HAPPY FACIAL EXPRESSIONS IMPAIR INHIBITORY CONTROL WITH RESPECT TO FEARFUL FACIAL EXPRESSIONS BUT ONLY WHEN TASK-RELEVANT

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ABSTRACT

The ability to generate appropriate responses, especially in social contexts, requires integrating emotional information with ongoing cognitive processes. In particular, inhibitory control plays a crucial role in social interactions, preventing the execution of impulsive and inappropriate actions. In this study, we focused on the impact of facial emotional expressions on inhibition. Research in this field has provided highly mixed results. In our view, a crucial factor explaining such inconsistencies is the task-relevance of the emotional content of the stimuli. To clarify this issue, we gave two versions of a Go/No-go task to healthy participants. In the emotional version, participants had to withhold a reaching movement at the presentation of emotional facial expressions (fearful or happy) and move when neutral faces were shown. The same pictures were displayed in the other version, but participants had to act according to the actor's gender, ignoring the emotional valence of the faces. We found that happy expressions impaired inhibitory control with respect to fearful expressions, but only when they were relevant to the participants' goal. We interpret these results as suggesting that facial emotions do not influence behavioral responses automatically. They would instead do so only when they are intrinsically germane for ongoing goals.

INTRODUCTION

Navigating in social environments requires a constant interplay between the processing of interpersonal emotional stimuli (e.g., processing facial expressions, body postures, and prosody of the speech) and cognitive control functions to select the most efficient behaviors in a given context (Pessoa, 2009). Inhibitory control plays a crucial role in regulating social interactions, preventing the execution of impulsive and inappropriate actions. In fact, inhibition is at the root of behavioral flexibility and, in humans, a sense of self-control (Mirabella, 2014). This paper will focus on the relationship between this executive function and a key feature of social information, i.e., facial emotional expressions. Such stimuli play a key role in nonverbal social communication (Crivelli & Fridlund, 2018; Jack & Schyns, 2015), allowing an individual to infer others' intentions and triggering either defensive responses when a threatening face is encountered (Adolphs, 2008; Davis et al., 2011) or approaching behaviors when one sees a happy face (Pool et al., 2016).

Several attempts to study the impact of emotional facial expressions on inhibitory control have been made in the literature, leading to highly contrasting results even when the same task has been employed. One commonly used task is the emotional version of the Go/No-go task. Typically, participants are instructed to respond to pictures of faces via a keypress ('go') or to withhold the keypress ('no-go') based on the valence of the facial expression (e.g., go for sad faces; do not go for happy faces). In all these studies, emotions are task-relevant; however, results are highly heterogeneous. For instance, Schulz et al. (2009) found that accuracy in No-go trials was higher for sad and happy faces than for neutral faces, i.e., those expressions seemed to improve inhibitory control. However, a few years later, the same authors found that happy faces impaired inhibition with respect to sad faces (Schulz et al., 2013). Brown et al. (2017), using the same Go/No-go design and comparing sad and happy faces, did not find any difference in No-go trial accuracy. By contrast, Tottenham, Hare, & Casey (2011), reported that the false alarm rate in No-go trials for sad expressions was higher than angry expressions. Both facial emotions impaired inhibition more than happy and fearful faces, which did not differ between each other. Still, Schel & Crone (2013) showed that fearful faces impaired inhibitory control with respect to neutral faces.

Another approach to investigating how emotional stimuli modulate inhibitory control is based on the stop-signal task (SST). The core difference between the SST and Go/No-go task is the temporal location of the inhibitory signal. On the Go/No-go task, the no-go signal is presented instead of the go stimulus. On the SST, the stop-signal is presented after the go stimulus, when the subject is already planning the action. Thus, the Go/No-go task provides a measure of action restraint while the SST assesses action cancellation (Wostmann et al., 2013). The SST allows the estimation of reactive inhibition, i.e., the ability to stop a response immediately when a stop-signal is presented. Operatively, reactive inhibition is measured via the stop-signal reaction time (SSRT, Logan et al., 1984), i.e., the time it takes to cancel a planned movement. Research exploiting this paradigm to investigate the impact of facial emotions on inhibition is also mostly inconclusive. Sagapse et al (2011) found that reactive inhibition was unaffected by fearful expressions. By contrast, Pessoa et al. (2012) showed that fearful and happy faces decreased the SSRT with respect to neutral ones. On the same line, Pawliczek et al. (2013) demonstrated that also angry faces decrease the SSRT with respect to neutral stimuli. By contrast, Gupta & Singh (2021), using an SST very similar to those of previous works, showed that angry but not happy expressions improve reactive inhibition. Notably, in all these studies, emotional expressions were task-irrelevant.

Several confounding factors can explain such discrepancies: 1) often the arousal level of the emotional stimuli was neither measured nor controlled, leaving open the question of whether the arousal instead of valence is the driving factor influencing the behavioral performance (Pawliczek et al., 2013; Pessoa et al., 2012; Sagaspe et al., 2011; Schel & Crone, 2013; Tottenham et al., 2011); 2) when facial expressions' emotional content is task-irrelevant, no additional control experiments were performed (Gupta & Singh, 2021; Pawliczek et al., 2013; Sagaspe et al., 2011), thus it is problematic to attribute unambiguously the behavioral effects to emotions; 3) when emotional expressions are task relevant, as in the versions of the Go/No-go tasks described above, the motor response is conflated with stimulus valence, therefore, it is not easy to disentangle the impact of emotions versus action suppression on the experimental outcomes (Brown et al., 2017; Schel & Crone, 2013; Schulz et al., 2013; Schulz et al., 2009; Tottenham et al., 2011); finally 4) not seldom the number of trials from which behavioral parameters are estimated is low, producing noisy data (Gupta & Singh, 2021; Schel & Crone, 2013).

Recently, to avoid these ambiguities, Mirabella (2018) devised an experimental design in which the effects of the same set of emotional facial expressions (happy and fearful) on reaching arm movement were evaluated when emotions were task-relevant and when they were not. Participants were required to perform two versions of a Go/No-go task. In the emotional version, they had to execute the same reaching movement when pictures of happy or fearful expressions were shown and refrain from moving when neutral expressions were presented. Importantly, participants were instructed to move whenever they saw an emotional expression. They were never told what emotional expressions would have been presented. In the gender version, the same pictures were shown, but participants had to move according to the actor's gender, disregarding the face's emotional valence. It was found that, in the emotional version of the task, participants had longer reaction times (RTs) and were less accurate when responding to fearful than to happy faces. Noteworthy, all these modulations disappeared in the gender task. Such results have been replicated and extended by including angry faces (Mancini et al., 2020). Overall, this evidence suggests that emotional expression affects behavioral performance only when task-relevant. Such experimental design is sound because i) it allows testing of the impact of task-relevance on the same emotional stimuli, having different valence but the same arousal, and are placed in the spatial location; ii) it does not conflate movement planning with target detection and task switching as when the Go-signal is provided by one specific emotional expression and another emotion indicates the No-go.

The Current Investigation

These studies could only assess facial expressions' effects on movement planning and execution but not on inhibitory control. To shed light on this issue, we modified the design of Mirabella (2018) by presenting the emotional facial expressions (fearful and happy) as No-go signals (Figure 1). In this way, participants have to move when a neutral expression is presented and refrain from moving at the presentation of an emotional face. Differently, in the gender task, participants are instructed to refrain from moving when pictures of a given gender are presented. Given that, in previous studies (Mancini et al., 2020; Mirabella, 2018), fearful faces increased the RTs and the rate of mistakes, i.e., they increased the number of times the participant did not move toward the target, we hypothesized that the presentation of fearful expressions would allow a better inhibitory control than happy expressions.

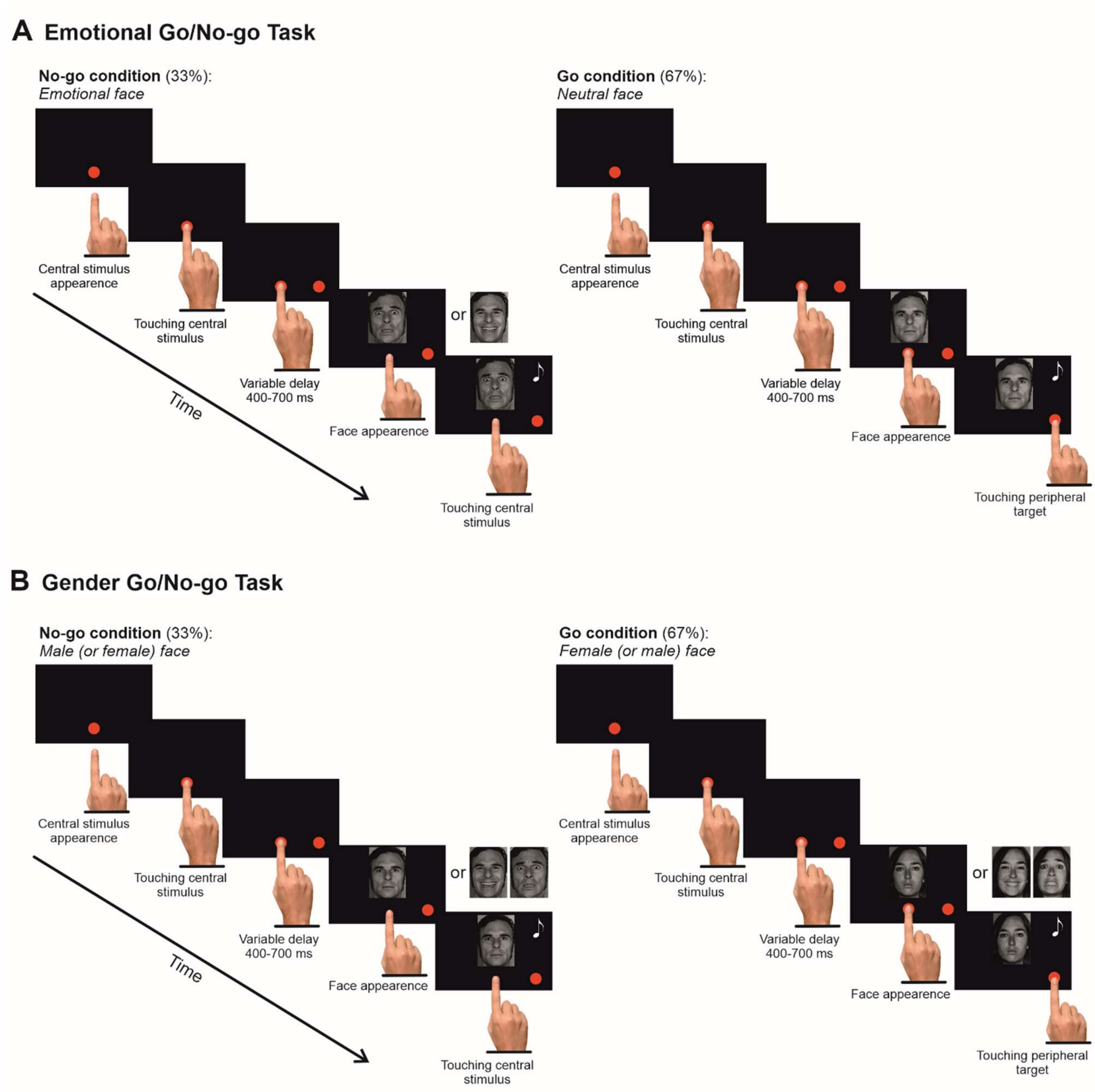

Figure 1. Emotion discrimination and Gender discrimination Go/No-go Task (**A**) Emotion discrimination task. Trials started with the appearance of a red circle at the center of the touchscreen. Immediately after participants had touched it, a peripheral red circle appeared. Holding the central stimulus for a variable period triggered its disappearance and, simultaneously, the appearance of one of the four facial expressions. Participants to keep holding the central position when the face expressed an emotion (happiness or fear; No-go condition), or they had to reach and hold the peripheral target when the face displayed a neutral expression (Go condition). Acoustic feedback signaled a correct trial (represented in the panels by a musical note). (**B**) Gender discrimination task. The sequence of the events was the same as in (**A**). However, in the female version of the task, participants were instructed to refrain from moving when a male face was presented (No-go condition) and to reach and hold the peripheral target only when a female face was shown irrespective of the depicted emotion (Go-condition) and, and vice versa in the male version of the task.

METHODS AND METHODS

In this section, we report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study.

Participants

We did not perform a power analyses as there were no data on which performing it. Thus, we decided to recruit a relatively large cohort of subjects and to evaluate the effect sizes and the Bayesian factors to assess the strength of the null and the alternative hypotheses. Forty university and postgraduate students were recruited for the study (20 males, mean ± SD age: 23.89 ± 4.72). All participants were right-handed, as assessed with the Edinburgh handedness inventory (Oldfield, 1971), and had a normal or corrected-to-normal vision. Subjects were naïve about the purpose of the study, and none had a history of neurological or psychiatric disorder. The study was conducted in accordance with the ethical guidelines set forth by the Declaration of Helsinki and had the approval from the Ethics Committee of 'ASST Spedali Civili' of Brescia, Italy (protocol number 4452). Informed consent was obtained from all participants.

Stimuli

Stimuli have been selected from the Pictures of Facial Affect (Ekman & Friesen, 1976) and consisted of 12 different grayscale pictures taken from four actors (two female and two male) who displayed three different facial expressions: fear, happiness, and neutral. After the experimental session, participants were asked to fill out a questionnaire to evaluate the level of arousal, by an 8-point Likert scale (0 meant 'no arousing' and 7 meant 'highest arousing') and valence, by a 15-point scale (−7 meant 'very negative,' 0 meant 'neutral,' +7 'very positive'), of each facial expression. Table 1 shows the mean values and corresponding standard deviations of each of these variables.

We performed statistical analyses to test whether the arousal level was balanced between pictures and to confirm that they differed for emotional valence, as assumed *a priori*. A one-way ANOVA with repeated measures on the pictures' level of arousal with Emotion as a factor (levels: fear, happiness, and neutral) revealed that the main effect was statistically significant [$F(1.81,70.74) = 130.2$, $\eta^2p = 0.95$, $p < 0.001$]. Post hoc tests with Bonferroni correction showed that fearful and happy faces did not differ for the level of arousal they evoked ($p = 1$). However, pairwise comparisons also revealed that each of these facial expressions was more arousing than a neutral one (both $p < 0.001$). One-way ANOVA on the emotional valence of the pictures revealed, again, a significant main effect of Emotion [$F(1.21, 47.26) = 794.2$, $\eta^2p = 0.95$, $p < 0.001$]. As expected, post hoc tests revealed that each of the three emotional expressions differed for this parameter (all $p < 0.001$).

	Fearful faces	Happy faces	Neutral faces
Arousal	5.04 ± 1.37	4.91 ± 1.61	1.00 ± 1.04
Emotional valence	-4.72 ± 1.48	5.78 ± 1.08	0.03 ± 0.30

Table 1. Mean value (±SD) of arousal and valence of the three different facial expressions used in the experimental tasks.

Experimental Apparatus and Behavioral Tasks

All subjects completed the experimental tasks in a dimly illuminated quiet room. Visual stimuli were presented on a 17-inch Liquid Crystal Display touchscreen monitor (MicroTouch M1700SS, 3M, Minnesota, MN, USA, 1280 × 1024 resolution, 32-bit color depth, refresh rate 75 Hz, sampling rate 200 Hz). Visual stimuli (5.8 cm × 7.4 cm or 8.25 × 10.9 degrees of visual angles; dva) were presented against a black background of uniform luminance (<0.01 cd/m2). The touchscreen was placed about 40 cm away from the subject, allowing him/her to reach the screen comfortably. The temporal arrangements of stimulus presentation were synchronized with the monitor refresh rate (75 Hz). The experimental paradigm consisted of Emotion and Gender discrimination Go/No-go task. Both tasks were administered in a single session, with a ten-minute interval between them. The presentation order of the tasks was counterbalanced across participants.

Emotion Discrimination Task

Participants were instructed to touch with their right index finger a red circle (2.43 cd/m2, diameter 2.8 cm or 4 dva) placed 2 cm below the center of the touchscreen (Figure 1A). Touching the central stimulus triggered the appearance of a red circle (diameter 2.8 cm or 4 dva) at 8 cm or 11.3 dva from the central stimulus along the horizontal meridian in the right visual field. Participants had to hold the central stimulus for 400–700 ms. Then the central stimulus disappeared and, simultaneously, one of the pictures depicting a facial expression appeared just above the index finger's tip. Whenever a neutral face was presented, participants were taught to lift the finger from the central stimulus as quickly as possible, touching the peripheral target, and holding it for 300-400 ms (Go condition). However, participants were instructed to refrain from moving whenever an emotional facial expression appeared, keeping the finger in the central position for 400-800 ms (No-go condition). Acoustic feedback signaled successful trials.

Participants performed either two blocks of 250 trials (n=19) or three blocks of 200 trials (n=21) due to a technical mistake. Resting periods were allowed between blocks whenever requested. Go-trial frequency was 66%. All experimental conditions were randomized. Error trials were repeated until participants completed the entire block. These trials were included in the statistic, but importantly they have not repeated right away, but randomly at a later point. This design was adopted in order to have an equal number of correct trials for each type of stimulus. Therefore, in No-go trials, each emotional face was presented until 21 or 25 times correct responses were given in the shorter and longer version of the task. To discourage subjects from slowing down during the task, in Go trials we set an upper reaction time limit, i.e., whenever RTs were longer than 500 ms, the Go trials were signaled as errors and aborted. Nevertheless, to avoid cutting the RTs' right tail distribution, we gave participants an extra time of an additional 100 ms for releasing the central stimulus (overtime reaching-trials (Mancini et al., 2020; Mirabella, 2018; Mirabella et al., 2006). Thus, when participants detached the index finger between 500 and 600 ms after the go-signal, the RT was recorded, but the trial was signaled as an error. Overtime reaching-trials accounted for 6.2± 4.3% of the total Go trials and were included in the analyses.

Gender Discrimination Task

Except for the fact that participants had to move according to the gender of the face (Figure 1B), this task had the same timing and stimuli as the Emotion discrimination task. To avoid a gender bias, one-half of the participants (n=20) had to move when a female face was presented, withholding the movement when a male face was shown, and vice versa for the other half of participants. Participants performed the same number of trials as in the Emotion discrimination task. Go-trial frequency was 66%. In No-go trials, each emotional face was presented until 28 or 34 correct responses were given in the shorter and longer version of the task. All experimental conditions were randomized, and error trials were repeated randomly. Go trials have an upper reaction time limit to 500 ms, but RTs were recorded until 600 ms after the go-signal. Overtime reaching-trials accounted for 3.49% ± 3.4% of the total Go trials and were included in the analyses.

Data analyses

Error rates in No-go trials were taken as behavioral parameters and were defined as those instances in which participants detached their index finger from the central stimulus. The error rate was computed for each participant as the ratio between the number of errors in a given condition and the sum of correct plus wrong trials for the same condition (e.g., number of mistakes for happy face divided by the sum of wrong and correct response to happy faces) multiplied by 100. A two-way repeated-measures ANOVA [within-subject factors: Emotion (fear and happiness) and Task (Emotion and Gender discrimination task)] was performed to analyze mean error rates across experimental conditions. Bonferroni corrections were applied to all post hoc tests (pairwise comparisons). In addition, even if not contemplated in our hypothesis, we used Student's *t*-test to evaluate statistical differences of RTs, MTs, and mistake rate in the Go trials.

As a measure of the effect size, we calculated the partial eta-squared (η_p^2; values equal to or above 0.139, 0.058, and 0.01 indicate large, medium and small effects, respectively) for the ANOVA and Cohen's *d* (values equal to or above 0.8, 0.5 and 0.2 indicate large, medium and small effects, respectively) for each *t*-test (Lakens, 2013). We calculated the Bayes factors (BF10) with an r-scale of 0.707 to quantify the null hypothesis's strength (Rouder et al., 2009). BF_{10} values >3 and >10 constitute moderate and strong support, respectively; for the alternative hypothesis, BF10 values < 0.1 and <0.33 provide robust and moderate support for a null hypothesis. Correlations between error rates in different conditions were computed employing the Pearson correlation coefficient (*r*), as the Shapiro-Wilk normality test confirmed that all conditions were normally distributed.

Transparency and Openness

All data, analysis code, and research materials will be freely available from the Open Science Framework platform at https://osf.io/24cq8/. The presentation of stimuli and the recording of behavioral responses were controlled by CORTEX, a non-commercial software package (Cortex Explorer: Real-Time Software and Data Analysis Tools. Available online at: https://www.nimh.nih.gov/research/research-conducted-at-nimh/research-areas/clinics-and-labs/ln/shn/software-projects.shtml). Data were analyzed using Matlab, version R2017a (The MathWorks, Inc.). Statistical analyses were made using R, version 4.0.0 (R Core Team, 2020). This study's design and its analysis were not pre-registered.

RESULTS

The impact of emotion-laden expressions on inhibitory control was assessed by computing the error rates in No-go trials in each experimental condition. We define errors as those instances in which participants detached their index finger from the central stimulus instead of holding it. First of all, we checked whether data were normally distributed via the Shapiro-Wilk test. We found that in all cases this was the case: a) condition happy of Emotional discrimination task (M = 29.91%; 95%

CI [26.45, 33.36] Shapiro-Wilk test, W = 0.98, p-value = 0.744); b) condition fear Emotional discrimination task (M = 25.18%; 95% CI [21.86, 28.50] Shapiro-Wilk test, W = 0.97, p-value = 0.509); c) condition happy of Gender discrimination task (M = 22.63%; 95% CI [19.07, 26.19], Shapiro-Wilk test, W = 0.97, p-value = 0. 267); d) condition fear Gender discrimination task (M = 22.77%; 95% CI [19.46, 26.08]) Shapiro-Wilk test, W = 0.97, p-value = 0. 294); e) condition neutral Gender discrimination task (M = 23.32%; CI 95% [18.46, 28.18], Shapiro-Wilk test W = 0.98, p-value = 0.838). Therefore, we used parametric tests. First, to assess the effect of emotional stimuli on inhibition in the two tasks, we run a two-way analysis of variance (ANOVA) on error rates [factors: Emotion (Happy, Fear) and Task (Emotion discrimination task, Gender discrimination task)]. This analysis revealed several effects (Table 2, Figure 2). First, there was a main effect of Emotions as participants made more errors after presenting happy faces (M = 26.27%; SD ± 11.5%) than after fearful faces (M = 23.97%; SD ± 10.4%). Second, we also found a main effect of Task as participants made more mistakes during the Emotion discrimination task (M = 27.54%; SD ± 10.8%) than during the Gender discrimination task (M = 22.70%; SD ± 10.7%). These effects are qualified by the significant interaction between the two factors. Indeed, in the Emotion discrimination task, the error rate significantly increased when a happy face was shown (M = 29.91%; SD ± 10.8%) relative to when a fearful face appeared (M = 25.18%; SD ± 10.4%). In contrast, in the Gender discrimination task there was no difference in error rates between 'happy' (M = 22.63%; SD ± 11.1%) and 'fear' (M = 22.77%; SD ± 10.4%) conditions. The Bayes factors provide i) moderate support for the null result in the post hoc comparison between the error rate for happy versus fearful faces in the Gender discrimination task and ii) strong support for the alternative hypothesis in the post hoc comparison between the error rate for happy versus fearful faces in the Emotion discrimination task. Finally, participants made more mistakes after presenting a happy facial expression in the Emotion discrimination task than in the Gender discrimination task. Differently, there was no difference in the rates of mistakes for fearful expressions between the two tasks.

Second, as in the No-go trials of the Gender discrimination task we presented fearful, happy, and neutral facial expressions, we compared the rates of mistakes among these conditions via a one-way ANOVA [factors: Facial Expressions (Happy, Fear, Neutral)]. We did not find any significant difference (one-way ANOVA [$F(1.89, 73.62) = 0.23$, η2p = 0.006, $p = 0.7831$, BF10= 0.095]).

Analyses of Error rates

	Value of parameters	***p* values**	M_{diff}	***95%* CI**	**Effect Size**	BF_{10}
Main effect: **Emotion**	*F*[1,39] = *7.05*	***p=0.011***	2.30	[0.55, 4.05]	$\eta_p^2 = 0.15$	2.2
Main effect: **Task**	*F*[1,39] = *17.21*	***p<0.001***	4.84	[2.48, 7.20]	$\eta_p^2 = 0.31$	>100
Interaction: **Emotion×Task**	*F*[1,39] = *11.60*	***p=0.002***			$\eta_p^2 = 0.23$	4.2
Post hoc Tests:						
Emotion Task - Happy vs. Fear	*t*(75.3) = *4.22*	***p<0.001***	4.73	[2.54, 6.92]	*d = 0.67*	>100
Gender Task - Happy vs. Fear	*t*(75.3) = -*0.12*	*p=1*	0.14	[-2.21, 2.48]	*d = 0.02*	0.17
Happy - Emotion Task vs. Gender Task	*t*(64.6) = *5.32*	***p<0.001***	7.27	[4.57, 9.98]	*d = 0.84*	>100
Fear - Emotion Task vs. Gender Task	*t*(64.6) = *1.76*	*p=0.499*	2.41	[-0.42, 5.23]	*d = 0.28*	0.66

Table 2. **Results of the statistical analysis on the percentage of mistakes**. Post hoc tests (pairwise comparisons) had an adjusted alpha level corrected according to Bonferroni. Statistically significant results are reported in bold. Bayes factors report the ratio of likelihood of the alternative hypothesis to the likelihood of the null hypothesis (BF_{10}). Measures of size effects: η_p^2 for ANOVAs and Cohen's *d* for post hoc tests. Differences in the estimated marginal means (M_{diff}) are reported along with their 95% confidence interval (CI).

Figure 2. Effect of facial expression on the mean error rates in the Emotion discrimination task (dark grey) and the Gender discrimination task (light grey) In the Emotion discrimination task, participants made more mistakes when the No-go signal was a happy face than when it was a fearful face (see Table 1 for the statistics). Differently, in the Gender discrimination task the effect of facial expressions on inhibitory control was the same. In each box plot, the box's boundary closest to zero indicates the first quartile, a bold black line within the box marks the median, and the boundary of the box farthest from zero indicates the third quartile. Whiskers indicate values 1.5 times the interquartile range below the first quartile and above the third quartile.

To assess the effect of facial expressions at the individual level, we performed a correlation between the error rates for happy and fearful faces for each subject separately for the Emotion and Gender discrimination tasks. In both tasks the correlations were significant (Emotion discrimination task: Pearson's $r = 0.79$; $p < 0.001$; Figure 3A. Gender discrimination task: Pearson's $r = 0.77$; $p < 0.001$; Figure 3B), suggesting that, overall, participants are either accurate or not on both facial emotions. However, in the Emotion discrimination task, most subjects made more mistakes for happy than fearful faces. In fact, 29 participants out of 40 were located below the first quadrant angle's bisector (Figure 3A). A Chi-Square goodness of fit test confirms this bias [$\chi^2(1) = 8.1$; $p = 0.004$]. In contrast, in the Gender discrimination task, exactly half of the participants (n=20; Figure 3B) are below the bisector and the other half (gray dots) are above [$\chi^2(1) = 0$; $p = 1$], indicating that in this task the error rate was the same for the two facial expressions.

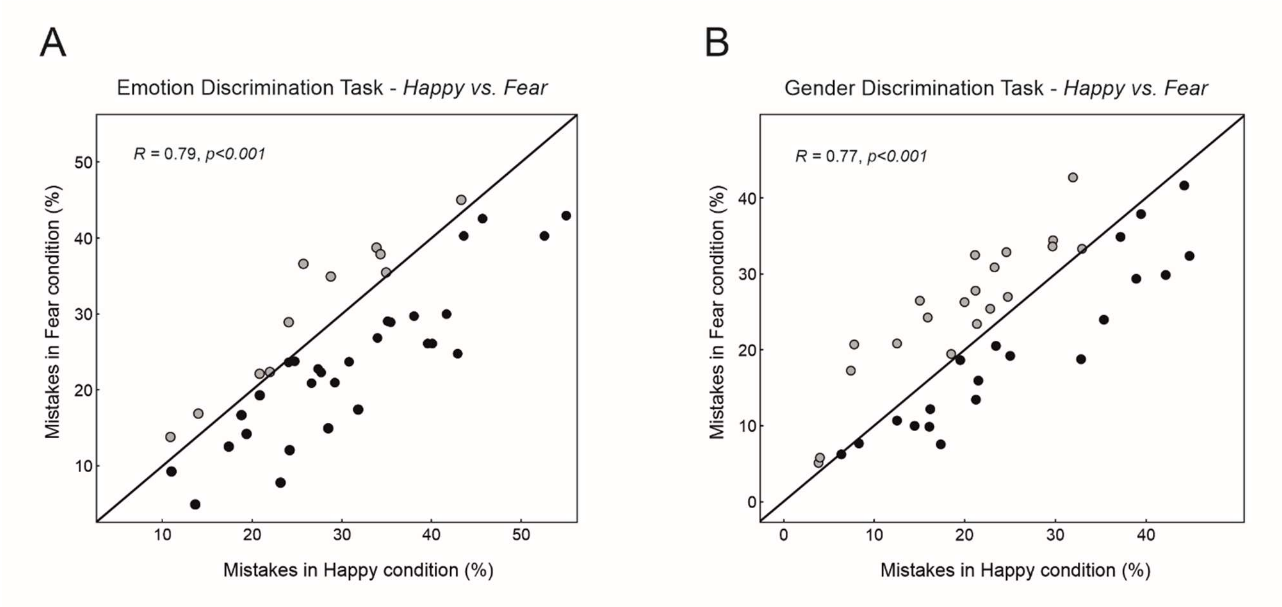

Figure 3. Scatterplot of error rates for happy and fearful faces for each subject in the two tasks Each dot represents one participant. (**A**) In the Emotion discrimination task, most of the subjects (n=29; full black dots) are located below the first quadrant angle's bisector, indicating a bias towards a larger error rate for happy than for fearful faces. (**B**) In the Gender discrimination task, exactly half (n=20; full black dots) are below the bisector, and the other half (gray dots) are above, indicating the error rates are similar for the two facial expressions.

DISCUSSION

Although the ability to deal with emotional stimuli is crucial to decision making processes, the way emotions impact behaviors is still poorly understood (Pessoa, 2009). Of great importance, consistent gaps remain in the comprehension of the interplay between such stimuli and executive functions. In this work, we focused on the interaction between a key executive function, i.e. inhibitory control (Mirabella, 2014) and emotional facial expressions, i.e., a key vehicle of social information (Jack & Schyns, 2015). As described in the Introduction, the impact of facial emotions on inhibition is mostly inconclusive as different studies show highly mixed results.

To overcome previous research limitations, we compared the effect on inhibitory control of the same set of facial expressions in two different experimental conditions using a within-subjects design. In one condition, participants had to refrain from responding when they perceived an emotional expression (fear or happiness). In the other condition, participants had to withhold their movements when either a male or female face was shown, irrespectively of their emotional expressions. Therefore, for the first time, we tested the impact of task-relevance of the same stimuli on the inhibitory control of the same type of movements net of other confounding factors (e.g., differences in arousal, conflating motor responses with emotional valence of the stimuli). We found a clear-cut result. Inhibition was affected only when emotional expressions were task-relevant both on average and at the individual level. In this instance, the capability of refraining from actions was significantly more impaired after the presentation of happy faces than after the presentation of fearful faces.

The importance of task-relevance

One crucial but still highly debated issue is whether emotional facial expressions influence behavioral responses even if they are irrelevant to the observer's current goal. All organisms have limited computational resources, and thus they cannot process and represent all incoming sensory information (Desimone & Duncan, 1995). Selective attention prevents brain overload by filtering out some sensory stimuli from the scene based on their current relevance or salience (Reynolds & Chelazzi, 2004). It has been claimed that emotional stimuli, particularly those with aversive content, have a special status in that they are able to bias selective attention, prioritizing their processing in a reflexive manner (Lang et al., 2000; Vuilleumier, 2005). According to this account, people would not be able to fully ignore the meaning of emotional stimuli, as they represent signs of social danger (Compton, 2003; Lang et al., 1997; Pourtois et al., 2013; Vuilleumier, 2005). However, a few studies have questioned this view, showing that attentional capture occurs only when such stimuli are task-relevant. For instance, Stein et al. (2009) probed the extent to which attention is captured by fearful faces using three different versions of the attentional blink task. In this task, two targets are embedded in a sequence of distractors presented at a rapid rate. Typically, when both targets (T1 and T2) must be reported, the identification of T1 decreases the accuracy of detecting T2 at short temporal lags, i.e., less than 500 ms (Shapiro et al., 1994) but this attentional blink improves with increasing lags.

In the three versions of the attentional blink task, T1 was a facial expression (neutral or fearful) and T2 was an indoor or outdoor scene. In the first version, participants were asked to judge the facial expression of T1 stimuli and identify whether the scene was an outdoor or indoor scene at T2 presentation. In the second version, participants were asked to judge T1's gender and, in the third, they were asked to ignore T1 stimuli. Stein et al. (2009) found that fearful faces induced a stronger attentional blink than neutral faces only when participants had been instructed to categorize the facial emotion. No difference was found in the other two conditions in which the emotional expression was not task-relevant. Thus, they concluded that the effect of emotion on attention and behavioral performance depends on the task goal. Similarly, Victeur et al. (2020), using a spatial cueing task, manipulated facial expressions' task-relevance and showed that attentional allocation to fearful faces is not automatic. Instead, it occurs only when facial features are relevant to individuals' goals.

In keeping with these findings, in two previous studies, we showed that the relevance of the emotional content of the stimuli is a crucial factor impacting motor readiness, accuracy in Go trials, and movement times (Mancini et al., 2020; Mirabella, 2018). The current study extends previous research, showing that not only motor preparation but also response inhibition is affected only when participants are instructed to focus on facial emotional attributes. Two other studies tried to assess the impact of task-relevance of facial emotional expressions on inhibition to the best of our knowledge. Williams et al. (2020) tested such relationship by administering three SST versions. In one version, participants were instructed to stop their movements whenever a face was shown regardless of its emotional expression (fear, happy or neutral). In the second version, the participants had to stop according to the gender of the actors' faces. Finally, in the third version, participants had to suppress their actions according to the facial expressions. Only in this last instance, Williams et al. (2020) found that positive emotions decreased the length of the SSRT, i.e., facilitated reactive inhibitory control. The difference with our findings, showing an impairment of inhibitory control to happy expression, could be explained in several ways. First, the Go/No-go task measures action restrain and not action cancellation as the SST. These two tasks likely assess different aspects of inhibitory control and rely on different neural networks (Raud et al., 2020). Second, and more importantly, in Williams et al. (2020) task participants had to stop on one facial expression when emotions were task-relevant but ignore the other two. Thus, in such a design, the motor response is conflated with stimulus valence. Third, Williams et al. (2020), unlike us, did not employ a within-subjects design.

Parkinson et al. (Parkinson et al., 2017), using a novel version of the Go/No-go task, showed that angry facial expressions presented subliminally before the instruction-cue induced participants to withhold intentional movements more often than fearful, happy, and neutral expressions. Interestingly, when the same images were shown supraliminally, i.e., participants could consciously perceive them, angry faces' effects on intentional inhibition disappeared. This experiment suggests that when emotional facial expressions are perceived unconsciously, they seem capable of modulating the decision-making process. However, when the same stimuli access consciousness, and they are task-irrelevant, they don't affect movement inhibition. To explain these results, Parkinson et al. (2017) suggested that an emotional face's conscious perception allows participants to discount it as task-irrelevant actively. However, the top-down goals cannot disengage attention from emotional stimuli when presented subliminally. Under these conditions, such stimuli influence movement planning in a bottom-up fashion. This hypothesis is worthy of further investigation as it could reconcile several past pieces of evidence concerning the effects of task-irrelevant emotional stimuli. In our study, we always presented facial expressions supraliminally; thus, according to the above account, in the Gender discrimination task, attentional allocation to emotional faces was prevented by task-related goals. In contrast, in the Emotion discrimination task, top-down goals promoted explicit attention to emotion, affecting behavioral performance.

Notably, the task-relevance of emotional stimuli does not affect only selective attention and inhibitory control but also another executive function, i.e., the working memory. Berger et al. (2017) gave two memory tasks to healthy participants in which a sequence of actors' faces of different ages and showing neutral, happy or angry expressions were presented. Participants were required to make match/non-match judgments of either the emotion or the age of the actors' faces with respect to images displayed one or two positions back in the sequence. The authors found that only when the emotional expression was relevant for the task did happy facial expressions facilitate the working memory performance.

Taken together, these results suggest that task-relevance represents a crucial feature of the way emotional facial expressions are processed, as it determines whether those stimuli impact behavioral responses. Relevantly, by no means we are suggesting that task-irrelevant emotional stimuli cannot change brain activity: they will probably do so as shown by several studies (Berkman et al., 2009; Sagaspe et al., 2011; Todd et al., 2012). Still, these changes do not produce overt behaviors, at least when they are consciously perceived.

The effect of happy and fearful faces on inhibition

We found that task-relevant happy expressions impaired inhibitory control with respect to facial expressions of fear. These results confirm our initial hypothesis. In previous research, we showed that fearful faces increase the RTs and the error rates with respect to happy faces in Go trials (Mancini et al., 2020; Mirabella, 2018). We interpret this finding in light of the fact that fearful faces exert a more efficient capture of attentional resources than happy expressions (Fox et al., 2002; Pourtois et al., 2013). It has been speculated that such attentional bias should allow the detection of potential threats and enable quick fight-or-flight responses (Öhman & Mineka, 2001). However, our data suggest that fearful and angry expressions do not speed up movement planning. Instead, they slow it down (Mancini et al., 2020; Mirabella, 2018). In our view, this happens because threatening faces require more accurate screening than happy faces, to uncover others' intentions to act congruently to the current social context and avoiding inappropriate hostile or aggressive behaviors. Such attentional locking towards threatening cues makes it difficult to direct the attention away from threat once relevant to current goals. Therefore, when fearful faces signal a go, RTs increase, and sometimes the lengthening is so emphasized that individuals do not move at all even though they should, making a mistake. This would explain the simultaneous increase of the RTs and the rates of mistakes. When fearful faces signal a no-go the attentional grabbing and the slowdown of motor planning allow a more accurate inhibition. This conclusion is almost in line with those of Parkinson et al. (Parkinson et al., 2017). They found that angry expressions made participants more likely to voluntarily withhold an action, i.e., increased volitional inhibitory control. The effect of fearful faces was not so strong and was similar to that of happy faces. This finding should be considered cautiously because the sample size was small (n=16), and the interindividual variability could have hidden the true effect. All in all, at least when Go/No-go task are employed and threatening facial expressions are task-relevant, they seem to improve inhibitory control. This phenomenon might allow individuals to assess the current situation and evaluate the best behavioral strategy to adopt. Future research should employ eye-tracking to measure how visual attention contributes to the observed results. In addition, it would be of great interest to study how facial emotional expressions impact inhibitory control in patients with anxiety disorders. Anxiety seems to disproportionally increase attention to threat-related stimuli (Koster et al., 2005), so that individuals tend to perceive the world around them as dangerous, triggering their worry and complaints. If our interpretation is correct, it could be plausible to hypothesize that even task-irrelevant expressions may affect action suppression in those patients.

which would impact neural activity and behavioral performance. In particular, it has been proposed that faces bearing negative expressions (angriness or fear) should automatically grab attention more efficiently than all other emotional expressions.

Conclusions

We compared the effect of task-relevance of fearful and happy facial expressions on inhibitory control using a within-subjects design in a relatively large sample of healthy individuals. We found that only when the emotional expressions are relevant to the task goals, i.e., when participants are explicitly instructed to move or refrain from moving according to emotional expressions, happy faces impair inhibition with respect to fearful faces. Together with our previous findings (Mancini et al., 2020; Mirabella, 2018), this evidence suggests that behavior is impacted only when individuals are aware of the emotional content of facial stimuli. We believe that our results are very robust for several reasons. First, the same participants performed the two versions of the task. Second, we compared the effect of the same pictures on the same reaching movements when they were task-relevant and task-irrelevant. Importantly, pictures were always placed in the focus of attention. Third, differences in arousal cannot explain the results. Fourth, Bayesian factors indicate that our findings are unlikely due to the sample's variability or statistical underpowering. This evidence could potentially open new avenues to comprehend pathologies affecting social cognition, such as anxiety disorders, Parkinson's Disease, autism spectrum disorders and sociopathic personality disorders.

Limitations of the study

One limitation of the current study is that given our experimental design, we cannot directly compare the effect of emotional facial expressions with the neutral ones when emotions are task-relevant. Thus, exploiting our paradigm, we can assess directly just the influence of fearful versus happy expressions on inhibitory control. However, using the results of the gender task as a baseline, we can infer the effect of emotion. For instance, in the gender task, participants show a similar rate of mistakes for emotional and neutral expressions. By contrast, happy expressions induce a significantly higher rate of mistakes than fearful faces in the emotional task. This suggests that it is the task-relevance of the emotional content of the happy face that modifies the inhibitory performance.

Another limitation is that in this experiment, we employed only two emotions (fear and happiness). However, it would be essential to test the effects of other facial negative emotions, especially those that specifically convey social signals as sad or angry expressions. We have already shown that angry faces have a much greater impact than fearful faces, as the former decreased response readiness with respect to happy expressions more than the latter. Furthermore, angry faces also increase the time of movement execution (Mancini et al., 2020). This leads us to predict that angry expressions should improve inhibitory control more than fearful faces. Future studies are needed to verify such hypothesis.

Finally, as already stated in the discussion, it is crucial to assess the effect of emotional expressions on visual attention measuring eye movements. This would represent a straightforward way to check the hypothesis that fearful expressions grab participants' attention stronger than happy faces.

AUTHOR CONTRIBUTIONS

Authors contributed to the study in the following manner: Conceptualization, G.M. Methodology, G.M. and Ch.M. (Christian Mancini). Formal analysis, G.M. and Ch.M. Validation, G.M., Ch.M., L.F., and C.M. (Claudio Maioli). Investigation, Ch.M. and L.F. Data curation, Ch.M. and L.F. Writing—original draft preparation, G.M. and Ch.M. Writing—review and editing, G.M., Ch.M., L.F., and C.M. Resources, G.M., Ch.M., L.F., and C.M. Software G.M. Supervision, G.M. and C.M. All authors have read and agreed to the published version of the manuscript.

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