	3.22
EPN						
Anger	2.85	2.66	1.79	2.60	1.75	3.07
Happiness	3.41	2.94	2.68	2.79	2.52	2.35
Neutral	3.70	2.64	3.14	2.73	2.77	2.44

Note. M and *SD* represent the mean and standard deviation, respectively.

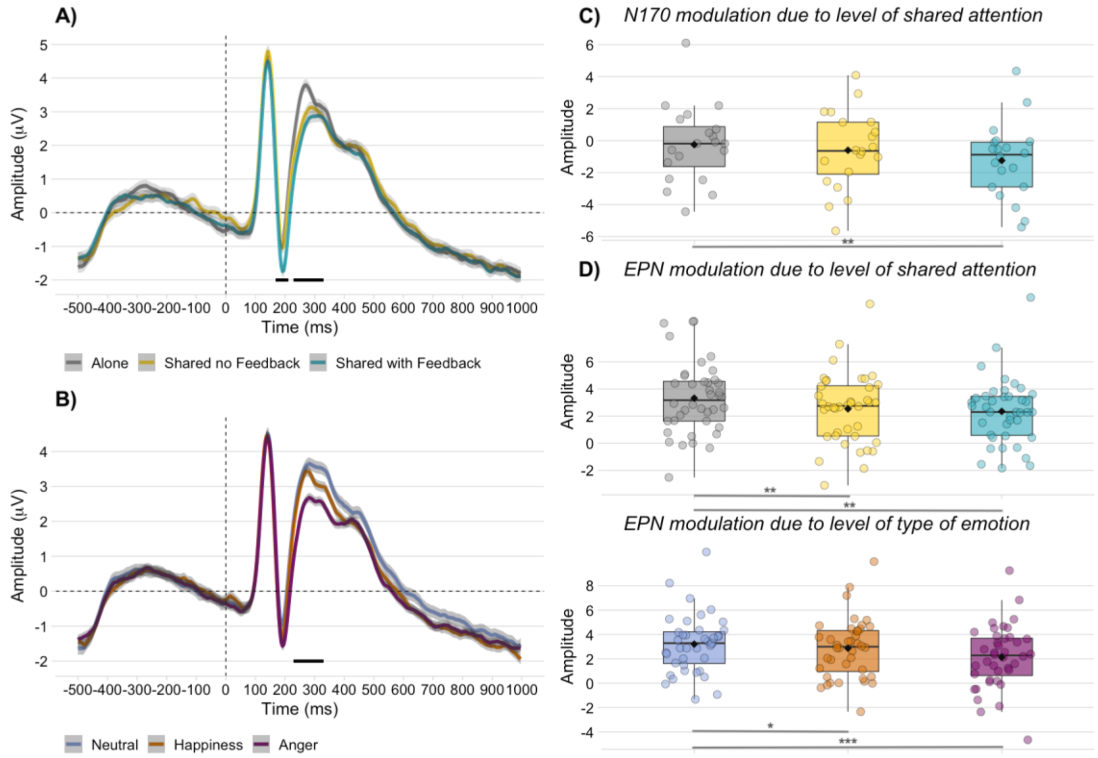

Figure 4. Grand averages of the ERP waveforms time-locked to the presentation of the face stimuli as a function of A) the level of shared attention (i.e., alone, shared without feedback, shared with feedback); B) the type of emotion (i.e., neutral, happiness, anger). Gray shading around each ERP waveform represents the 95% confidence interval. On the right side, the boxplots depict C) the N170 and D) the EPN modulation due to the level of shared attention (top) and the type of emotion (bottom). Dots represent participants' mean responses. The rhombus in each boxplot represents the average across participants for that condition. Asterisks indicate the level of significance (* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$), according to the planned comparisons.

Figure 4 depicts the ERP waveforms time-locked to the presentation of the target stimulus both for each level of shared attention and type of emotion; as well as the box plots of the N170 and EPN components for each of the significant results. We found that only the EPN (and not the N170) was modulated by the type of emotion, showing an enhancement for emotional compared to neutral faces. Moreover, both components showed a modulation due to the level of shared attention, revealing that the presence of feedback increased both the ERPs component's amplitude in relation to the alone condition. Interestingly, the EPN was also sensitive to the mere presence of another person simultaneously attending to the same activity, resulting in a higher amplitude for both shared feedback conditions in contrast to the alone condition.

To further investigate the robustness of these results, we also applied cluster permutation t-tests in the 0-350ms time window (cluster α = .05 and 5000 within-participant random permutations of the data) on all 64 electrode locations. This analysis found a significant difference between shared with feedback and alone conditions with two negative clusters, in the 170-200ms (*p* = .018) and 230-350ms (*p* = .015) time windows (see Figure 5 a) and b)). In addition, we found a significant difference between both shared with and without feedback conditions (*p* = .042), and shared without feedback and alone conditions (*p* = .020), with negative clusters in the 230-350ms time window (see Figure 5 c) and d)). This is consistent with the N170 and EPN results from the LME models.

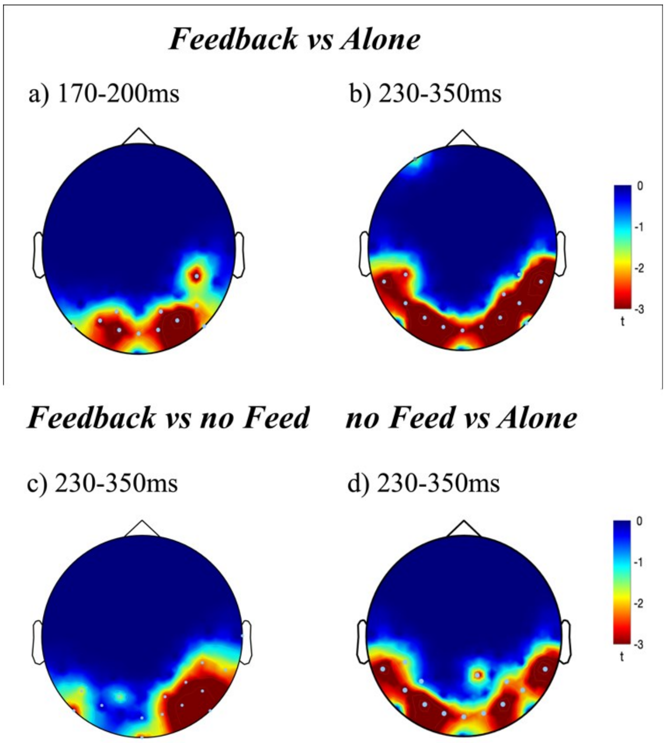

Figure 5. Topographic maps depict the cluster results of the paired cluster permutation t-tests for the different comparisons, where a) and b) correspond to the two clusters in the Feedback vs Alone contrast, c) corresponds to the Feedback vs no Feedback contrast, and d) corresponds to the no Feedback vs. Alone contrast.

Finally, in order to account for potential order effects in the study, we tested whether the order of conditions may have had an impact on each of the dependent variables (ratings, N170, EPN) separately, with fixed effects of order of conditions (i.e. 1 [start alone], 2 [shared], 3 [end alone]), as well as with a model including the order of the conditions, level of shared attention, and interaction between them. No statistical differences emerged.

Discussion

Using the ERP technique, we aimed to measure the neural mechanisms underlying shared attention while participants were attending to and judging the same faces simultaneously or independently, reflected in a potential modulation of the N170 and EPN ERP components. Our results showed that the two selected time-windows (i.e., the N170 and the EPN) were differently influenced by the participants' levels of shared attention. In particular, with respect to the N170, we found that it was larger in response to the onset of a face in the context where individuals were aware that they would receive feedback of the other person's rating, whilst the EPN amplitude was enhanced by the mere presence of the other person. Importantly, we found that the type of emotion and the level of shared attention independently modulated these early ERP components; hence, these findings are only partially in agreement with our initial hypotheses. To note, we first ran a classical hypothesis testing approach using LME models, then we implemented a more data driven approach (i.e., cluster permutation t-test), which produced consistent results.

Interestingly we found that the N170 was more prominent when participants received the feedback from the other person's response in relation to the alone condition, indicating that early processing of visual face perception is modulated by high-order cognitive processes. Previous ERP studies have shed light on the N170 as a face-specific ERP component that is not prone to cognitive modulation (Hudson, et al. 2021; Carmel & Bentin, 2002; Cauquil et al., 2000) , arguing that perceptual systems, or input modules, are computational but impervious to cognitive influences. However, there is some limited evidence in favour of its modulation by top-down mechanisms (Jemel et al., 2003; Ran & Chen, 2017; Schinkel et al., 2014). In particular, Jemel and colleagues' ERPs study (1999) had investigated the face priming effect when masked eyes of familiar faces were filled in with either the true features or incongruent ones. The authors found that the N170 was more prominent for incongruent than for congruent faces. This is consistent with the idea that, when top-down expectations are active in a priming situation, they facilitate more effective responses to matched bottom-up information (Grossberg, 2000). Further, in the context of facial expressions, it has been reported that the N170 modulation might be dependent on the congruency between expression targets and picture or sentence contexts. This modulation has been observed at different post-stimulus onset times, particularly already at the beginning at early stages of perceptual face processing. The N170 has been found to be modulated by the effect of congruence between contexts and expression targets across some previous studies (Hietanen & Astikainen, 2013), while other studies have not found these effects (see e.g. Aguado et al., 2019).

Moreover, our result supports other evidence suggesting that cognitive factors can exert influence when the bottom-up information conveyed by the face is not enough (e.g. parts of faces are ambiguous), as reflected by a modulation of the N170 component (Bentin et al., 2002; Raftopoulos, 2001). Bentin and Golland (2002) directly tested the top-down influence on perception by recording the N170 to meaningless stimuli before and after the participants associated the ambiguous patterns (e.g. scrambled schematic faces) to a face. The authors found that the schematic faces having the inner components misplaced did not elicit an N170 effect in participants not yet exposed to the perceptual priming. In contrast, the same visual patterns that did not trigger a face-characteristic encoding process did elicit an effect on the N170 after their physiognomic value was suggested to the participants. Notably, Arbel and colleagues' study (Arbel et al., 2017) had advanced the hypothesis that the N170 is an electrophysiological marker of the medial temporal lobe activation, which reflects the processing of feedback. While the N170 was elicited by both immediate and delayed feedback, its amplitude was larger under the delayed feedback condition.

What is important in this context is that the tasks implemented in this study used identical facial expression stimuli (randomized in order), and the only significant difference was the level of shared context in which participants were engaged in. Thus, we can conclude that the effect obtained at the N170 amplitude due to the feedback of the other person's response cannot be attributed to other effects (i.e., differences in images or blocking, which were controlled for), but we interpret them as related to the top-down influence of the shared context. Our results thus consolidate previous evidence suggesting that the function of the N170 is linked to both structural analysis of faces and an early top-down modulation, that in-turn can shape the visual percept (i.e., facial expression).

Concerning the EPN component, we observed a modulation as a function of the type of emotion, showing that its amplitude was more pronounced when participants had to evaluate emotional compared to neutral facial expressions (for a review, see Schindler & Bublatzky, 2020). Previous studies have interpreted this modulation as reflecting increased allocation of attentional resources (i.e., motivated attention) toward motivationally relevant stimuli (Eimer & Holmes, 2003; Schupp et al., 2007; Mxühlberger et al., 2009; Schacht & Sommer, 2009). At the functional level, the EPN is defined both as a call for attentional resources after an initial stage of perceptual encoding, and spontaneous selective processing and decoding of emotionally significant facial expressions (Schupp et al., 2003; Schupp, Flaisch, Stockburger & Junghöfer, 2006). In other words, the EPN can reflect a “motivated” attentional process, suggesting that perceptual encoding is in part directed by underlying motivational systems (Schupp et al., 2006). Our results are consistent with this hypothesis.

Importantly, even though both the task and stimuli were the same across all conditions, our results provide evidence that the EPN is affected by the *sole* presence of someone else co-attending to the same stimulus, as suggested by the increase in amplitude when participants performed the task simultaneously with another person compared to when they were alone. This result suggests increased motivated attention to the stimuli, and consequently more cognitive resources allocated when participants co-attended to the same stimulus. While previous studies have tested whether sharing an experience might lead people naturally to think more about the contents of each other’s minds (i.e. mentalizing; see Teufel, Fletcher, & Davis, 2010 for an in-depth analysis of the interplay between perception and top-down processes), we speculate that mentalizing is an unlikely explanation for the amplification in subjective perception found across different studies (see for example Boothby et al., 2014, 2016; Shteynberg et al., 2014). Shared-attention in the absence of a joint task does not require a reflection or consideration of another person's mental states, and previous research has proposed that a basic social attentional stance toward the world precedes theory of mind abilities (Echterhoff et al., 2009; Shteynberg, 2015). Along the same lines, it is reasonable to interpret the absence of a modulation of the EPN when comparing the condition in which participants received the feedback to when they did not, as the fact that the mere presence of the other person co-attending was enough to determine a change in how individuals processed the same stimuli. Thus, unlike with the N170, there was no further top-down influence on the modulation of the EPN (as also demonstrated in Hudson at al. 2021), but rather an effect of a psychologically shared state, in which individuals "stayed tuned" (Nishitani et al., 2005), resulting in an increase in motivated attention (Lang et al., 1997). Moreover, this result could also be related to audience effects (Hamilton, 2016), suggesting that we process information differently while being observed by someone else, even in the absence of a communicative task. Interestingly, a recent study found stronger intra-individual functional connectivity when producing actions while being observed by another participant, presumably as a result of increased self-monitoring and attention towards one's own actions when being observed (Zimmermann et al., 2021).

Behaviorally, beyond the result due to the type of emotion, we did not find any amplification depending on the level of shared attention as we expected. The lack of impact of the shared attention manipulation on overt behavior, and the discrepancy between the neural and behavioral levels of our investigation, could originate from at least two possible sources. On the one hand, the neural measure might be more sensitive to shared attention than subjective ratings, at least in the context of judging the intensity of facial expressions. The literature offers several examples of this discrepancy between neural and behavioral findings (e.g. Heil, Rolke, & Pecchinenda, 2004; Luck, Vogel, & Shapiro, 1996). An alternative explanation of this incongruity could be that the two selected ERP components and ratings provide estimates of different aspects of visual perception.

While the N170 and the EPN focus on the early structural and emotional face processing, respectively, the ratings reflect the whole process of evaluation.

Future studies could focus on how the pairs of participants align their responses when they receive the feedback from the other person. This would address whether there is also an effect of social influence that modulates subjective ratings, as well as shared attention.

A recent study that looked at the effect of shared attention (doing a task alone versus next to another person) on behaviour and neural activity when viewing emotional stimuli and performing a memory task also found an effect of shared attention on accuracy in an attention task, but contrary to our findings, it did not find any effects on ERP components (Mairon et al. 2020). Notably, this study did not create a minimal sense of “co-attending” to something together, which is fundamental to experience shared attention. Indeed, the authors did not implement a situation in which participants could spend a few minutes chatting to “break the ice” (Boothby et al. 2014). As previous studies have demonstrated, stronger shared attention states are more likely for people who are relationally close (Shteynberg, 2015). Moreover, it involved a memory flower counting task while viewing emotional images – in this case not necessarily socially relevant images – as well as looking at different ERP components (P3b and the Late Positive Potential (LPP)); hence, there are numerous interpretations for the difference in results. First, the participants performed an active (memory) task where the other person’s performance was not relevant, and without receiving feedback of the other’s performance. It could thus be that the social context did not invoke shared attention, as the participants were more focused on their own task rather than on the presence of the other. Secondly, it could be that shared attention has a bigger effect on socially salient images (i.e., faces) over non-social emotional images (i.e., IAPS as used in Mairon and colleagues’ study). Finally, the authors focused on later ERP components that are modulated by arousal and anticipation (i.e., novelty), which may be less affected by mere changes in social context – or alternatively, are more driven by the intensity of images.

In conclusion, our study provides evidence of the impact of shared attention on the stages of face processing, demonstrating that co-attending to stimuli with someone else modulates the early stages of processing – with top-down modulation of early structural processing of faces, and attentional modulation as a result of the social context alone. We have thus provided initial evidence that knowing another person's perception of the same observed stimulus activates top-down mechanisms that affect how the stimulus is processed. On the other hand, sharing the experience with another person results in an increased motivated attention, and consequently cognitive resources allocated toward the facial stimuli. Whether these effects of shared attention would be found for other types of (non-facial) stimuli, is an open question for further research.

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The authors declare no competing financial interests.